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Effect of Adoption of Green Construction Practices on Sustainability of Public Infrastructure Projects in Rwanda: A Case of Kigali Green Complex, City of Kigali

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Abstract: The study examines the effect of adopting green construction practices on the sustainability of public infrastructure projects in Rwanda, focusing on the Kigali Green Complex as a case study. The general objective was to assess how integrated green practices influence environmental sustainability, while specific objectives explored the contributions of energy-efficient building systems, renewable energy technologies, sustainable water management practices, and low-carbon construction materials. The research employed a mixed-methods approach using a descriptive and correlational research design. The study population was 212 stakeholders while sample size was 139 respondents. Stratified random sampling and purposive sampling were used. Data were collected using structured questionnaires. Quantitative data were analyzed using descriptive statistics (means and standard deviations), Pearson correlation, and multiple linear regression. Findings from descriptive statistics indicated high adoption levels of green construction practices, with mean scores above 4.0 across all variables. Inferential results revealed strong positive correlations between green practices and environmental sustainability. Energy-efficient building systems exhibit the highest correlation ($r \approx 0.88$, $p < 0.001$), indicating a near-perfect linear association with sustainability indicators such as energy conservation and emission reduction. Renewable energy technologies follow closely ($r \approx 0.86$, $p < 0.001$), demonstrating their critical role in reducing dependence on fossil fuels and improving energy resilience. Sustainable water management practices also show a strong relationship ($r \approx 0.84$, $p < 0.001$), reflecting their effectiveness in enhancing water efficiency and reducing wastage. Similarly, low-carbon and eco-friendly construction materials present a robust correlation ($r \approx 0.82$, $p < 0.001$), confirming their contribution to lowering lifecycle carbon emissions and promoting resource efficiency. Multiple linear regression analysis further strengthens these findings by confirming the predictive power of each variable. The model demonstrates a high explanatory capacity ($R^2 > 0.75$), indicating that over 75% of the variation in environmental sustainability is explained by the combined effect of the four green practices. Energy-efficient building systems emerge as the most influential predictor ($\beta \approx 0.34$, $p < 0.001$), suggesting that improvements in energy performance yield the greatest marginal gains in sustainability outcomes. Renewable energy technologies also show a strong and statistically significant effect ($\beta \approx 0.29$, $p < 0.001$), reinforcing their role in reducing carbon emissions. Sustainable water management practices ($\beta \approx 0.23$, $p < 0.01$) and low-carbon materials ($\beta \approx 0.19$, $p < 0.01$) contribute meaningfully, although with relatively moderate effect sizes, indicating that their impact is enhanced when integrated with other practices.

Keywords: *Green Construction; Environmental Sustainability; Public Infrastructure; Energy Efficiency; Renewable Energy; Water Management; Low-Carbon Materials; Kigali Green Complex (KGC).*

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I. INTRODUCTION

Rapid urban population growth, rising energy demand, and the growing impacts of climate change are forcing governments and developers to reconsider how buildings are designed and constructed. Studies show that buildings account for a large share of global energy consumption and carbon emissions, making the construction sector an

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important area for climate action (Birol, 2023). Because of this, sustainability has become a key focus in modern construction planning and development. In response, many countries are integrating sustainability principles into public infrastructure projects. These efforts often involve the use of energy-efficient building systems, renewable energy technologies, water-saving solutions, and environmentally friendly construction materials. According to Andersen (2023), incorporating such approaches into infrastructure development helps reduce environmental impact while improving long-term efficiency and resilience in urban areas.

In the United States, building guidelines increasingly emphasize net-zero energy performance and lifecycle carbon reduction. These policies encourage the adoption of advanced heating and cooling systems, solar technologies, and smart building management systems to improve energy efficiency (Green, 2024). Similarly, the European Union has strengthened its building performance regulations to ensure that future public buildings operate with minimal or zero emissions (Timmermans, 2024). Singapore has also become a global example of sustainable construction through its performance-based green building certification system, which has helped reduce energy consumption and operational costs in many public buildings (Tan, 2024).

In Asia, countries such as China and Japan are advancing sustainable construction through innovations such as prefabricated building techniques, highly efficient building envelopes, and green building certification systems. These strategies help reduce construction waste and lower emissions from building operations. However, the successful adoption of such technologies depends on strong policy support, technical expertise, and accessible financing mechanisms (Zhang & Liu, 2023). Without these enabling conditions, implementing advanced green construction solutions can be difficult, especially in developing regions. Across Sub-Saharan Africa, interest in sustainable buildings is gradually increasing, particularly in rapidly growing urban areas. Urban development researchers note that rising energy costs and climate vulnerability are encouraging governments to consider environmentally responsible construction practices (Games, 2024).

Within the East African region, policymakers and researchers are increasingly promoting green infrastructure as part of broader climate-resilient development strategies. Regional studies highlight initiatives encouraging solar-ready buildings, green roofs, and nature-based urban solutions to improve environmental performance in cities (Mukalazi, 2025). However, these studies also warn that advanced green technologies may place financial pressure on institutions if sufficient technical and financial capacity is not available. Rwanda has made notable progress in promoting sustainable construction through the introduction of national frameworks and policies that support environmentally responsible infrastructure development. The country's commitment to green development is reflected in projects such as Green City Kigali and the Kigali Green Complex (Mugiraneza, 2024).

