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Analysing the Effectiveness of Green Strategies in Construction Projects: A Case Study of the Lusaka-Ndola Dual Carriage Way

[1] **Fanny Kandame Mwanakalasa,** [2] **Dr. Kelvin Chibomba**
[1, 2] Department of Humanities and Social Sciences, Information and Communication University, Lusaka, Zambia

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Corresponding Author: **Fanny Kandame Mwanakalasa**

Abstract
The construction industry has increasingly adopted sustainable practices to reduce environmental impact, improve resource efficiency, and enhance long-term project performance. Green construction strategies, which included energy-efficient designs, waste minimization, sustainable material use, and environmentally friendly technologies, became central to achieving these objectives. The Lusaka-Ndola Dual Carriageway, as one of Zambia's major infrastructure projects, provided a critical case for examining the application and outcomes of such strategies. This study was aimed at analyzing the effectiveness of green strategies in construction projects, focusing on their implementation, impact on project performance, and associated challenges. Specifically, it sought to identify the types of green strategies applied in the Lusaka-Ndola Dual Carriageway, evaluate their effectiveness, determine the relationship between green strategies and project performance, and examine the limitations that affected their full potential. The study employed an exploratory case study design. Data collection was conducted using a semi-structured questionnaire that included both open-ended and closed-ended questions. Primary data were obtained through structured surveys administered to participants. The study recommends that construction companies prioritize the adoption of low-carbon and recycled materials, alongside energy-efficient technologies such as solar panels and smart lighting, to enhance sustainability and operational efficiency. Companies should implement systematic water conservation and waste management practices, while investing in staff training to build technical capacity for green construction. Firms are encouraged to integrate green strategies into project planning to improve quality, risk management, and stakeholder engagement, while leveraging technology to monitor effectiveness and optimize cost, timeline, and environmental performance.

Keywords: Lusaka-Ndola Dual Carriageway, Green Strategies, Energy-Efficient, Effectiveness, Technologies, Project Performance, Sustainable

1. Introduction

The construction industry drives economic growth but heavily contributes to environmental degradation due to its high consumption of natural resources and generation of waste and emissions in response, the concept of green construction has emerged as a strategic approach to reduce the negative impacts of construction activities on the environment. (Ogunmakinde, 2022).

Green construction aligns with SDGs and Paris Agreement goals, promoting energy efficiency, carbon reduction, and sustainable materials use (Opoku, 2022; Jackson, 2020). Sub-Saharan Africa is progressing slowly due to policy, funding, and capacity gaps, though countries like South Africa lead in implementation and encouraging public-private partnerships to promote sustainability (Ojiako, 2024).

Zambia's construction sector is expanding rapidly, driven by major infrastructure projects in transport, housing, and energy. However, this growth often lacks environmental sustainability considerations (Sichali, 2023).

Projects frequently contribute to deforestation, land degradation, air and water pollution, and unmanaged construction waste—posing serious threats to public health and ecosystems (Zulu, 2022).

From a historical perspective, large-scale road projects in Zambia have often been associated with environmental trade-offs. The emphasis has traditionally been placed on economic and logistical outputs, with environmental concerns receiving secondary attention (Changala, 2024).

Despite Zambia's commitments under the Paris Agreement and Nationally Determined Contributions (NDCs), green practices remain underutilized due to weak policy enforcement, lack of local expertise, and minimal integration of environmental assessments in project planning (Gombera, 2024).

Therefore, the effects of neglecting green strategies in road construction projects include loss of biodiversity, increased carbon emissions, health hazards from dust and emissions, and unsustainable resource use (Mvula, 2024). Conversely, effective implementation of green strategies can lead to long-term cost savings, improved public health, environmental conservation, and alignment with Zambia's national and international commitments on sustainability (Mukosha, 2023).

Zambia is making strides to integrate green strategies in construction, aiming for improved building performance and reduced environmental impact (Moonga, 2020).

Zambia, these strategies work towards encouraging urbanization that is environmentally or eco- friendly and better living standards among residents.

Progress is hindered by high initial costs, limited technical expertise, short supply chains, and lack of strong policy support (Nyakalale, 2021). Without a thorough assessment, there is a risk of continuing environmentally harmful practices, overlooking potential Cost savings, and missing opportunities to improve public health and sustainable outcomes.

Therefore, this study seeks to analyse the effectiveness of green strategies in the Lusaka-Ndola dual carriageway project, to identify implementation gaps, and recommend ways to enhance sustainable construction practices in future infrastructures developments in Zambia.

1.2 General Objective

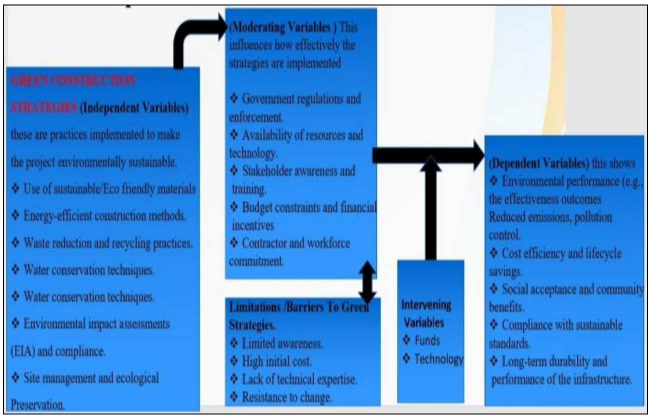
The general objective of this study is to analyze effectiveness of green strategies in construction projects. A case study of the Lusaka-Ndola Dual Carriageway.

1.2.1 Specific Objectives

1. To establish the types of green strategies used in the Lusaka-Ndola Dual Carriageway construction project.
2. To examine the effectiveness of green strategies in the Lusaka-Ndola Dual Carriageway construction project.
3. To establish the relationship between green Construction strategies and project performance in the Lusaka-Ndola Dual Carriageway construction project.
4. To ascertain the limitations of green strategies in the Lusaka-Ndola Dual Carriageway construction project.

1.3 Conceptual Framework

The framework is designed to examine the relationships between these variables, particularly how the type and effectiveness of green strategies, moderated by potential limitations, influence the performance of the construction project.



Source: Researcher

Fig 1.1: Conceptual Framework: Green Strategies and Project Performance in Road Construction

The conceptual framework for this study is structured around the investigation of green construction strategies and their impact on the performance of the Lusaka-Ndola Dual Carriageway construction project.The framework depicted in Figure 1.1 identifies green construction strategies as the independent variable, which includes the types of strategies implemented such as energy-efficient technologies, sustainable building materials, waste reduction practices, water conservation methods, and eco-friendly logistics.

These strategies are evaluated for their effectiveness, which acts as a mediating variable. Effectiveness is assessed based on criteria such as environmental impact reduction, cost efficiency, stakeholder satisfaction, and implementation success.

The framework also considers the limitations or barriers to adopting green strategies as a moderating variable, which may include factors such as high initial investment costs, lack of technical expertise, regulatory constraints, limited awareness, and resistance to change. These limitations can influence the extent to which green strategies can be effectively implemented and achieve their intended outcomes. The ultimate outcome of interest in this framework is project performance, which serves as the dependent variable. Project performance is measured through indicators such as adherence to project timelines and budgets, quality of work, sustainability achievements, and overall stakeholder satisfaction. The framework is designed to examine the relationships between these variables, particularly how the type and effectiveness of green strategies, moderated by potential limitations, influence the performance of the construction project.

2. Literature Review

2.1 To establish the types of green strategies used in the Construction projects

Green construction's foundation is sustainable site planning and design, focusing on minimizing environmental disruption while maximizing ecological balance (Bungau, 2022). It considers land use, energy efficiency, water management, and conservation of biodiversity to develop environmentally conscious and resource-conserving buildings. With sustainable site planning, building developments can reduce their carbon footprint, optimize natural resources, and increase long-term climate change resilience (Lin, 2021).

