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Evaluation of Green Building Practices Effective in Reducing Carbon Emissions in South African Housing and Barriers to Adoption

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The construction sector is a significant contributor to energy consumption and greenhouse gas emissions. This paper examines green building practices that reduce carbon emissions and enhance sustainability in the construction of South African housing. The study adopts a sequential exploratory, qualitative-dominant mixed-methods research approach, comprising semi-structured interviews and an online questionnaire survey, to obtain practitioner perspectives. The study found that passive and active energy-efficiency measures, renewable energy integration, the use of low-emission carbon and recycled materials, water-sensitive design, and waste minimization are effective in reducing operational and embodied CO_2. At the same time, the barriers to implementing energy-efficient measures include perceived and real upfront costs, limited local data on performance and returns, weak policy enforcement, and limited skills and awareness among stakeholders. Based on the findings, the study concludes that policy and industry actions involving regulation, incentives for using energy-efficient technologies, and capacity-building/training initiatives can substantially reduce carbon emissions in housing construction, while delivering social and economic co-benefits in line with the Sustainable Development Goals. The study is exploratory and based on a small, practitioner-focused sample, and therefore generates indicative insights rather than statistically generalizable results.

Keywords: Carbon emissions, Green building, Housing, Life-cycle perspective, South Africa

Introduction

The built environment is central to sustainable development and climate mitigation. Globally, buildings (construction and operation) account for a substantial share of energy use and carbon dioxide (CO_2) emissions, with estimates suggesting that around 40% of global energy consumption and associated CO_2 (Chau et al., 2015; Huang et al., 2018). Housing contributes a significant component of this footprint through material use, energy for heating, cooling, hot water, lighting, and occupant behaviour. In many low- and middle-income contexts, the challenge is acute due to rapid urbanization, rising housing demand, and constrained fiscal and technical capacities, which create tensions between affordability and environmental performance (Adetooto et al., 2022).

Green building practices that encompass energy-efficient design, the use of renewable energy solutions, low-emodied-carbon materials, water efficiency, and improved waste management offer ways to reduce both operational and embodied carbon while improving occupant health and building resilience (GhaffarianHoseini et al., 2013; Liu et al., 2022). However, implementation is patchy. Mosly (2015) and Jaradat et al. (2023) note that knowledge gaps, cost perceptions, limited local evidence on long-term benefits, and weak regulatory environments hinder broader uptake.

This paper examines the practices perceived to be effective in reducing carbon emissions within housing construction in South Africa, drawing on empirical input from construction practitioners and an international evidence base. The goal is to produce policy-relevant, practice-oriented evidence that supports industry adoption and informs regulation. The specific objectives of the research are to identify the key building practices adopted in housing delivery, assess the barriers and enablers to implementing green building practices, and propose recommendations to scale the use of low-carbon housing solutions.

To operationalise these objectives, the study addresses three research questions: 1) Which green building practices do South African construction practitioners perceive as most effective in reducing operational and embodied carbon emissions in housing? 2) What barriers and enabling factors influence the adoption of these practices in the South African housing sector? What implications do these practitioners' perspectives have for policies and practices aimed at aligning housing development with life-cycle carbon-reduction and sustainability goals? The study adopts a mixed-methods, exploratory design to provide insights for policymakers, housing developers, construction practitioners, financiers, and researchers by identifying actionable strategies and institutional measures that align housing development with national and global climate targets and the Sustainable Development Goals (SDGs).

Literature Review

The literature review is structured according to the following sub-sections:

Green Building Practices and Carbon Reduction

According to Chau et al. (2015) and Jayasinghe et al. (2022), green building practices reduce environmental impact by reducing operational energy demand via passive and active design measures and renewable energy integration, and by reducing embodied carbon through low-carbon or recycled materials and optimised construction processes. Passive design - orientation, building envelope insulation, natural ventilation and daylighting – can significantly reduce heating and cooling demand (Morrissey et al., 2011; Pacheco et al., 2012; Tian et al., 2018). Technologies such as kinetic façades and double-skin façades also support daylight and thermal control (Kensek & Hansanuwat, 2011).

Renewable energy, particularly rooftop photovoltaic (PV) systems and solar water heating, reduces dependence on grid electricity and associated fossil-fuel emissions (Zhai et al., 2007; Ghaffarian-Hoseini et al., 2013). Life-cycle assessment (LCA) methods quantify the full carbon footprint, highlighting that material choice and construction processes can represent a significant share of the lifetime carbon in energy-efficient buildings (Chau et al., 2015; Jayasinghe et al., 2022).