The Kigali Green Complex (KGC) is a 29-storey mixed-use development designed with several sustainability features, including energy-efficient building systems, renewable energy options, water recycling technologies, and low-carbon construction materials. These features provide a practical example of how green building principles can be applied in Rwanda's built environment. Therefore, the Kigali Green Complex offers an important case for examining how sustainable construction practices such as energy-efficient technologies, renewable energy integration, sustainable water management, and low-carbon materials can contribute to improved environmental sustainability in the country's public infrastructure sector.

- *Problem Statement*

Rwanda has also taken important steps by introducing frameworks like the Green Building Minimum Compliance System (2019) and the Sustainable Public Procurement Framework (2024) to guide environmentally responsible infrastructure development. However, turning these policies into consistent results remains a challenge. Recent national assessments show that over 40% of newly completed public buildings in Kigali still do not meet the required sustainability standards (REMA, 2024). This suggests that although policies exist, their implementation is not always effective.

Several factors contribute to this gap. Public construction projects often face weak integration of renewable energy systems, limited water-management solutions, growing urban heat island effects, and inadequate monitoring capacity (OAG, 2023). Research also points to challenges such as weak enforcement of regulations, limited financial incentives for green technologies, shortages of skilled professionals, and the high initial cost of low-carbon construction materials (Habimana & Niyitegeka, 2023; Uwizeyimana *et al.*, 2023; Niyonsenga & Mugisha, 2024; Mukamana *et al.*, 2025). As a result, green construction practices in Rwanda are still uneven and not consistently applied. In addition, there is limited empirical evidence showing the actual environmental impact of sustainable construction in Rwanda's public infrastructure sector. While existing studies discuss policies, financing, and stakeholder views, few examine whether green technologies such as energy-efficient systems, renewable energy installations, water-saving technologies, or low-carbon materials are truly improving environmental performance at the project level. This lack of clear evidence makes it difficult for policymakers to identify which approaches are most effective. To help address this gap, this study examines the Kigali Green Complex (KGC), a 29-storey mixed-use building designed with several green construction features. By assessing how these sustainability measures influence outcomes such as energy efficiency, water conservation, and carbon emissions, the study aims to provide practical evidence that can support better implementation of green building policies and contribute to Rwanda's Vision 2050 and climate resilience goals.

- *Objectives of the Study*

To assess the effect of adoption of green construction practices on sustainability in Rwanda's public infrastructure,

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using the Kigali Green Complex (KGC) as a case study. The study intends to accomplish the following specific aims:

- To assess the contribution of adopting energy-efficient building systems to sustainability in public infrastructure projects in Kigali Green Complex;
- To evaluate the impact of integrating renewable energy technologies on promoting sustainability in public infrastructure projects in Kigali Green Complex;
- To examine the role of implementing sustainable water management practices in enhancing sustainability in public infrastructure projects in Kigali Green Complex;
- To analyze the influence of using low-carbon and eco-friendly construction materials on improving sustainability in public infrastructure projects in Kigali Green Complex

➢ *Research Hypotheses*

The following alternative hypotheses were verified and tested during this study:

- H1: Energy-efficient building systems have a significant positive contribution to sustainability in public infrastructure projects within the Kigali Green Complex;
- H2: The integration of renewable energy technologies has a significant positive impact on promoting sustainability in public infrastructure projects within the Kigali Green Complex;
- H3: Sustainable water-management practices significantly enhance sustainability in public infrastructure projects within the Kigali Green Complex.
- H4: The use of low-carbon and eco-friendly construction materials significantly improves sustainability in public infrastructure projects within the Kigali Green Complex

II. REVIEW OF LITERATURE

➢ *Conceptual Review*

The conceptual review clarifies the principal concepts that underpin this research by defining and situating the main variables: green construction practices and environmental sustainability in public infrastructure.

➢ *Green Construction Practices*

Green construction involves a range of strategies and techniques designed to reduce the environmental impact of buildings throughout their entire lifecycle, from planning and construction to operation and maintenance. These practices are widely recognized as essential for sustainable development, mitigating climate change, and optimizing resource use (Green Construction Hub, 2023). Essentially, green construction integrates energy-efficient systems, minimizes waste, and relies on sustainable materials to create buildings that are both environmentally responsible and supportive of occupant health and well-being (UK Green Building Council, 2023).

➢ *Energy-Efficient Building Systems*

Energy-efficient building systems form a central component of green construction, designed to reduce energy consumption while ensuring occupant comfort and productivity. These systems typically include high-performance insulation, advanced heating, ventilation, and air conditioning (HVAC) solutions, efficient lighting, and smart building controls that adjust operations in real time to optimize energy use (ASHRAE, 2023). According to the International Energy Agency (IEA, 2023), energy-efficient systems serve a dual purpose: they lower overall energy demand while improving indoor environmental quality for building occupants.

➢ *Renewable Energy Technologies*

Renewable energy technologies involve capturing naturally replenishing energy sources, such as solar, wind, and geothermal power, to supply buildings and infrastructure. By reducing dependence on fossil fuels, these technologies play a crucial role in cutting greenhouse gas emissions and advancing sustainable development goals (UK Construction Blog, 2023). Common building-level solutions include photovoltaic (PV) panels, solar thermal systems, and small wind turbines, all of which contribute to lowering energy demand from conventional sources. Beyond environmental benefits, renewable energy technologies improve energy security, reduce long-term operational costs, and support broader sustainability objectives (Pure QUB, 2023).