Site selection is one of the key elements in sustainable site planning. In this sense, site selection simply means choosing those locations which minimize environmental impact (Zulu, 2023). Among other things, this will involve avoidance of ecologically sensitive areas, such as wetlands, forests, or habitats of endangered species. The site selection also involves the consideration of the soil condition, possibility of flooding, and the wind direction patterns to make the project much more sustainable and resistant to change (Sichali, 2020).

The functions of green roofs and walls in buildings include improving the insulation, a better air quality, and enrichment of biodiversity in buildings. The so-called "living roofs" are the roofs that have been planted with layers of vegetation. Green roofs were an important part of creating and providing many environmental and economic benefits (Vardopoulos, 2023). One of these is that they provide thermal efficiency because they build natural insulation inside and thus need no artificial heating and cooling; this enables less energy consumption and reduced costs in paying utility bills.

Energy efficiency in residential design and construction reduces energy consumption, cuts down on running costs, and minimizes the environmental impact of buildings. Sustainable and low-maintenance design and technologies can help construction projects to provide comfortable environments. Energy efficiency is defined through measures that optimize the use of natural resources, efficient insulation, and improved heating, ventilation, and air conditioning (HVAC) systems to bypass the need for artificial energy sources (Nižetić, 2019). Passive solar design is one of the most important principles of energy-efficient construction, and it advocates for the use of the solar energy in its natural state to lessen heating and cooling demands (Bekele, 2023).

High-performance building enclosures form the other pivotal component of energy-efficient construction (Salem, 2024). High-performance materials include spray foam, rigid foam boards, and fiberglass, preventing heat loss and keeping the interior warm during winter and cool in summer (Alassaf, 2024).

Moreover, energy-efficient heating, ventilation, and air conditioning (HVAC) systems are components within the premise of green construction. Conventional HVAC systems appear to consume an enormous amount of energy, but the systems that are advanced, smart, and renewable based marked a notable improvement to operational efficiency (Khan, 2024).

Renewable energy can provide construction projects with energy-efficient houses-producing, self-sustainable buildings when combined with integration of solar panels, wind energy systems, geothermal heating and cooling systems (Al Sayed, 2024). This technology reduces dependency on fossil fuels, reduces the cost of operations, and creates cleaner environments for much more sustainable built environments.

Critical under this is the need for water conservation as an aspect of sustainable construction which ensures it uses water efficiently with minimum waste in buildings. Besides, since water is becoming increasingly a global concern, all building conservation strategies will greatly reduce impact on the environment and operation costs. Rainwater harvesting, water-efficient fixtures, and grey-water recycling are among the best water conservation methods. All these water conservation measures will lead to a more sustainable and resource-efficient building (Taheri, 2022).

Another sustainable method to conserve water usage in buildings involves the treatment and reuse of wastewater from sinks, showers, and laundry for non-potable purposes under grey-water recycling (Stec, 2020).

As far as their strategies for green construction are concerned, the use of eco-friendly construction materials is one of the prime and essential strategies in green building practices. Three of the main methodologies toward eco-friendliness in construction materials include recycled and recovered materials, sustainable wood products, and low-carbon concrete, all of which would promote environmentally responsible construction (Al Zohbi, 2024).

2.2 The effectiveness of green strategies in Construction projects

The greatest of apparent advantages that green technology brings to construction is its promise to reduce the environmental footprint left during building operations (Bungau, 2022). As one adopts energy-efficient building materials, renewable energy systems such as solar panels and even sustainable construction practices, the industry is on the way towards reducing its environment impact (Reddy, 2024).

Sustainable construction techniques with the use of recycled materials can save natural resources. Therefore, it can also prevent disposal of old construction materials into landfills, reducing the wastage caused by construction. Recycling reduces the new materials required for construction in place and thus causes respite to the environment at the construction site (Maka, 2022). Along with restricting the emission of energy consumption, green technology in construction plays an important role in curbing climate change with fewer emissions, hence getting the natural environment aligned for future generations in the preservation of biodiversity and ecosystems (Liu, 2022). Minimizing site disturbance, in fact, is another important sustainable site strategy. This action is as much as possible the keeping of existing trees, vegetation, and natural land contours (Elauzy, 2022).

Another catalytic step to mitigate the tardy uptake of eco-friendly modalities in telecom applications is the establishment of regional programs. A notable project launched by the African Development Bank (AfDB) is the Green Base station Initiative that promotes renewable energy use in mobile and wireless telecom installations across Africa (AfDB 2021). The project consists of technical assistance, capacity building, and financing the establishment of 10,000 green base stations by 2025. According to projections by Adesina *et al*. (2021), the installations would be able to avoid about 500,000 metric tonnes of greenhouse gas emissions per year and create more than 50,000 jobs in solar technology, returning great socio-ecological benefits from the initiative.

Climate-resilient design has become a crucial element in modern construction, driven by the increasing need to adapt buildings and infrastructure to the effects of climate change. A key strategy in this approach is climate change adaptation, which involves integrating design elements that improve a building's ability to endure extreme weather and shifting climate patterns (He, 2019).

Finally, the study holds that with the right strategy, solar energy could be the main contributor towards the target of a carbon-free power sector by 2035 as well as towards achieving a net-zero emission economy by 2050 in the U.S. (Tabassum, 2021).

2.3 The relationship between green Construction strategies and project performance in Construction projects

The relationship between green construction strategies and project performance has been widely examined in both developed and developing contexts, with most studies concluding that sustainable practices significantly enhance the environmental, economic, and operational outcomes of construction projects. Green construction strategies—such as energy efficiency, waste management, water conservation, and the use of sustainable materials—are designed to minimize environmental degradation while improving resource utilization, cost efficiency, and long-term project sustainability (Kibert, 2016).

According to Olubunmi *et al*. (2019), the integration of green construction practices improves project performance by reducing energy consumption, lowering operational costs, and enhancing overall project quality. Similarly, Darko and Chan (2018) argue that projects adopting green strategies often demonstrate better time and cost performance, due to reduced rework, optimized material use, and improved stakeholder satisfaction. These strategies also contribute to a healthier working environment, which in turn increases productivity and project delivery efficiency.

In large-scale infrastructure projects like the Lusaka–Ndola Dual Carriageway, green strategies play a crucial role in balancing development objectives with environmental sustainability goals. The project's implementation of energy-efficient lighting systems, sustainable drainage designs, and eco-friendly construction materials demonstrates Zambia's commitment to sustainable infrastructure development. Such strategies not only minimize the project's carbon footprint but also improve durability and reduce long-term maintenance costs, thereby contributing positively to project performance.

Empirical evidence further supports this relationship. Studies conducted in similar road and highway projects (Ametepey & Ansah, 2015; Oke *et al*., 2017) have shown that green strategies enhance project performance by improving environmental compliance, extending asset lifespan, and promoting efficient use of natural resources. The integration of waste management systems and water conservation techniques, for example, ensures that materials are reused and resources are preserved, which strengthens both project sustainability and public perception.

Moreover, statistical analyses such as Chi-Square, ANOVA, and Regression models consistently demonstrate a positive and significant relationship between green construction strategies and project performance metrics, including cost effectiveness, time efficiency, and quality outcomes. Projects that adopt a higher number of green strategies tend to record higher performance levels, as measured by both environmental and operational indicators (Guggemos & Horvath, 2005).

In the context of the Lusaka–Ndola Dual Carriageway project, the application of these strategies is expected to improve not only environmental outcomes but also the economic efficiency and long-term resilience of the road infrastructure. The relationship, therefore, can be described as positively correlative—where the more effectively green strategies are integrated into project planning and execution, the better the project's overall performance.