Building Materials and Circularity

Matthews (2019), Gheni et al. (2019), and Jayasinghe et al. (2022) found that material substitution and circular practices (recycled aggregates, fly ash, recycled steel, and alternative construction materials such as bamboo or earthbags) reduce embodied carbon and waste. Also, replacing energyintensive clinker in cement with fly ash or slag, and adopting prefabrication, can lower manufacturing energy use and onsite waste (Mohammed et al., 2020).

Standards, Certification and Finance as Enablers of Carbon Emission Reduction

Certification schemes (e.g., Green Star, LEED, BREEAM) and building energy codes establish performance benchmarks and incentivise adoption through market recognition and validation. However, according to Wafula and Talukhaba (2011), local adaptation and enforcement are important. Additionally, Liu et al. (2022) noted that financial incentives, green finance mechanisms, and life-cycle cost assessments help developers offset higher upfront costs through long-term operational savings.

Barriers and Governance

Barriers to the use of energy-saving technologies include limited local performance data, upfront cost differentials, skill shortages, fragmented procurement practices, and weak regulatory enforcement (Darko et al., 2013; Mosly, 2015; Jaradat et al., 2023). Addressing these barriers requires integrated policy instruments, capacity building and alignment of procurement with life-cycle carbon goals.

Summary of the Literature Review and Identified Research Gaps

The reviewed literature establishes that green building practices – including passive and active design strategies, renewable energy integration, and low-carbon material selection- are effective in reducing both operational and embodied carbon emissions (Chau et al., 2015; Jayasinghe et al., 2022). Studies on building materials and circularity further demonstrate that material substitution, recycling, and prefabrication can significantly reduce carbon footprints and construction waste. Additionally, standards, certification systems, and green finance instruments are recognised as important enablers of sustainable construction, although their impact depends on local adaptation, enforcement, and financial viability.

Despite these advances, several critical knowledge gaps remain. First, there is limited empirical evidence on how these green building practices perform in developing countries, particularly in South Africa's housing sector, where affordability and informal construction dynamics present unique challenges. Second, while the literature identifies numerous barriers such as skill shortages, high upfront costs and weak governance, few studies assess their relative impact on carbon reduction and housing affordability in practice. Third, existing research tends to focus on either the technical or policy dimensions in isolation, rather than exploring the interactions among technological innovation, regulatory frameworks and socio-economic realities. To address these gaps, this study adopts a mixed-method research approach that combines qualitative inquiry with a small exploratory survey, interpreted through a life-cycle perspective rather than a full quantitative LCA.

Research Methodology

A pragmatic research philosophy, involving a sequential, exploratory, mixed-methods research approach, was adopted to evaluate green building practices in housing construction in South Africa. The overall design is qualitative-dominant, with interviews providing in-depth insights that informed the subsequent survey of construction practitioners (engineers, quantity surveyors, consultants, inspectors) and the interpretation of results. The aim is to gain a deeper understanding of practice-based realities, barriers, and context-specific solutions, rather than statistical generalisability.

Purposive sampling targeted six practitioners with direct experience in green building projects, including those affiliated with the Green Building Council and private developers. Data saturation guided sample adequacy. Semi-structured interviews were conducted face-to-face and via online meetings between May and August 2024, lasting 45-75 minutes. The interview guide covered themes including 1) experiences with green housing projects, 2) perceived effective practices for reducing operational and embodied carbon, 3) barriers and enablers to implementation, and 4) suggestions for policy and industry action. Interviews were audio-recorded with the participants' consent, transcribed verbatim, and anonymised.

Drawing on the themes and terminology emerging from the interviews, a Google Forms survey was developed and distributed to 50 randomly selected construction practitioners affiliated with the Green Building Council and listed in the Construction Industry Register. The survey included rating-scale questions (e.g., 1-5 Likert scales for perceived sustainability of housing archetypes and effectiveness of different practices) and open-ended questions on barriers and recommendations. At the end of the survey period, 12 responses were received, representing a response rate of 24%. Document reviews that focused on LCA studies, building codes, certification documentation, and case studies of green housing were used to contextualise practitioner perspectives within a wider life-cycle and policy framing. In total, 18 practitioner inputs (six interviewees and twelve survey respondents) were obtained. The two strands are treated as complementary data sources.