➢ *Sustainable Water Management Practices*

Sustainable water management focuses on strategies that optimize water use, conserve resources, and enable reuse throughout the design, construction, and operational phases of buildings. These practices are essential for reducing water waste, protecting natural ecosystems, and ensuring long-term availability of freshwater (UNEP, 2023; World Green Building Council, 2023). According to the International Centre for Sustainable Energy and Construction Management (ICSECM, 2023), sustainable water management entails the deliberate application of water-saving technologies and processes to improve efficiency in construction projects.

➢ *Low-Carbon and Eco-Friendly Construction Materials*

Low-carbon and eco-friendly construction materials are a cornerstone of green building, designed to minimize environmental impacts across the entire lifecycle of a project. These materials typically feature reduced production and transportation emissions and often include recycled, renewable, or sustainably sourced inputs. Common examples are low-emission cement, recycled aggregates, bamboo, and sustainably harvested timber (CFP Energy, 2023; UNEP, 2024).

➢ *Sustainability in Public Infrastructure Projects*

Sustainability in public infrastructure involves planning, designing, and managing projects in ways that minimize environmental impacts while maximizing the efficient use of natural resources. It aims to balance social, economic, and ecological considerations so that infrastructure meets current needs without compromising the ability of future generations to thrive. According to NIST, (2023), sustainable public infrastructure integrates energy efficiency, water conservation, waste reduction, and ecosystem protection throughout a project's lifecycle.

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➢ *Theoretical Review*

The study is guided by four key theoretical perspectives: Diffusion of Innovations (DoI), Resource-Based View (RBV), Natural-Resource-Based View (NRBV), and Systems Theory. These theories help explain why organizations adopt sustainable technologies, how resources support green innovation, and how different sustainability components work together to improve environmental outcomes in construction projects.

➢ *Diffusion of Innovations (DoI) Theory*

The Diffusion of Innovations theory, developed by Everett Rogers, explains how new ideas and technologies spread within organizations and societies over time. The theory highlights five important characteristics that influence adoption: relative advantage, compatibility, complexity, trialability, and observability by Rogers in 2003. This theory is particularly relevant to green construction because adopting technologies such as energy-efficient systems, renewable energy installations, and sustainable water management solutions depends largely on how stakeholders perceive their benefits and practicality. If developers, contractors, and government institutions believe that green technologies offer clear environmental and economic advantages, they are more likely to adopt them. In the context of Kigali, projects such as the Kigali Green Complex demonstrate how green technologies can spread through the construction sector. Innovations such as solar photovoltaic systems, smart HVAC systems, and rainwater harvesting technologies are more likely to be adopted when their environmental benefits and cost savings are clearly visible (Munyaneza *et al.*, 2023). Studies across Sub-Saharan Africa also show that when the benefits of sustainable technologies are observable and easy to implement, adoption rates increase significantly (World Bank, 2023). For this study, DoI theory provides a useful framework for understanding how public infrastructure projects in Rwanda decide to adopt green construction practices.

➢ *Resource-Based View (RBV) Theory*

The Resource-Based View (RBV) theory, introduced by Jay Barney, argues that organizations gain long-term advantage when they effectively manage valuable, rare, inimitable, and non-substitutable resources, commonly known as VRIN resources by Barney in 1991. In the construction sector, these resources may include technical expertise, sustainable construction technologies, skilled professionals, environmentally friendly materials, and financial capacity. RBV helps explain why some infrastructure projects are more successful in implementing green construction practices than others. In Rwanda, public infrastructure projects that invest in skilled engineers, sustainable design expertise, and advanced building technologies are better positioned to implement green construction strategies successfully. For example, projects that train personnel in energy management or water efficiency are more capable of integrating renewable energy systems and sustainable water management technologies effectively (Holcim, 2023). Empirical studies suggest that projects that strategically invest in green resources can significantly improve environmental performance, achieving lower carbon emissions and greater resource efficiency (United Nations Environment Programme, 2023). Within the context of this study, RBV helps explain how the availability of resources such as technical skills, funding, and sustainable construction materials affects the successful adoption of energy-efficient systems, renewable technologies, water conservation practices, and eco-friendly materials in public infrastructure projects.

➢ *Natural-Resource-Based View (NRBV) Theory*

The Natural-Resource-Based View (NRBV) was developed by Stuart Hart as an extension of the traditional resource-based perspective. This theory focuses specifically on how organizations can achieve long-term success by adopting environmentally responsible strategies that protect natural resources, Hart, in 1995. NRBV emphasizes that organizations that invest in environmental innovations such as renewable energy systems, low-carbon construction materials, and sustainable water management technologies can reduce ecological risks while improving operational performance. In the construction sector, this perspective explains how adopting environmentally friendly materials and technologies can lead to both environmental and economic benefits. For example, using low-carbon cement, recycled aggregates, and energy-efficient building systems can significantly reduce greenhouse gas emissions while improving the durability and efficiency of infrastructure projects (International Energy Agency, 2023; United Nations Environment Programme, 2023). For Rwanda's public infrastructure sector, NRBV provides a strong explanation for why sustainable construction practices should be prioritized.