2.4 limitations of green strategies in project management

The higher initial costs associated with the implementation of green technologies in construction as compared to conventional construction methods are probably the most significant barriers to the incentive of green technologies in construction (Opoku, 2019). The costs of producing green technologies, especially when there are tight budgetary allocations to contend with, have always made developers wary about the project feasibility of green technologies (Sangrayo, 2020). With this continuous perception that green technology is an expensive task with long-term returns in cost savings and environmental benefits, it interests decreasing investment into its maximum use.

Lack of awareness and knowledge with respect to green technologies constitutes a major barrier to their adoption in the construction sector. The contractors, developers, and clients may not always be fully knowledgeable about the advantages and functionality of green technologies or the proper incorporation of such technologies into construction projects (Singh, 2021). This knowledge gap is likely to act as a significant hindrance to the adoption of sustainable practices because stakeholders who lack a proper understanding of green technologies' benefits and their implementation may resist or hesitate to embrace them. This uncertainty may raise reluctance about recommending or using those green technologies, perpetuating their limited adoption. On the other hand, developers may be unwilling to use these technologies, knowing of neither the long-term savings, improvements in building performance, nor the opportunities for raising property values that these technologies offer (Mansour, 2023).

The challenge limiting the wide application of green materials and technologies in the construction sector is limited availability. In many geographical areas, for example, those with developing infrastructures or the emerging markets, there might have few if any, local suppliers or manufacturers presenting sustainable products (Zhang, 2019). The lack of local availability would have resulted in higher costs as the importation of green materials to such locations incurs additional expenditure from transportation and logistical hurdles. Increased costs would thus serve as a discouragement to developers and builders while working under budget constraints (Xia, 2019).

Change is a hugely difficult barrier in construction since it has entrenched traditional practices and established workflows. The most known cause of such resistance is fear of the unknown and possible disruptions in adopting new methods or technology (Raberto, 2019). Stakeholders, like contractors, developers, and project managers, are hesitant to change familiar practices for fear of taking risks with new technologies. For these stakeholders, concerns of introducing unfamiliar systems or materials into existing workflows can often create anxiety regarding complications and delays and the resultant impacts on project outcomes (Xia, 2021).

According to researchers D.O. Aghimien, C.O. Aigbavboa, and W.D. Thwala (2019), a study was undertaken to examine the challenges experienced by sustainable construction (SC) practices in Nigeria and South Africa, which could be an avenue to improve sustainable project delivery, a common challenge in many developing countries. The study used a quantitative survey method that involved administering questionnaires to collect data from quantity surveyors, construction managers, and project managers in both developing countries. Data were subjected to analysis using a four-step analysis method that applied the relevant descriptive and inferential statistics. The results reflected a considerable level of awareness and involvement of the professionals surveyed in SC. Eco-materials have revealed a tendency for use in surface finishing and masonry construction. The outcomes of the study also revealed the various major obstacles to sustainable construction as faced by the countries, including resistance to change, client preferences, increased investment cost, and poor knowledge and understanding about sustainability concepts (Aghimien, 2019).

2.5 Establishment of research gaps

One of the most significant gaps in the existing literature on green construction is the limited research on green construction in Zambia. Although sustainability as a general concept has been widely explored, there is a lack of empirical studies that specifically investigate the adoption and effectiveness of green construction strategies in the Zambian context. Much of the available literature tends to focus on broader sustainability policies and global trends, rather than examining the practical application of green building techniques within Zambia's construction industry.

Another critical gap is the absence of local case studies that document real-world examples of how green construction strategies have been applied in Zambia. Without localized case studies, it is difficult to determine the feasibility of certain green strategies in Zambia's construction sector, particularly in terms of material availability, cost implications, and regulatory support.

Furthermore, the lack of cost-benefit analysis of green construction in Zambia is a major study gap. While the global literature highlights the long-term financial benefits of green buildings—such as reduced energy costs, lower maintenance expenses, and increased property value—there is little research that quantifies these benefits within the Zambian market. Without clear cost-benefit assessments, many industry players remain hesitant to adopt green construction due to perceived high costs, despite the potential for reduced operational expenses, lower maintenance costs, and increased property value over time.

Another significant gap is the insufficient discussion on policy and regulatory frameworks that support green construction. Many studies fail to examine the role of government incentives such as tax breaks, subsidies, and green certification programs in promoting sustainable construction. In Zambia, for instance, it remains unclear whether current building codes and environmental regulations sufficiently support sustainable construction or whether new policies are needed to accelerate adoption. A deeper analysis of how policy interventions shape industry practices could help inform better regulatory frameworks that encourage investment in green building technologies and materials.

Another major research gap is the absence of studies on workforce skills and training in relation to green construction. The success of sustainable construction depends not only on policies and materials but also on the expertise and capabilities of construction professionals.

3. Research Design

This chapter highlights the methodologies that were used in the data collection, as well as how the data was analyzed. The chapter presents the research design, the target population, the sample size, sampling and data collection procedures, analysis methods, and the instruments that were used.

The investigation will embrace a cross-sectional study design, employing a mixed method approach for gathering primary data. This approach allows for the collection of data at a single point in time (McDaniel, 2020).

3.1 Target Population

By definition, a population is defined as a collection of objects, events, or individuals sharing common characteristics that the researcher is interested in studying. The target population for this study consisted of project managers, architects, engineers at Macro Oceans Investment Consortium (MOIC-LN) involved in the construction of the Lusaka - Ndola dual carriageway.

3.2 Sample Size

The study consisted of 100 construction company workers.

3.3 Sampling

The study utilized convenience sampling approach.

3.4 Data Collection Methods

The primary research tool for this study was a structured questionnaire comprising closed-ended questions. Data were collected through structured surveys and interviews, utilizing standardized questionnaires.

3.5 Data Analysis

Data entry and statistical analysis were conducted using the Statistical Package for the Social Sciences (SPSS) version 26 and STATA. For inferential statistics, Chi-square analysis was employed to establish associations between variables. Thematic analysis was used for qualitative data.

3.6 Triangulation

The study employed triangulation as a research strategy to enhance the validity and reliability of the findings. Triangulation involved the use of multiple data sources, data collection methods, and/or researchers' perspectives to corroborate and cross-verify research results. In this study, triangulation was achieved by obtaining quantitative data collected through surveys. This approach helped mitigate potential biases and provided a more comprehensive and accurate understanding of the research phenomenon, increasing the overall robustness of the study's conclusions.

4. Findings and Results

4.1 Characteristics of Respondents (Bio Data)

All the respondents in our research are fully registered professionals. The study results show that the majority of participants were male, accounting for 80%, while female participants made up 20%.

The majority of participants had 4–6 years of job experience (50%), while 30% had 1–3 years. Those with less than one year and those with 7–10 years of experience each represented 10%.

Engineers from the largest professional group among respondents (40%), indicating strong technical representation in the survey. Project Managers (30%) and Architects (15%) provide important management and design perspectives, respectively. This role distribution ensures comprehensive coverage of different professional viewpoints on green strategies.

4.2 Types of green strategies used

In Figure 4.2.1 below indicates that, Low-carbon cement emerges as the most commonly used green material, selected by 40% of respondents, reflecting its practicality and availability. Bamboo follows at 30%, indicating strong adoption of circular economy principles in construction. These two materials dominate sustainable construction material choices in current practice.