Thematic analysis and descriptive statistics were employed to identify and synthesise patterns across interviews, survey responses, and literature. NVivo was used to code the qualitative data. Two researchers first independently open-coded three interview transcripts, then compared and reconciled their codes to create a shared codebook of possible themes. The codebook was applied to all interview transcripts and open-ended survey responses, with any coding disagreements resolved through discussion and the evolving theme structure reviewed by a third researcher. Through iterative refinement and constant comparison, five overarching themes - energy efficiency, sustainable materials, cost and finance, knowledge and capacity, and certification and governance- were identified. To enhance analytical rigour, the findings were triangulated across data sources (interviews, survey responses and documents). Survey data were analysed using descriptive statistics (frequencies and means) appropriate for the small sample size. Ethical clearance was obtained from the University of Cape Town. Participation was voluntary, with informed consent, and respondent anonymity was preserved.

The study has several limitations: small sample sizes; practitioner-focused, self-selected respondents; localisation to the South African housing sector; and reliance on self-reported perceptions rather than measured performance data. As such, the findings are exploratory and indicative, not statistically representative; they are best viewed as hypotheses and practice insights that require further testing.

Results and Discussion

Overview of Participants and Survey Responses

Participants included engineers, quantity surveyors, consultants, building inspectors and green building specialists. Experience ranged widely (1–25 years), with 18 practitioner inputs across two strands (6 interviewees and 12 survey respondents) engaged in both private and selective public projects. Three of the interview respondents are engineers, with an equal number drawn from the fields of quantity surveying, consulting, and inspection. Survey respondents rated single-family homes, multi-family homes, and mixed-use developments on sustainability; responses highlighted notable variations in performance related to design, materials, and proximity to services. Figure 1 illustrates the survey respondents' perceived sustainability levels across housing archetypes.

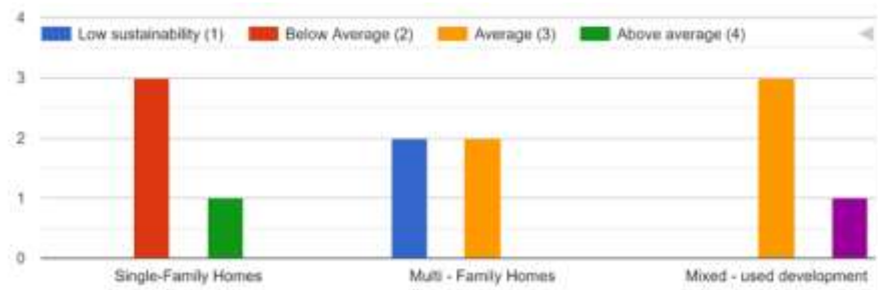

Figure 1. Perceived level of Sustainability in housing archetypes

The ratings presented in Figure 1 reflect perceptions, not measured environmental performance. It shows that single-family homes were rated as the most sustainable type of housing (average ~ 3.5), followed by mixed-use development (~ 3.0) and multi-family homes (~ 2.5). The discrepancy between these perceptions and established evidence on the inherent efficiency advantages of compact, multi-family housing underscores the need for more evidence-based guidance on actual carbon outcomes.

Emergent themes

Thematic synthesis of the two strands of empirical data collected and literature identified five principal themes underpinning effective carbon reduction and sustainability in housing: energy efficiency, sustainable materials (embodied carbon), cost and financing, knowledge and capacity, and certification and governance. Each theme is discussed below. Energy efficiency and cost/finance were mentioned by all interviewees and most survey respondents, indicating particularly high salience. Materials, knowledge/capacity and governance were raised by several participants in each strand.

Energy Efficiency and Renewables (Operational Carbon Reductions)

Practitioner data and the literature converge on the centrality of energy efficiency for operational carbon reductions. Passive strategies, such as orientation, envelope insulation, shading, glazing selection, natural ventilation, and daylighting, emerged as cost-effective first steps in energy reduction, supporting earlier research by Pacheco et al. (2012) and Morrissey et al. (2011). Interviewees emphasised low-cost measures, such as LED lighting, appliance management (plug load control), water heating scheduling (geyser control), and occupant behavioural measures, as high-impact, fast-payback interventions. For example, an engineer, INV001, observed that switching to LED lighting reduces energy by about 95% for equivalent service.