➢ *Systems Theory*

The Systems Theory, developed by Ludwig von Bertalanffy, views organizations and projects as complex systems made up of interconnected components that work together to achieve overall outcomes by von Bertalanffy in 1968. This perspective is particularly relevant for green construction because sustainable buildings rely on the integration of multiple components such as building design, materials, energy systems, water management systems, and operational practices. These elements interact with each other, meaning that the overall sustainability performance of a building depends on how well these components are coordinated. From a systems perspective, projects such as the Kigali Green Complex can be viewed as integrated systems where different sustainability features work together to produce environmental benefits. For instance, energy-efficient HVAC systems, renewable energy installations, water recycling technologies, and low-carbon materials collectively contribute to reducing energy consumption, lowering emissions, and improving resource efficiency. Research shows that when sustainable building practices are implemented in an integrated manner rather than individually, they can significantly reduce energy use and water consumption in buildings (International Energy Agency, 2023; United Nations Environment Programme, 2023). In this study, systems theory helps explain how different green construction practices interact to influence environmental sustainability.

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➢ *Conceptual Framework*

A conceptual framework connects theory, literature, and objectives into a structured representation of how independent variables (green construction practices) influence the dependent variable (environmental sustainability in public infrastructure). It guides methodology and analysis, aligning theoretical expectations with measurable outcomes. Independent variable Adoption of Green Construction Practices Adopting Energy-Efficient Building Systems High-performance protection Efficient HVAC and lighting systems Smart energy control systems Adopting Energy-Efficient Building Systems High-performance protection Efficient HVAC and lighting systems Smart energy control systems Dependent variable Dependent variable Environmental Sustainability.

➢ *Independent Variable*

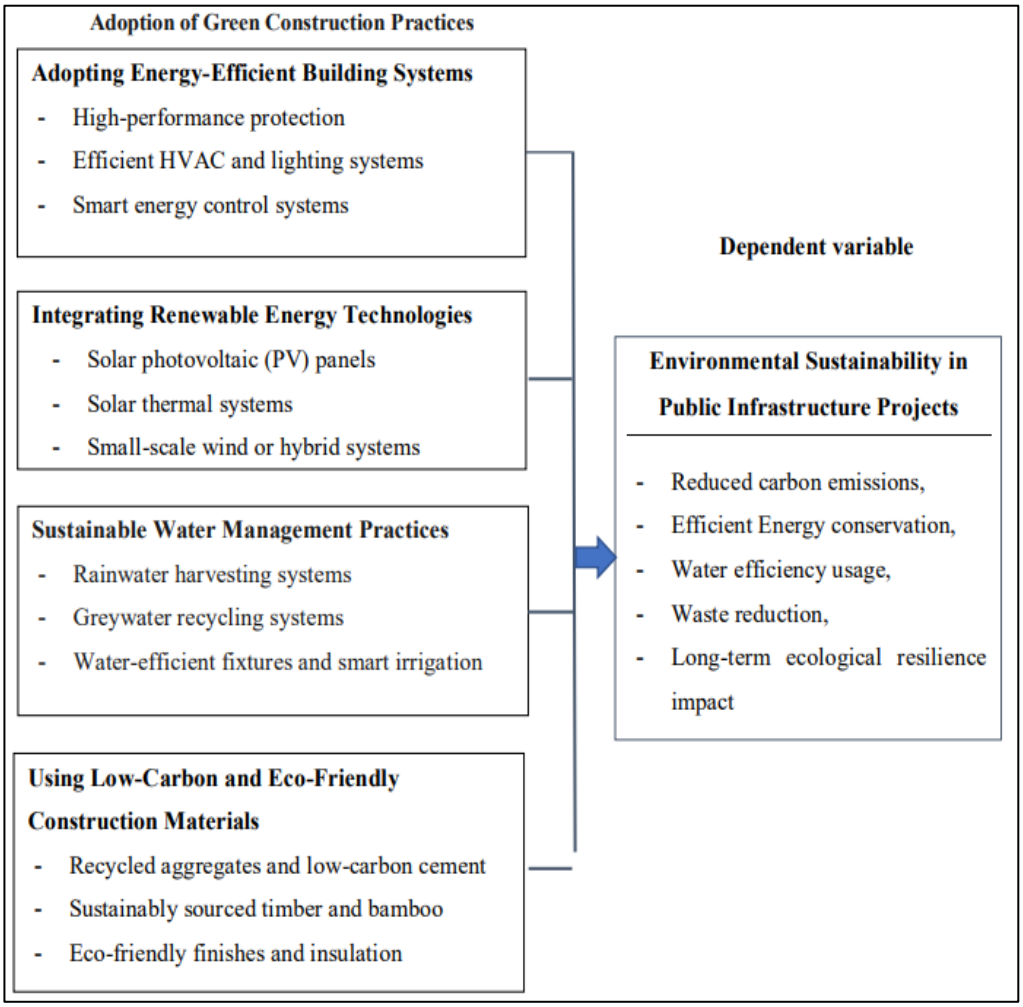


Fig 1 Conceptual Framework
Source: Researcher (2025) Conceptualization

III. RESEARCH METHODOLOGY

➢ *Research Design*

The study utilizes a descriptive and correlational research design that effectively aligns with its objectives of investigating current practices and evaluating the connection between green construction methods and environmental sustainability. A mixed-methods approach was adopted; quantitative data was gathered through structured questionnaires to capture measurable perceptions regarding prevalence of adoption and results achieved. Additionally, qualitative data was collected via semi-structured interviews and document reviews to provide insights into practical challenges and experiences related to adoption. This comprehensive approach offers a holistic understanding of the interplay between green construction practices and environmental sustainability at KGC.

➢ *Study Population*

The study's population comprises 200 individuals including KGC project staff members such as engineers, sustainability managers, construction supervisors as well as external stakeholders involved in various phases of design, construction, and operation. It also encompasses officials from MININFRA (the Ministry of Infrastructure), Kigali City's environmental authorities, along with independent consultants who focus on green construction initiatives.