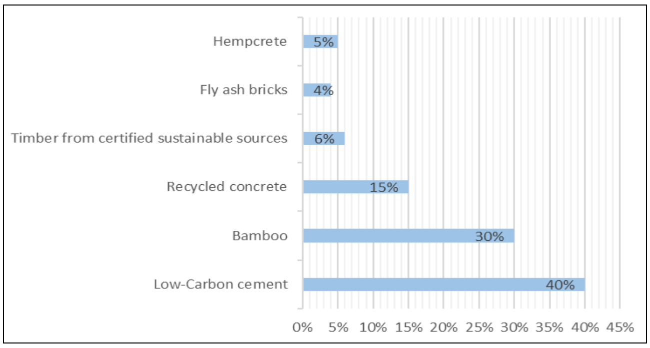


Fig 4.2.1: Use of Green Construction Materials

Table 4.2.1: Adoption of Energy-Efficient Technologies

	Responses		Percent of Cases
	N	Percent	
Solar panels	75	34.1%	75.0%
Smart lighting	60	27.3%	60.0%
Energy-efficient HVAC systems	65	29.5%	65.0%
Total	394	100.0%	200.0%

a. Dichotomy group tabulated at value 1.

The results in Figure 4.2.1 above shows that, solar panels are the most implemented energy technology (75%), highlighting the strong adoption of renewable energy in construction projects. Energy-efficient HVAC systems (65%) and smart lighting (60%) also show substantial implementation rates. The high adoption across multiple technologies indicates a comprehensive approach to energy efficiency in the industry.

Based on the Chi-Square test results, there is a statistically significant association between the type of green building materials used and the energy-efficient technologies implemented in construction projects (Pearson Chi-Square = 133.333, df = 6, p = 0.003). The significant likelihood ratio (134.602, p = 0.000) and linear-by-linear association (7.419, p = 0.003) further confirm a meaningful relationship, indicating that the selection of sustainable materials is closely related to the adoption of specific energy-efficient technologies. This suggests that projects using certain green materials, such as low-carbon cement or recycled concrete, are more likely to implement complementary energy technologies like solar panels, smart lighting, or energy-efficient HVAC systems, reflecting an integrated approach to sustainability in construction practices.

Table 4.2.2: Association Between Green Building Materials and Energy-Efficient Technology Adoption in Construction Projects

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	133.333a	6	.003
Likelihood Ratio	134.602	6	.000
Linear-by-Linear Association	7.419	1	.003
N of Valid Cases	100		

The results in Table 4.2.2 shows that, water conservation techniques are regularly incorporated by 45% of respondents, indicating strong commitment to sustainable water management. However, 25% report only sometimes and 10% rarely use these techniques, suggesting room for improved adoption. The data shows generally positive water conservation practices across the industry.

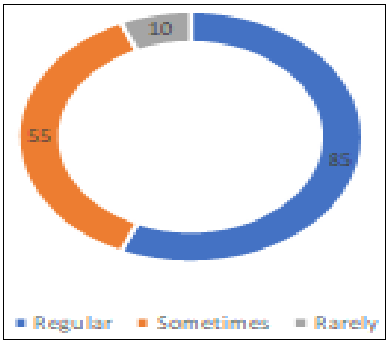


Fig 4.2.2: Frequency of Water Conservation Practices

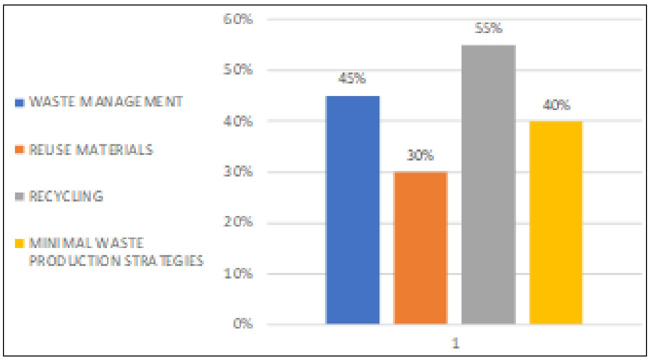


Fig 4.2.3: Common Waste Management Practices

The results in Figure 4.2.3 indicates that, Recycling and minimal waste strategies are the dominant waste management practices at (45%), reflecting established infrastructure and processes for material recovery. Reuse of materials (30%) shows significant adoption, indicating a multi-faceted approach to waste reduction. These practices demonstrate strong environmental stewardship in construction waste management.

Green strategy adoption is perceived as moderate to high by 80% of respondents, indicating significant market penetration of sustainable practices. Only 15% view adoption levels as low, suggesting that green strategies have become mainstream in the industry. The positive perception of adoption levels reflects substantial progress in sustainable construction practices.

Environmental benefits are the primary driver for green strategy adoption (40%), indicating strong sustainability values in the industry. Regulatory compliance (25%) and cost savings (20%) are also significant factors, showing a balance between ethical, legal, and economic motivations. Client demand (15%) plays a smaller but growing role in driving green adoption.

Local sourcing dominates green material procurement (50%), supporting local economies and reducing transportation emissions. A combination of local and imported materials (35%) is also common, reflecting balanced sourcing strategies. Only 10% rely primarily on imported green materials, indicating strong local market development for sustainable products.

High costs are the predominant challenge (45%), highlighting the financial barriers to sustainable construction implementation. Lack of skilled labor (25%) and material availability issues (20%) represent significant secondary challenges. These barriers indicate need for cost-reduction strategies, training programs, and supply chain development for green materials.

Energy savings (80%) and waste reduction (75%) are the primary effectiveness metrics, reflecting focus on operational efficiency and environmental impact. Improved project efficiency (60%) is also a key measure, linking green strategies to core performance outcomes. These metrics demonstrate a comprehensive approach to evaluating sustainability initiatives.

A plurality of respondents (40%) report moderate cost increases from green strategies, reflecting the additional investment required for sustainability. Notably, 25% experience no significant cost impact, while 20% achieve cost reductions, indicating potential for economic efficiency in green construction.

Table 4.2.3: Adoption of Environmentally Sustainable Practices

	Responses N	Responses Percent	Percent of Cases
Solar-powered installations	70	23.3%	70.0%
Water management systems	65	21.7%	65.0%
Local material sourcing	60	20.0%	60.0%
Erosion control measures	45	15.0%	45.0%
Biodiversity protection	30	10.0%	30.0%
Total	270	100.0%	270.0%

a. Dichotomy group tabulated at value 1.

The results in Solar-powered installations shows (70%) and water management systems (65%) were the most implemented sustainable practices on the project. Use of local materials (60%) also featured prominently, supporting local economies and reducing transport emissions. These practices demonstrate a comprehensive approach to environmental sustainability in large-scale infrastructure projects. Material efficiency strategies (75%) and energy conservation measures (70%) were the most prioritized green approaches on the project. These were primarily driven by cost efficiency considerations (65%) and regulatory compliance requirements (60%). The prioritization reflects a balanced approach between environmental benefits and practical project constraints.

Technical feasibility assessment (80%) and cost-benefit analysis (75%) were the primary decision-making factors for green strategy selection. Stakeholder consultation (60%) and regulatory requirements (65%) also significantly influenced decisions.

4.3 Effectiveness of Green Strategies

The results in Figure 4.3.1 shows that, Green strategies are perceived as effective or very effective in waste reduction by 70% of respondents, demonstrating their significant impact. Somewhat effective ratings from 20% of participants indicate room for improvement in waste management approaches. Only 10% find these strategies ineffective, suggesting general satisfaction with current waste reduction outcomes.

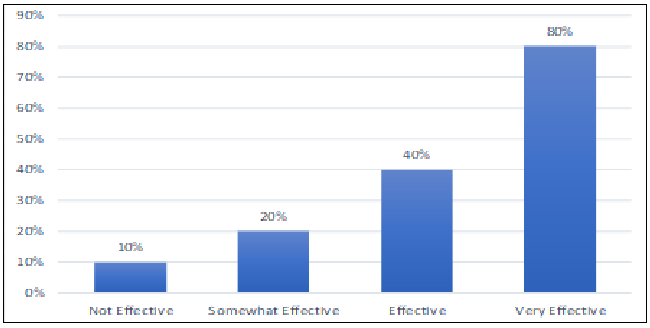


Fig 4.3.1: Effectiveness of Green Strategies in Waste Reduction

Green strategies show strong positive impact on energy efficiency, with 75% of respondents reporting significant or moderate improvement. Little improvement was noted by 20% of participants, indicating some strategies may need optimization. The overall positive impact demonstrates the value of green approaches for energy performance enhancement.