Renewable integration (PV for electricity, solar thermal for water heating) is effective but requires upfront investment and a suitable roof area. Evidence suggests that combined approaches (efficiency + PV) produce the best life-cycle carbon-emission reductions and economic outcomes (Zhai et al., 2007; Khahro et al., 2021). Practitioners stressed the importance of matching technology choices to local grid reliability, tariff structures and occupant energy behaviour. INV003, a Green Building specialist, noted that *"…that would be putting my geyser off every morning and switching it back on at night, making sure my lights are switched off, making sure all my unnecessary plug loads are taken out of the wall."*

Materials and Embodied Carbon (supply-side carbon)

Materials selection was highlighted as an increasingly important lever as operational energy use declines. Embodied carbon in concrete, steel, and masonry can dominate life-cycle emissions, particularly in low-energy buildings (Chau et al., 2015; Jayasinghe et al., 2022). Practitioners reported adopting coal ash and industrial byproducts as cement extenders and using recycled aggregates and recycled plastics to reduce embodied energy. According to INV003, a Green Building specialist, "*Coal ash used as cement extender actually reduces the emission of carbon during the manufacturing of bricks.*" INV004, a Quantity Surveyor, noted the use of recycled plastic bottles as a green practice in sustainable housing. Alternative materials such as bamboo, earthbags, and "grass concrete" were noted in the literature as viable, locally appropriate options in many contexts (Matthews, 2019; Adetooto et al., 2022)

Prefabrication and modular construction were recognised as potential means of reducing onsite waste and improving quality control (Sepasgozar et al., 2020), although practitioners cautioned about supply-chain limitations, quality assurance and the need for local testing and standards for many alternative materials.

Cost, Financing and Life Cycle Returns

Upfront cost perceptions were widely cited as a principal barrier to the adoption of carbon-reducing technologies in buildings. Practitioners noted the price sensitivity of residential markets and high interest rates, which make initial capital more decisive than life-cycle cost savings (INV002, Building Inspector). According to INV002, "*Cost is still a big driver in the residential market because the industry is very price sensitive.*" The interview findings also showed decreasing costs for key interventions (LEDs, PV) and the potential to capture rental premiums and lower operational costs for owners. INV004 highlighted that energy-efficient buildings may attract higher rents and lower insurance premiums due to reduced operational risk. These findings support literature calling for the integration of life-cycle cost analysis into project appraisal and procurement to demonstrate value for money and to justify higher upfront investments (Liu et al., 2022). Cost and finance were raised by every interviewee and in most survey responses, indicating a central theme.

Knowledge, Skills and Awareness

A lack of knowledge among homeowners, contractors, and some professionals constrains adoption (Mosly, 2015). Practitioners noted that misconceptions about complexity and cost persist among clients; contractor skills for sustainable techniques are uneven. INV001, an Engineer, asked rhetorically whether practitioners and clients *"even know about the implementation of green building and practice."* Education, demonstration projects and training (both vocational and professional) were seen as essential to mainstream practices. INV004 emphasised the need to "*educate the communities about the implementation of green practices or green building practices in housing.*"

Community engagement and neighbourhood initiatives (e.g., recycling programmes, bulk solar schemes) were cited as effective models for building social acceptance and delivering co-benefits. Digital platforms (WhatsApp groups) were used locally for coordination and knowledge sharing. According to INV002, a building inspector, community programmes that upskill graduates or young professionals entering the construction industry could help build capacity.

Certification, Standards and Governance

Certification schemes (such as Green Star) and building energy codes were recognised as key instruments for codifying expectations and providing benchmarks. There was consensus amongst the interviewees that certification provides market recognition and measurable carbon reductions. Survey responses suggested that certified buildings may reduce emissions by roughly one-third compared with conventional buildings, aligning with international evidence. However, Wafula and Talukhaba (2011) noted that certification frameworks require codes to be calibrated to local climate, resource availability and market realities. Participants highlighted variability in enforcement and alignment across planning approvals, building control and procurement, which can reduce the effectiveness of regulations such as SANS 204 in South Africa. Certification and governance issues were referenced by most participants, indicating a significant though slightly less ubiquitous theme compared to energy efficiency and cost.

Policy and Practice Implications

Several policy and practice implications emerge from the five themes. Firstly, building codes and public procurement should emphasise passive design strategies and minimum standards for insulation, airtightness, solar shading and glazing. Incentives and financing mechanisms should prioritise PV and solar water heating in residential retrofits and new builds, particularly in areas with poor grid reliability. Secondly, embodied carbon estimates and procurement criteria should be embedded into public housing contracts at the design stage. Also, the use of supplementary cementitious materials (e.g., fly ash, slag), recycled aggregates, and recycled steel should be incentivised. Additionally, support for local pilots, testing, and standards for alternative building materials would help de-risk adoption.