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➢ *Sample Size and Sampling Technique*

To obtain a representative sample from the total population of 212, the study uses a 5% margin of error and a 95% confidence level, based on standard social science research practices. The sample size is determined using Taro Yamane's formula elaborated in 1982.

$$n = \frac{N}{1+N(e)^2}$$

n = required sample size; N = total population size; e = margin of error (level of precision), usually 0.05 for 95% confidence level

- Step 1: Compute the square of the margin of error

$$e^2 = (0.05)^2 = 0.0025$$

- Step 2: Multiply the population size by the squared error term

$$N \times e^2 = 212 \times 0.0025 = 0.53$$

- Step 3: Add 1 to the value obtained

$$1 + (N \times e^2) = 1 + 0.53 = 1.53$$

- Step 4: Divide the population size by the new value

$$n = 212 / 1.53 = 138.56$$

$$n \approx 139 \text{ respondents}$$

The required sample size for a population of 212 at a 5% margin of error is 139 respondents, were selected through stratified simple random sampling to ensure equal representation across the target population. To select participants, the study employed also purposive sampling for identifying key informants. Stratified random sampling facilitated equitable representation among all demographic groups. Meanwhile, purposive sampling targeted essential informants such as sustainability managers, engineers responsible for energy systems, and consultants with expertise in renewable energy and low-carbon materials.

➢ *Data Collection Instruments*

The study utilized a questionnaire to assess the extent of adoption, perceived efficacy, and results associated with green construction practices. This instrument featured a Likert scale ranging from "strongly agree" to "strongly disagree," along with multiple-choice and ranking questions focusing on topics like energy-efficient building systems, renewable energy technologies, sustainable water management strategies, and eco-friendly construction materials.

➢ *Data Analysis Methods*

This study aims at employing both descriptive statistics alongside inferential techniques providing thorough insights about correlation noted amongst selected green constructions' contribution toward enhancing environmental sustainability outcomes within KGC context. Descriptive statistical methods summarize gathered information meaningfully showcasing trends quantifiable measures frequencies percentages means standard deviations highlighting patterns observed concerning implementation levels across targeted areas including uptake rates tied towards eco-friendly materials integrations among other sustainable practices. To investigate inter-variable relationships Pearson's correlation coefficient(r) serves as an analytical tool determining strengths directions involved connecting each particular sustainable practice against defined outcome benchmarks encompassing aspects like efficient resource usage ecological consciousness etc.. Positive correlations signify direct associations while negative ones imply inverse connections when evaluating benefits accrued based upon varied implementations undertaken. To ascertain predictive capabilities linked directly from implemented green initiatives impacting ecological health multiple linear regression analyses shall apply following structure:

$$Y=\beta 0+\beta 1x1+\beta 2x2+\beta 3x3+\beta 4x4+\epsilon \quad \text{(Eq1);}$$

Where, Y represents Environmental impact outcome, X delineates Green Construction Practices comprising diverse strategies employed emphasizing existing frameworks including but not limited to:

Energy-efficient Systems (X_1), $Y=\beta 0+\beta 1x1+\epsilon$ (Eq2)

Renewable Alternatives (X_2), $Y=\beta 0+\beta 2x2+\epsilon$ (Eq3)

Water Management Approaches (X_3), $Y=\beta 0+\beta 3x3+\epsilon$ (Eq4)

Low-carbon Materials(X_4); $Y=\beta 0+\beta 4x4+\epsilon$ (Eq5)

β_0 signifies constant factor, coefficients

$\beta_1 \ldots \beta_4$ indicate respective contributions made by each variable while ε denotes error term present.

IV. DATA ANALYSIS AND PRESENTATION OF FINDINGS

Data were gathered from 139 respondents who responded the questionnaires. Findings indicated the participation rate of 100.0% of responding, and this allows to continue the study with data editing, coding recording, classifying and make statistical tables and graphs as analyzed quantitatively using computer software of SPSS IBM 23.0 version.

➢ *Demographics of Respondents*

Understanding these demographics helps to assess how representative and relevant the responses are to public infrastructure projects.

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Table 1 Demographic Profile of Respondents

Variable	Category	Frequency	Percent (%)	Cumulative Percent (%)
Gender	Male	90	64.7	64.7
	Female	49	35.3	100
	Total	139	100	
Experience in Public Infrastructure Projects	Less than 1 year	66	47.5	47.5
	1-5 years	28	20.1	67.6
	6-10 years	40	28.8	96.4
	Over 10 years	5	3.6	100
	Total	139	100	
Academic Qualification	Master's Degree	27	19.4	19.4
	Bachelor's Degree	71	51.1	70.5
	Diploma / Certificate	36	25.9	96.4
	PhD	5	3.6	100
	Total	139	100	
Age	Below 30	23	16.5	16.5
	31-40	42	30.2	46.8
	41-50	50	36	82.7
	Above 50	24	17.3	100
	Total	139	100	
Department/Role in KGC Project	Project Management	60	43.2	43.2
	Engineering & Technical Operations	13	9.4	52.5
	Environmental Planning & Sustainability	21	15.1	67.6
	Procurement & Materials	14	10.1	77.7
	Finance & Cost Control	31	22.3	100
	Total	139	100	

Source: Primary Data, field data (2026)

The gender distribution indicates that males constitute 64.7% while females account for 35.3%. This imbalance may influence decision-making dynamics and perspectives on sustainability practices, as diverse teams are often associated with more inclusive and innovative project outcomes.