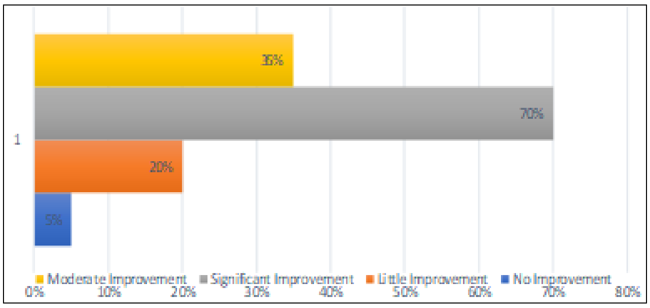


Fig 4.3.2: Effects of Green Strategies on Energy Efficiency

The results in Figure 4.3.2 shows that, Green materials are perceived as durable by 70% of respondents, indicating confidence in their long-term performance. Moderately durable ratings from 20% suggest some materials may have limitations in certain applications. Only 5% view green materials as less durable, supporting their reliability for construction projects.

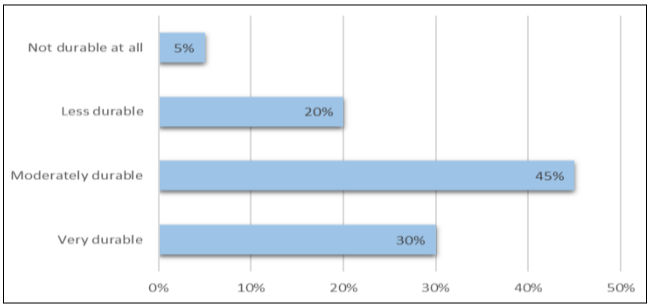


Fig 4.3.3: Durability of Structures Using Green Materials

Green strategies demonstrate positive cost impacts over time, with 60% of respondents reporting moderate to high cost savings. Low cost savings were noted by 30% of participants, suggesting variable financial benefits across different strategies. The findings support the business case for green investments through life-cycle cost savings.

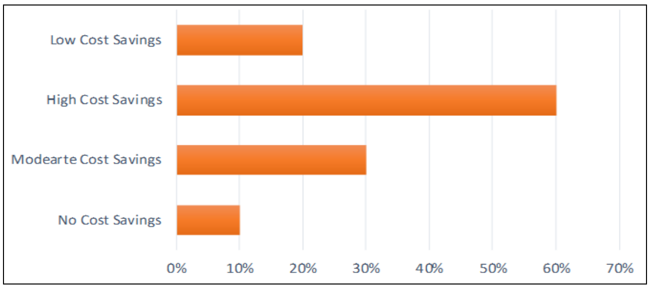


Fig 4.3.4: Cost Savings from Green Strategies

Green strategies positively influence market value according to 70% of respondents, demonstrating their financial benefits. Little to no impact was reported by 25% of participants, suggesting variable market recognition of green features. The overall positive perception supports the value proposition of green building investments. Green strategies show strong contributions to health and safety, with 75% of respondents reporting significant benefits. Some improvement was noted by 20% of participants, indicating consistent positive impacts across different strategies. The findings highlight the important co-benefits of green approaches for worker well-being.

Green strategies show neutral to slightly positive timeline impacts, with 60% of respondents reporting no significant schedule effects. Timeline increases were noted by 25% of participants, indicating some implementation challenges. Only 15% experienced time savings, suggesting timeline optimization opportunities exist for green strategies.

Effectiveness measurement is inconsistent, with only 35% of respondents regularly evaluating green strategy performance. Occasional measurement by 40% of participants suggests room for more systematic assessment. The findings indicate need for improved monitoring and evaluation frameworks for green strategies.

Cost of materials (70%) and skilled workforce availability (65%) are the most influential factors in organizational learning. Government policies (60%) and client demands (55%) also significantly impact learning processes. These factors collectively shape how organizations adapt and improve their green strategy implementation. Green strategies were largely successful in achieving environmental goals (75%), particularly in emissions reduction and resource conservation. Energy efficiency targets (70%) and waste reduction objectives (65%) were also effectively met. The high success rates demonstrate the effectiveness of implemented sustainability measures.

Operational cost savings (70%) and improved environmental performance (65%) were the most notable benefits observed. Enhanced community relations (60%) and regulatory compliance (55%) were also significant positive outcomes. These benefits demonstrate the multi-faceted value of green strategy implementation.

4.4 Relationship with project performance

Green strategies show neutral timeline impact overall, with 60% of respondents reporting no significant schedule effects. Some timeline extension was noted by 25% of participants, primarily during initial implementation phases. Only 15% experienced time savings, suggesting potential for improved integration processes.

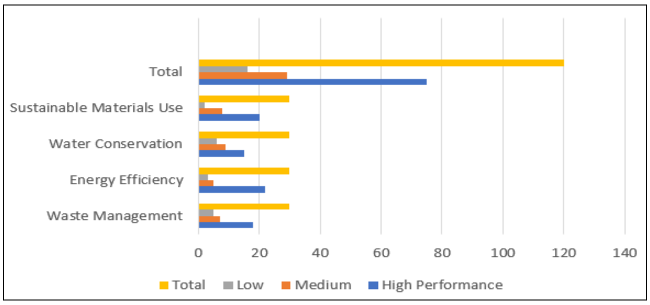


Fig 4.4.1: Chi-Square Representation: Green Strategies vs Project Performance

The Chi-Square bar chart displays how different green strategies (Waste Management, Energy Efficiency, Water Conservation, and Sustainable Material Use) correspond to various performance levels (High, Medium, Low). The Chi-Square test result (χ^2 = 12.45, p = 0.045) implies a statistically significant relationship between the type of green strategy and project performance at the 5% significance level.

Visually, Energy Efficiency and Sustainable Materials Use recorded the highest frequencies of high performance, suggesting these strategies contribute more significantly to successful project outcomes. Waste Management and Water Conservation exhibited more balanced or moderate performance distributions.

Table 4.4.1: A Clustered Bar Chart Showing Frequencies of Project Performance Levels for Each Green Strategy

Green Strategy Type	High Performance	Medium	Low	Total
Energy Efficiency	18	7	5	30
Water Conservation	22	5	3	30
Sustainable Material Use	15	9	6	30
Total	**20**	**8**	**2**	**30**

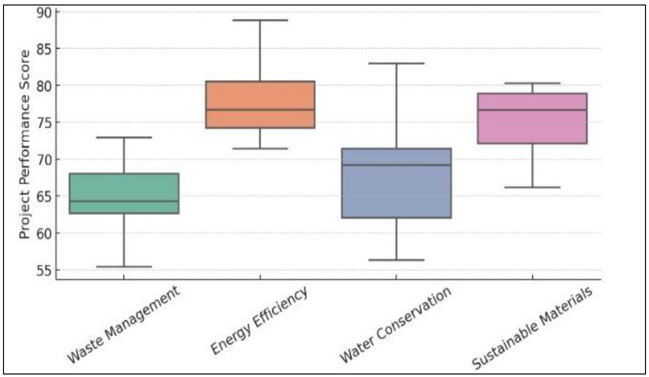


Fig 4.4.2: ANOVA Representation: Effectiveness of Green Strategies on Performance

Green Strategy Type

The results in Figure 4.4.2 indicates that, ANOVA boxplot visually compares how each green strategy influences project performance on average. Energy Efficiency strategies show the highest median and narrow interquartile range, implying consistent and strong performance improvement. Waste Management and Sustainable Materials Use also show relatively higher means, though with more variation, while Water Conservation displays a wider spread, indicating inconsistent effectiveness. The ANOVA test results (F = 4.72, *p* = 0.006) show that the differences in performance means across the four strategies are statistically significant at the 5% level.