Thirdly, green finance instruments (tax incentives, grants, concessional loans, and green mortgages) and fiscal incentives for low-carbon housing should be introduced or expanded if they are not already in place to help offset higher upfront costs. Life-cycle cost analysis should be required in public procurement, and private lenders should be encouraged to incorporate energy performance into their credit assessment and property valuation. Fourthly, there should be investment in targeted capacity building for tradespeople and designers, expanding pilot projects, and developing accessible guidance and toolkits for homeowners and small developers. Finally, municipalities and building inspectors should enforce energy-related provisions in building regulations and recognise third-party certification calibrated to local climatic zones. Institutional coordination between planning, building control and procurement is necessary to ensure that low-carbon objectives are not undermined by conflicting rules.

Integrative Strategies and Cross-cutting Considerations

The findings highlight the importance of life-cycle thinking, considering both operational and embodied carbon, to ensure that carbon-reduction interventions do not simply shift emissions between project phases (Chau et al., 2015; Jayasinghe et al., 2022). For example, highly insulated buildings with carbon-intensive materials may have mixed net benefits if embodied carbon is not managed. Furthermore, it shows that different housing archetypes offer different opportunities. High-density apartments exhibit inherent advantages for improved energy performance and lower transport-related carbon emissions; single-family homes offer rooftop areas for PV but may be more exposed to envelope inefficiencies. Informal settlements pose unique challenges (poor insulation, vulnerability to climate hazards) but also opportunities for incremental, low-cost interventions (water harvesting, improved cookstoves, community PV) as illustrated in Figure 2.

Figure 2. Incremental House Construction in an Informal Settlement, Cape Town (Source: authors)

Adetooto et al. (2022) argue that policy should be tailored to archetype-specific levers. The findings reinforce this view and suggest that the social benefits (improved indoor air quality, thermal comfort, reduced energy bills, and resilience to energy/water service interruptions) (Balaban & de Oliveira, 2017) can be powerful drivers when appropriately framed in policies and financing models.

Conclusions and Recommendations

Conclusions

This paper examined the practices perceived to be effective in reducing carbon emissions within housing construction, assessed the barriers and enablers that shape their uptake in South Africa, and proposes policy- and practice-oriented measures to support low-carbon housing. Using a qualitative-dominant, sequential mixed-methods research approach that combined six-interviews and twelve survey responses from South African construction practitioners, triangulated with a literature review, the study found that the practices perceived as most effective in reducing carbon emissions within housing are the use of renewables (PV for electricity and solar thermal for water heating); demand reduction through passive design and targeted efficiency upgrades (e.g., LED lighting, plug-load control, water heating management); and intentional material selection including substitution of materials with high embodied energy with those with lower embodied energy (such as use of coal ash and industrial byproducts as cement extenders) as well as prefabrication and modular construction to reduce onsite waste.

Cost, lack of knowledge, skills, and awareness, certification, standards, and governance are identified as key barriers to scaling up low-carbon solutions in housing. Substantial and cost-effective emission reductions appear achievable when projects combine demand reduction through passive design, targeted efficiency upgrades, and appropriately sized renewable energy sources, with deliberate choices that lower embodied carbon in materials and construction. Certification and codes can drive adoption when adapted to local conditions and enforced; without such alignment, rules risk being aspirational rather than transformative.

The South African practitioner's evidence adds three nuances. First, perceptions of "sustainability" across housing types do not always align with system-level carbon outcomes (e.g., single-family homes were rated as the most "sustainable" by respondents, despite the inherent efficiency advantages of compact, well-designed multi-family buildings), underscoring the need for clearer, evidence-based guidance. Second, community-level initiatives and simple behavioural practices were seen as effective and scalable entry points for carbon reduction. Third, while alternative materials and off-site methods show promise, their adoption will depend on established standards, rigorous testing, and predictable demand through procurement.

Recommendations

To address the identified barriers and translate proven practices into uptake of carbon-reducing technologies, the following actions are proposed: the government should build skills and market capacity – targeted training for trades and site supervisors on airtightness, insulation detailing, PV installation and low-carbon concrete; the cidb/National Home Builders Registration Council (NHBRC) should fund demonstration projects with open data on costs, performance and user experience; and create a public repository of South Africa-specific embodied carbon factors; and municipalities and Building Inspectors should enforce energy provisions outlined in building regulations and recognise third-party certification calibrated to local climatic zones.

The study is exploratory, with a small, practitioner focuses and sample confined to the South African housing sector. The findings are therefore not statistically generalizable and should be interpreted as indicative insights and hypotheses for further study. Future research should expand measured performance datasets across housing types and climatic zones, develop South Africa-specific embodied carbon benchmarks, and evaluate the real cost/social impact of using carbon-reducing technologies in housing. Comparative studies in other developing and developed contexts, using larger samples and quantitative performance data, would help validate and extend the findings.

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