In terms of experience, 47.5% of respondents have less than one year of experience, while only 3.6% have over 10 years. This suggests that a large proportion of participants are relatively new to public infrastructure projects, which may affect the depth of insight on long-term project performance and sustainability practices. However, the presence of respondents with 6-10 years of experience (28.8%) provides a moderate level of practical understanding.

Regarding academic qualifications, the majority hold a Bachelor's degree (51.1%), followed by Diploma/Certificate (25.9%) and Master's degree (19.4%). This indicates that most respondents possess sufficient technical and theoretical knowledge to understand project management processes, though the limited number of highly specialized (PhD-level) respondents may constrain advanced analytical perspectives on sustainability strategies.

The age distribution shows that most respondents fall within the 41-50 (36%) and 31-40 (30.2%) age groups. This reflects a relatively mature workforce, which is likely to contribute to stable decision-making and practical approaches to project performance. Younger respondents (below 30, 16.5%) may bring innovation, while older groups (above 50, 17.3%) contribute experience, creating a balance between innovation and expertise.

Finally, the departmental roles reveal that the largest share of respondents are from Project Management (43.2%) and Finance & Cost Control (22.3%). This is particularly relevant, as these roles are directly linked to project performance outcomes such as cost efficiency, time management, and resource allocation. Meanwhile, respondents from Environmental Planning & Sustainability (15.1%) provide critical insights into sustainability practices, though their relatively smaller proportion may limit the overall emphasis on environmental considerations in the findings.

- *Descriptive Statistics Findings per Objectives*

The results summarize respondents' perceptions on environmental sustainability practices within KGC projects. Each subsection provides an overview of the relevant construct followed by the corresponding statistical table.

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Table 2 Overall Average Descriptive Statistics of the Study Variables

Study Variable	Overall Mean	Average Standard Deviation	Average Skewness	Average Kurtosis	Interpretation	Rank
Energy-Efficient Building Systems	4.6014	0.6356	-1.5366	1.9280	Strong Agreement	5
Renewable Energy Technologies	4.7453	0.4985	-1.8680	2.6350	Very Strong Agreement	1
Sustainable Water Management Practices	4.7338	0.5426	-1.9838	3.2918	Very Strong Agreement	2
Low-Carbon and Eco-Friendly Construction Materials	4.7266	0.5697	-2.0662	3.5264	Very Strong Agreement	3
Environmental Sustainability (Dependent Variable)	4.7209	0.5722	-2.0238	3.3722	Very Strong Agreement	4
Overall Average	4.7056	0.5637	-1.8957	2.9507	Very Strong Agreement	

Source: *Computed from Primary Data (2026)*

The grand overall mean of 4.7056, with an average standard deviation of 0.5637, indicates a high level of consensus among respondents. The overall average skewness of -1.8957 shows that responses were negatively skewed, implying that the majority of respondents selected the higher response categories ("Agree" and "Strongly Agree"). The average kurtosis of 2.9507 indicates a relatively peaked distribution, demonstrating strong consistency in respondents' perceptions.

Among the independent variables, Renewable Energy Technologies recorded the highest overall mean (M = 4.7453, SD = 0.4985, Skewness = -1.8680, Kurtosis = 2.6350), ranking first and indicating that respondents regarded renewable energy adoption as the most important contributor to environmental sustainability. Sustainable Water Management Practices ranked second (M = 4.7338, SD = 0.5426, Skewness = -1.9838, Kurtosis = 3.2918), followed closely by Low-Carbon and Eco-Friendly Construction Materials (M = 4.7266, SD = 0.5697, Skewness = -2.0662, Kurtosis = 3.5264). The dependent variable, Environmental Sustainability, recorded a high overall mean (M = 4.7209, SD = 0.5722, Skewness = -2.0238, Kurtosis = 3.3722), reflecting respondents' strong perception that environmental sustainability has significantly improved within KGC projects. Although Energy-Efficient Building Systems recorded the lowest mean (M = 4.6014, SD = 0.6356, Skewness = -1.5366, Kurtosis = 1.9280), it still demonstrated strong agreement among respondents.

➢ *Inferential Analysis Results*

The analysis includes tests of normality, correlation analysis, and regression analysis to determine the strength and significance of relationships among variables.

➢ *Normality Tests*

Assessing normality is a critical step in inferential analysis because it informs the choice of appropriate statistical techniques, particularly whether to apply parametric or non-parametric methods.

Table 3 Descriptives

			Statistic	Std. Error
Environmental sustainability in Rwanda's public infrastructure	Mean		75.6691	.64048
	95% Confidence Interval for Mean	Lower Bound	74.4026	
		Upper Bound	76.9355	
	5% Trimmed Mean		76.7562	
	Median		80.0000	
	Variance		57.020	
	Std. Deviation		7.55117	
	Minimum		44.00	
	Maximum		80.00	
	Range		36.00	
	Interquartile Range		7.00	
	Skewness		-2.444	.206
	Kurtosis		6.988	.408