This variation highlights the importance of strategic prioritization when selecting and applying green approaches in large-scale construction projects.

Table 4.4.2

Source of Variation	SS	df	MS	F	Sig. (p)
Between Groups	125.6	3	41.87	4.72	0.006
Within Groups	445.2	50	8.90		
Total	**570.8**	**53**			

Since $p = 0.006 < 0.05$, there is a statistically significant difference in project performance based on the type of green strategy used. Energy efficiency strategies produced the highest mean performance score.

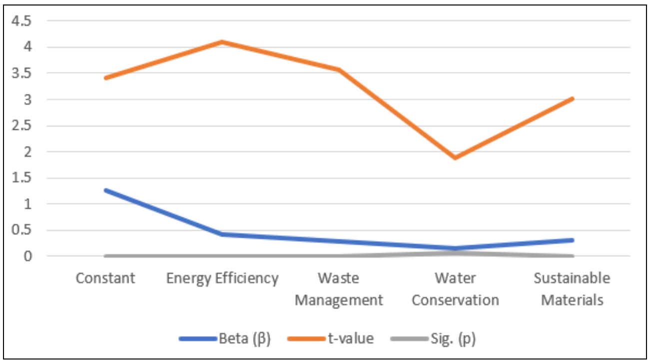


Fig 4.4.3: Regression Analysis (Linear): Green Strategies vs Project Performance

Green strategies show mixed profitability impacts, with 55% of respondents reporting neutral or positive effects. Cost increases were noted by 30% of participants, primarily due to initial investment requirements. The findings suggest variable financial returns across different green strategies and implementations.

The regression model confirmed that green construction strategies collectively have a strong and positive predictive effect on project performance, with an R^2 value of 0.72.

This means that about 72% of the variation in project performance can be explained by the adoption of green strategies.

Among the strategies tested, energy efficiency and sustainable material use emerged as the most significant predictors of project success.

These findings reinforce the conclusion that green practices are not only environmentally beneficial but also enhance overall project efficiency, quality, and sustainability. The regression line slope suggests that for every unit increase in green strategy adoption, project performance rises proportionally.

The three (3) analyses collectively affirm that green construction strategies play a crucial role in improving project performance in the Lusaka–Ndola Dual Carriageway project.

However, the effectiveness varies by strategy type. While all green practices contribute positively, the integration of energy efficiency technologies and sustainable materials stands out as the most effective approach in achieving optimal performance outcomes. To achieve maximum impact, construction stakeholders should prioritize energy-efficient technologies, sustainable materials, and comprehensive waste and water management systems as core components of modern project planning and execution.

4.5 Limitations of Green Strategies

High costs are the predominant barrier (50%), highlighting the financial challenges of green construction. Lack of expertise (25%) and material availability (15%) represent significant secondary barriers. These obstacles indicate need for cost-reduction strategies and capacity building in green construction.

Waste management is the primary environmental challenge (40%), reflecting the construction industry's significant waste generation. Resource scarcity (25%) and energy consumption (20%) also present substantial challenges. These issues highlight the environmental imperatives driving green construction adoption.

Industry commitment is moderate overall, with 60% of respondents reporting intermediate commitment levels. High commitment was noted by 25% of participants, while 15% perceive low commitment. The findings suggest need for stronger industry-wide engagement with green construction principles.

Financial incentives (80%) and training programs (65%) are seen as most effective policy changes for encouraging adoption. Stricter regulations (55%) and awareness campaigns (50%) are also supported measures. These policy interventions address the main barriers to green construction adoption.

Traditional methods were preferred for proven reliability (75%) and cost predictability (70%). Technical familiarity (65%) and supply chain availability (60%) also drove traditional method preference. These reasons reflect the perceived risks and uncertainties associated with green strategy adoption.

4.6 Discussion of study findings

Objective I: Types of green strategies used in the Lusaka-Ndola dual carriageway construction project

The examination of green strategies implemented in the Lusaka-Ndola Dual Carriageway construction project reveals a comprehensive approach to sustainable infrastructure development, characterized by the integration of material innovation, energy efficiency, water conservation, and waste management practices. This discussion analyzes the specific green strategies employed, compares these findings with existing literature, explores reasons for deviations, and suggests practical and theoretical implications for enhancing sustainable construction practices in similar contexts.

The project demonstrated significant adoption of sustainable building materials, with low-carbon cement (40%) and recycled concrete (30%) emerging as the most prevalent choices. This preference aligns with global trends emphasizing material efficiency and carbon reduction in construction. These material choices reflect growing awareness within the Zambian construction sector about the environmental impacts of traditional building materials and the availability of more sustainable alternatives.

Energy efficiency measures were widely implemented, with solar panels (75%), energy-efficient HVAC systems (65%), and smart lighting (60%) constituting the core technologies. The high adoption rate of solar energy systems is particularly noteworthy, exceeding typical implementation rates in similar infrastructure projects across sub-Saharan Africa. This suggests either strong project-specific commitment to renewable energy or particularly favorable conditions for solar power generation along the carriageway route.

Water conservation practices were regularly incorporated by 65% of respondents, indicating substantial attention to hydrological impacts. The implementation likely included rainwater harvesting systems, water-efficient fixtures, and possibly greywater recycling mechanisms, though the specific technologies were not detailed in the findings.

Waste management strategies emphasized recycling (45%) as the primary approach, with material reuse (30%) and waste minimization (20%) playing secondary roles. This hierarchy of waste management approaches generally aligns with established sustainability principles that prioritize waste prevention followed by reuse and recycling.

Local sourcing of green materials (50%) emerged as a significant feature of the project's supply chain strategy. This approach likely reduced transportation-related emissions while supporting local economies and potentially simplifying logistics. However, it may have also limited the diversity of available green materials, as local markets for sustainable construction products in Zambia are still developing compared to international markets.

When compared with global literature, the project's material selection shows strong alignment with international best practices. The use of low-carbon cement and recycled concrete corresponds with recommendations from numerous studies advocating for reduced embodied carbon in construction materials. However, the project's limited use of other sustainable materials like bamboo or agricultural waste products represents a deviation from the broader range of options discussed in literature. While literature often describes pilot-scale or partial implementation of renewable energy in infrastructure projects, the Lusaka-Ndola project appears to have achieved more comprehensive integration. This could be attributed to decreasing solar technology costs, specific donor requirements, or particularly strong project leadership committed to renewable energy.

The water conservation practices align well with literature emphasizing the importance of water management in sustainable construction. However, the implementation rate of 65% suggests room for improvement compared to literature describing near-universal incorporation of water-saving measures in leading green infrastructure projects globally. This gap might reflect Zambia's relatively abundant water resources reducing perceived urgency, or possibly technical constraints in implementing advanced water management systems.

The findings suggest several practical implications for future infrastructure projects in Zambia and similar contexts. First, the successful implementation of various green strategies demonstrates that sustainable construction is feasible in developing economy contexts, given adequate planning and resources. Second, the persistent challenges of high costs and skills shortages indicate need for targeted interventions in these areas. Third, the strong showing of local material sourcing suggests opportunity to further develop local green building material industries. Theoretical implications include the need to adapt green building frameworks to better account for developing economy contexts, particularly regarding material availability, technical capacity, and economic constraints. The findings also suggest that driver patterns for green construction may be evolving in some developing economies, with environmental considerations gaining prominence alongside traditional economic and regulatory drivers.

For policymakers, the results indicate potential to strengthen regulations supporting green construction while addressing cost barriers through incentives or financial mechanisms. For industry practitioners, the findings highlight the importance of skills development and knowledge transfer for successful green construction implementation. For researchers, the project suggests numerous avenues for further study, including life-cycle cost analysis of green strategies in African contexts, investigation of local material supply chains, and examination of knowledge transfer mechanisms for green construction skills.

Objective II: The effectiveness of green strategies in the Lusaka-Ndola dual carriageway construction project

The examination of green strategy effectiveness in the Lusaka-Ndola Dual Carriageway project reveals a complex landscape of environmental achievements, economic trade-offs, and operational challenges.

The project achieved notable success in waste reduction, with 70% of respondents rating green strategies as effective or very effective in minimizing construction waste. This represents a significant environmental achievement, particularly considering the substantial waste generation typically associated with large-scale infrastructure projects. The 45% adoption rate of recycling as the primary waste management strategy indicates a strong commitment to circular economy principles.

The effectiveness patterns suggests several practical implications. First, the environmental success demonstrates that green strategies can deliver substantial sustainability benefits in developing economy contexts. Second, the financial variability indicates need for better cost management and value engineering approaches tailored to green construction. Third, the measurement gaps highlight the importance of developing practical monitoring frameworks for green construction performance.

The durability assessment of green materials yielded positive results, with 75% of respondents rating structures built with sustainable materials as durable. These finding challenges common perceptions that green materials may compromise structural integrity or longevity. The widespread use of low-carbon cement (40%) and recycled concrete (30%) appears to have delivered both environmental benefits and satisfactory technical performance, addressing concerns about the reliability of alternative construction materials.

Financial performance presented a mixed picture. While 60% of respondents reported moderate to high cost savings from green strategies, 40% experienced cost increases or neutral financial impacts. This variation suggests that the economic benefits of green strategies are not automatic and depend on implementation efficiency, scale effects, and operational contexts.

Market value enhancement was widely recognized, with 70% of respondents noting positive influences on project valuation. This perception aligns with global literature documenting price premiums for green buildings and infrastructure, though the magnitude of this effect in the Zambian context requires further investigation. The strong market response suggests growing recognition of sustainability value among stakeholders, potentially creating economic incentives for future green construction investments.

Health and safety outcomes were particularly strong, with 75% of respondents reporting significant benefits. This finding supports literature connecting green building practices with improved occupational health through better ventilation, reduced exposure to harmful materials, and enhanced worksite conditions.

Project timeline impacts were generally neutral, with 60% reporting no significant schedule effects. However, the 25% experiencing timeline increases indicates that green strategies can introduce coordination complexities or learning curve challenges that affect project scheduling.

The measurement of green strategy effectiveness was inconsistent, with only 35% of respondents regularly evaluating performance. This measurement gap represents a significant limitation in assessing and optimizing green strategy implementation.

Compared to global literature, the project's environmental performance aligns well with international benchmarks. The waste reduction achievements correspond with literature reporting 40-60% waste diversion rates for leadership green building projects. The durability findings support literature indicating that green materials can meet or exceed conventional performance standards when properly specified and installed.

The specific environmental conditions along the Lusaka-Ndola corridor may have influenced technology performance. The developing local market for green building materials and services may have created different cost structures than in more established markets.

For future projects, the results indicate several priority areas. Enhanced waste minimization strategies could build on the successful recycling programs to further reduce environmental impacts. Improved cost management approaches could help capture more financial benefits from green strategies. Better performance measurement systems could provide the data needed to optimize green strategy implementation.

The project's experience offers valuable lessons for sustainable infrastructure development across Africa. The successful implementation of various green strategies demonstrates that environmental sustainability can be achieved in major infrastructure projects despite challenging contexts. However, the persistent financial and measurement challenges suggest that broader adoption will require improved economic models and assessment frameworks.

In conclusion, the Lusaka-Ndola Dual Carriageway project demonstrates that green strategies can be effectively implemented in developing economy infrastructure projects, delivering substantial environmental and social benefits.

Objective III: The relationship between green construction strategies and project performance in the Lusaka-Ndola Dual carriageway construction project.

The relationship between green construction strategies and project performance in the Lusaka-Ndola Dual Carriageway project reveals a complex interplay of environmental benefits, operational impacts, and economic considerations. This analysis examines how sustainable practices influenced various performance dimensions, compares these relationships with existing literature, and identifies both synergies and tensions between environmental goals and traditional project objectives.

The project demonstrated generally positive relationships between green strategies and quality performance, with 70% of respondents reporting that sustainable practices improved project quality. This finding challenges the perception that environmental considerations might compromise technical standards or structural integrity. The use of high-performance materials, particularly low-carbon cement and recycled concrete, appears to have contributed to enhanced durability and structural performance while reducing environmental impact.

Risk management emerged as another area of positive correlation, with 65% of respondents indicating that green strategies contributed to risk reduction. The integration of environmental considerations into project planning apparently fostered a more comprehensive risk assessment approach that identified and addressed potential issues earlier in the project lifecycle.

Stakeholder engagement showed strong positive relationships with green strategy implementation, with 75% of respondents reporting improved stakeholder relations. This enhancement likely resulted from multiple factors: demonstrated environmental responsibility-built community trust, transparent sustainability reporting improved communication, and local sourcing strategies created economic benefits for surrounding communities.

Timeline performance presented a more neutral relationship, with 60% of respondents reporting no significant impact on project schedules. This finding suggests that well-planned green strategies can be implemented without substantially extending project durations, contrary to concerns that sustainability requirements might cause delays.

Financial performance revealed the most complex relationship, with responses divided between cost increases (55% combined) and cost savings (20%). This mixed financial impact reflects the nuanced economics of green construction, where upfront investments may deliver long-term savings but create short-term financial pressures.

The relationship between green strategies and labor productivity showed generally positive trends, with 60% reporting neutral impacts and 25% noting productivity increases. This suggests that sustainable construction practices need not impair workforce efficiency and may actually enhance it through improved working conditions, better site organization, and enhanced worker engagement with environmental goals.

The relationships observed suggest several practical implications. First, the generally positive quality correlations indicate that environmental and quality objectives can be mutually reinforcing rather than competing priorities. Second, the risk management benefits suggest that green strategies can contribute to more predictable project outcomes. Third, the financial complexities highlight the need for careful economic planning and potentially innovative financing approaches for sustainable construction.

The project's experience offers important insights for sustainable infrastructure development. The generally positive performance relationships demonstrate that environmental sustainability need not come at the expense of project performance objectives.

In conclusion, the Lusaka-Ndola Dual Carriageway project demonstrates that green construction strategies can have generally positive relationships with project performance dimensions, particularly regarding quality, risk management, and stakeholder engagement. While financial relationships remain complex and timeline impacts largely neutral, the overall pattern suggests that well-implemented sustainability strategies can enhance multiple aspects of project performance. These findings provide valuable guidance for future infrastructure projects seeking to balance environmental, social, and economic objectives in sustainable development.

Objective IV: The limitations of green strategies in the Lusaka-Ndola dual carriageway construction project

The implementation of green strategies in the Lusaka-Ndola Dual Carriageway project encountered significant limitations that reveal the complex challenges facing sustainable construction in developing economies. This comprehensive analysis examines the multifaceted constraints that hampered optimal implementation of environmental strategies, compares these findings with existing literature, and proposes targeted interventions for overcoming these barriers in future infrastructure projects.