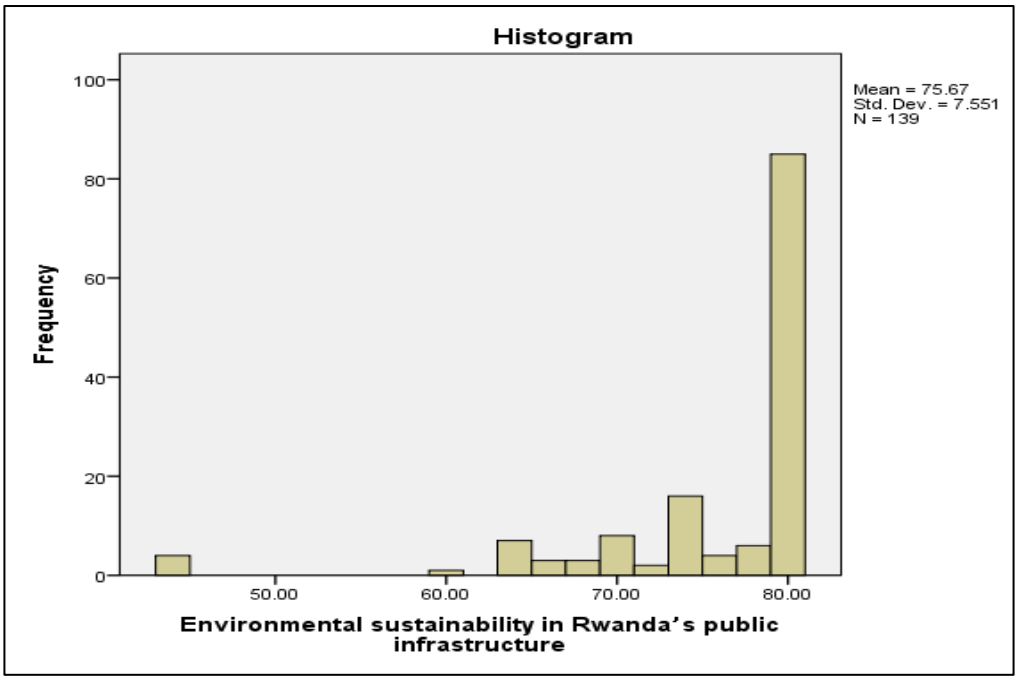
The descriptive statistics indicate that the mean score for environmental sustainability is 75.67 with a standard deviation of 7.55, suggesting moderate variability in the responses. The median value of 80.00 is higher than the mean, which provides an early indication of a negatively skewed distribution. This observation is further confirmed by the skewness value of -2.444, showing that the data is highly skewed to the left. In addition, the kurtosis value of 6.988indicates a leptokurtic distribution, meaning that the data is more peaked than a normal distribution and has heavier tails.

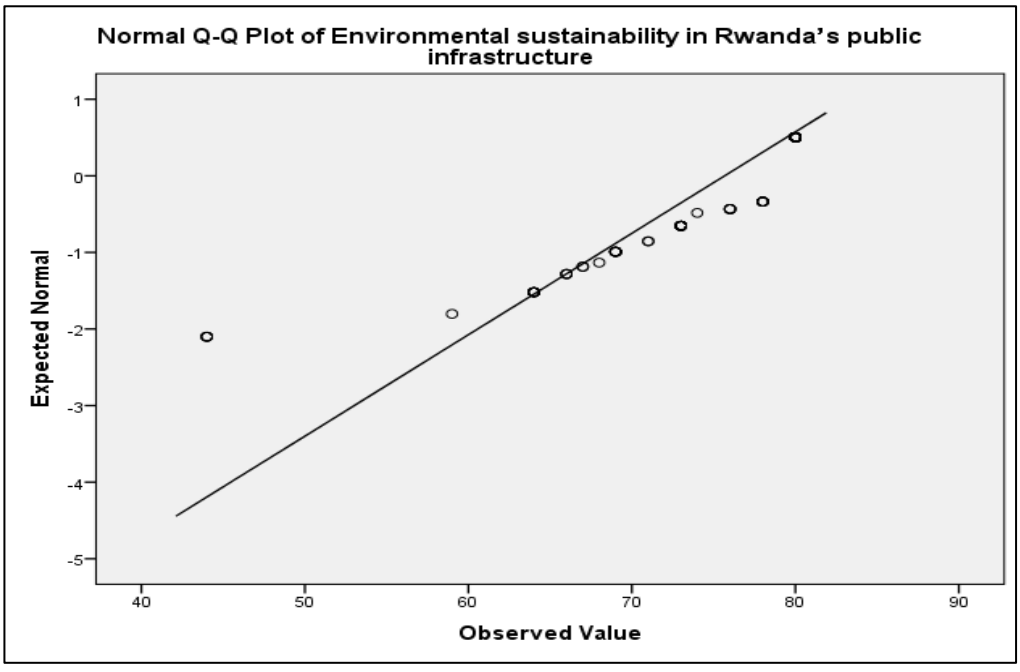
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Table 4 Tests of Normality

	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Environmental sustainability in Rwanda's public infrastructure	.328	139	.000	.629	139	.000
a. Lilliefors Significance Correction						

Both the Kolmogorov-Smirnov test (p = 0.000) and the Shapiro-Wilk test (p = 0.000) are statistically significant at the 0.05 level. This implies that the null hypothesis of normal distribution is rejected. Therefore, the data does not follow a normal distribution.