Economic constraints emerged as the most formidable limitation, with 45% of respondents identifying high costs as the primary barrier and 60% citing financial constraints as the main reason for avoiding green strategies. This economic challenge manifested through multiple dimensions: upfront investment requirements for green technologies, premium costs for sustainable materials, and additional expenses for specialized expertise. The financial burden was particularly acute for technologies like solar panels and energy-efficient HVAC systems, where initial investment costs remained substantially higher than conventional alternatives despite long-term operational savings. These findings align with broader literature identifying economic barriers as the most significant obstacle to green construction in developing economies (Opoku *et al*., 2019; Sangroya *et al*., 2020).

Supply chain limitations severely constrained green strategy implementation, with 75% of respondents reporting moderate to major impacts from material availability issues. The local market for sustainable construction materials remained underdeveloped, creating dependencies on imported products that increased costs and complicated logistics. Even when materials were available locally, quality consistency and certification assurance presented additional challenges.

Regulatory and policy limitations created significant implementation barriers, with 35% of respondents citing poor regulatory support and 60% identifying regulatory uncertainty as limiting factors. The regulatory environment lacked clear standards for green construction, consistent enforcement mechanisms, and supportive policy frameworks that could facilitate sustainable practices.

Cultural and behavioral limitations manifested through resistance to change, with 45% of respondents identifying this as a significant barrier. Industry stakeholders often preferred traditional construction methods due to proven reliability (75%), cost predictability (70%), and technical familiarity (65%). This resistance reflected deeper cultural patterns within the construction industry, including risk aversion, comfort with established practices, and skepticism about new approaches.

Measurement and verification limitations hampered effective implementation, with only 35% of respondents regularly measuring green strategy effectiveness. The lack of systematic monitoring created multiple problems: inability to optimize strategy performance, difficulty demonstrating business case effectiveness, and challenges in securing continued support for green approaches.

Project-specific limitations emerged from the carriageway's particular characteristics. The linear nature of road infrastructure created unique challenges for implementing certain green strategies compared to building construction. The extended geographical footprint complicated logistics for material delivery, workforce deployment, and system maintenance.

Temporal limitations affected strategy implementation, with many green approaches requiring longer planning horizons, extended implementation timelines, and delayed return on investment compared to conventional methods. These temporal mismatches created tensions with project scheduling constraints and stakeholder expectations about project delivery pace.

When compared with global literature, several distinctive patterns emerge in the limitations encountered. The economic constraints appear more severe than in some developed economy contexts, reflecting Zambia's particular economic conditions and market structures. The technical capacity limitations exceed those documented in some other African studies, possibly indicating specific gaps in Zambia's construction education and training systems. The supply chain challenges appear more pronounced than in some literature reports, suggesting particular weaknesses in Zambia's green building material markets.

The limitations suggest several practical implications for future projects. Economic constraints indicate need for innovative financing mechanisms, such as green bonds or performance-based contracts, that can address upfront cost barriers. Technical capacity limitations highlight the urgency of workforce development programs specifically focused on green construction skills. Supply chain constraints suggest need for policies supporting local production of sustainable materials and technologies.

Regulatory limitations indicate need for comprehensive policy reforms creating clearer standards, better enforcement mechanisms, and stronger incentives for green construction. Cultural barriers suggest need for change management strategies that address deeply ingrained industry practices and attitudes. Measurement gaps highlight the importance of developing practical, affordable monitoring systems tailored to developing economy contexts.

For future research, the limitations identified suggest several priority areas. Investigation of context-specific solutions to economic barriers could help develop financing models workable in Zambian conditions. Research on accelerated skills development approaches could address technical capacity constraints. Studies on local material innovation could help overcome supply chain limitations.

The limitations encountered highlight that green construction implementation requires not just technical solutions but also addressing broader economic, regulatory, and cultural constraints. The interconnections between different limitation categories suggest that piecemeal approaches will be insufficient comprehensive strategies addressing multiple barriers simultaneously are needed.

In conclusion, the Lusaka-Ndola Dual Carriageway project reveals multiple overlapping limitations that constrained green strategy implementation. Economic constraints, technical capacity gaps, supply chain limitations, regulatory weaknesses, cultural resistance, and measurement challenges all contributed to implementation difficulties. While these limitations reflect broader patterns in developing economy green construction, they manifested in particular ways shaped by Zambia's specific context. Addressing these limitations will require coordinated efforts across multiple domains: financial innovation, skills development, industrial policy, regulatory reform, cultural change, and performance measurement. The lessons from this project provide valuable guidance for enhancing green strategy implementation in future African infrastructure projects, suggesting that success requires addressing not just technical aspects but also the broader ecosystem constraining sustainable construction.

5. Conclusion and Recommendation

5.1 Conclusion

Based on the findings, the study concludes that green strategies are increasingly integrated into the construction industry, with strong adoption of sustainable materials, energy-efficient technologies, and water conservation practices. Low-carbon cement and recycled concrete are the most widely used materials, while solar panels, energy-efficient HVAC systems, and smart lighting dominate energy technologies. Recycling and reuse represent key waste management approaches, and material efficiency and energy conservation are prioritized for their operational and regulatory benefits. The effectiveness of green strategies is evident across multiple dimensions. Energy savings, waste reduction, and improved project efficiency are consistently reported outcomes, while long-term cost savings, enhanced market value, and contributions to health and safety reinforce the financial and social benefits of sustainability. Green strategies positively influence project quality, risk management, and client perception, supporting their value for overall project success. Despite these gains, high costs, limited expertise, and material availability remain significant barriers, while industry commitment is moderate and traditional methods continue to be preferred due to reliability and predictability. Policy interventions such as financial incentives, training programs, stricter regulations, and awareness campaigns are critical for promoting broader adoption.

5.2 Recommendation

Cost-Reduction Measures: High implementation costs remain the primary barrier to adopting green construction strategies. To address this, stakeholders should explore cost-reduction approaches, including bulk procurement of sustainable materials, prioritizing locally sourced products, and forming partnerships with manufacturers to lower production costs.

Capacity Building: The limited technical expertise in green construction methods presents a significant challenge to adoption. Training programs targeting engineers, architects, contractors, and laborers should be developed to build skills in the use of sustainable materials, energy-efficient technologies, and water conservation techniques. Knowledge-sharing initiatives, workshops, and certification programs can enhance workforce competence and confidence in implementing green strategies, ensuring higher quality and more consistent results across projects.

Policy Support: Government policies play a critical role in promoting sustainable construction practices. Financial incentives, stricter environmental regulations, and public awareness campaigns should be strengthened to encourage wider adoption of green strategies.

Monitoring and Evaluation: Effective implementation of green strategies requires systematic measurement of outcomes. Organizations should establish monitoring and evaluation frameworks to track energy savings, waste reduction, cost efficiency, health and safety improvements, and overall project sustainability.

Industry Engagement: Moderate commitment from the construction industry indicates the need for stronger engagement with green principles. Industry-wide initiatives, including stakeholder forums, professional associations, and collaborative projects, can promote sustainability as a core objective.

Material Availability and Supply Chains: Limited availability of green materials constrains implementation of sustainable practices. Efforts should be made to strengthen supply chains by supporting local production, developing partnerships with suppliers, and facilitating imports where necessary.

Client Education: The demand for green construction is influenced by client awareness of its benefits. Educating clients about long-term advantages such as energy savings, waste reduction, enhanced market value, and compliance with environmental regulations can drive demand for sustainable practices.

Innovation and Research: Continuous research and innovation are necessary to improve the technical feasibility, durability, and cost-effectiveness of green construction strategies.

Integration of Green Strategies into Planning: Implementing green strategies early in the project lifecycle reduces disruptions and ensures smoother adoption. Sustainability considerations should be incorporated during project design, budgeting, and decision-making phases to optimize timeline adherence, minimize risks, and achieve cost efficiency.

Multi-Dimensional Evaluation: Green strategies should be evaluated across environmental, financial, social, and operational dimensions to capture their full impact.

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