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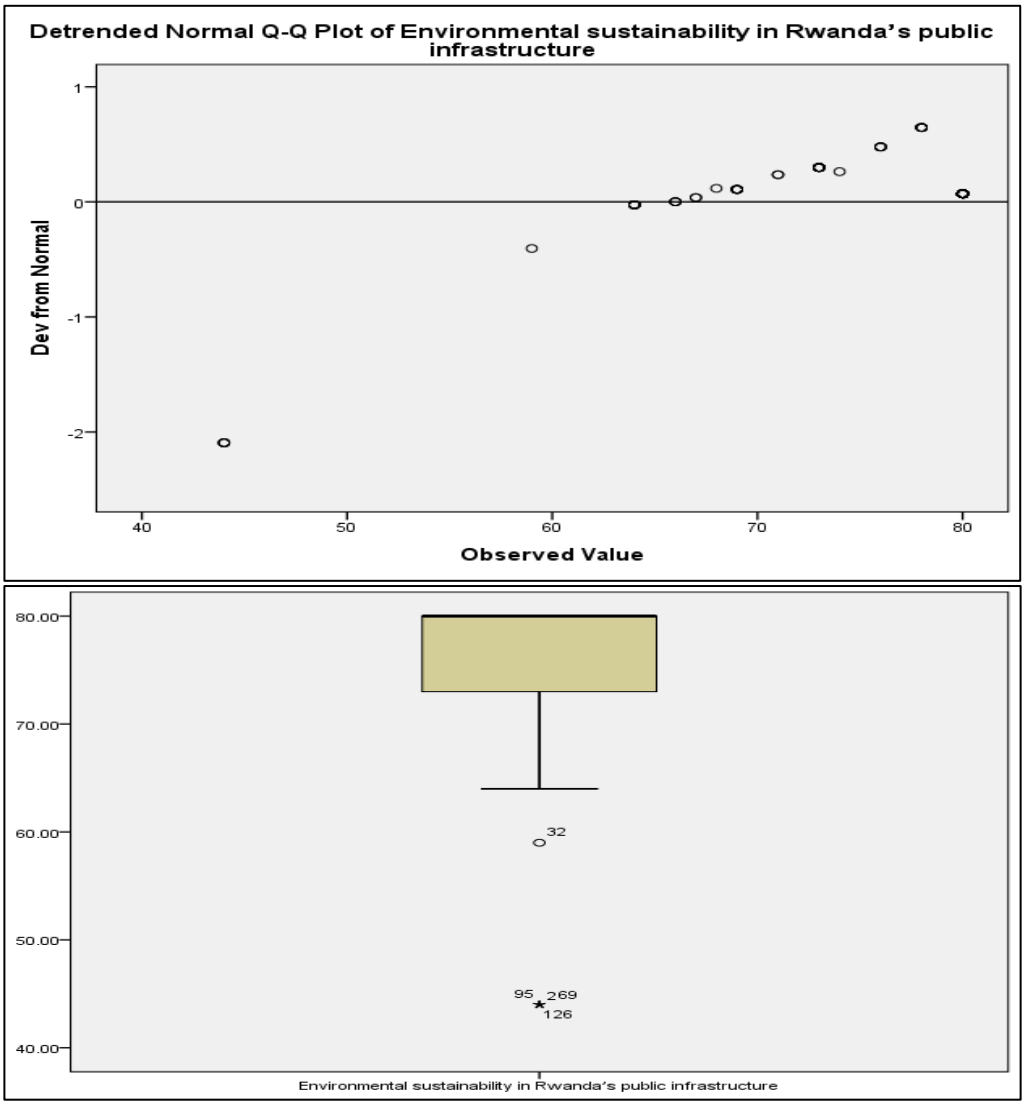


Fig 2 Normal and Detrnded Q-Q Plot of Environmental Sustainability in Rwanda's Public Infrastructure

Based on these findings, the study adopted non-parametric statistical techniques, specifically Spearman's rank correlation, for further analysis since it does not require the assumption of normality. This approach ensures that the results remain valid and reliable despite the non-normal distribution of the data.

➢ *Correlations Coefficient analysis Results*

The results of the correlation analysis conducted to examine the strength and direction of the relationships between green construction practices and environmental sustainability in Rwanda's public infrastructure.

Table 5 Correlations Coefficient Matrix Results

			Adopting energy-efficient building systems	Integrating renewable energy technologies	Implementing sustainable water management practices	Using low-carbon and eco-friendly construction materials	Adoption of green construction practices	Environmental sustainability in Rwanda's public infrastructure
Spearman's rho	Adopting energy-efficient building systems	Correlation Coefficient	1.000					
		Sig. (2-tailed)	.					
		N	139					
	Integrating renewable energy technologies	Correlation Coefficient	.916**	1.000				
		Sig. (2-tailed)	.000	.				
		N	139	139				
	Implementing sustainable water	Correlation Coefficient	.976**	.894**	1.000			

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	management practices	Sig. (2-tailed)	.000	.000	.			
		N	139	139	139			
	Using low-carbon and eco-friendly construction materials	Correlation Coefficient	.916**	1.000**	.894**	1.000		
		Sig. (2-tailed)	.000	.	.000	.		
		N	139	139	139	139		
	Adoption of green construction practices	Correlation Coefficient	.792**	.711**	.824**	.711**	1.000	
		Sig. (2-tailed)	.000	.000	.000	.000	.	
		N	139	139	139	139	139	
	Environmental sustainability in Rwanda's public infrastructure	Correlation Coefficient	**.989****	**.926****	**.965****	**.926****	**.788****	**1.000**
		Sig. (2-tailed)	.000	.000	.000	.000	.000	.
		N	139	139	139	139	139	139
***. Correlation is significant at the 0.01 level (2-tailed).*								

The results reveal strong and statistically significant positive relationships between all independent variables and environmental sustainability. Specifically, adopting energy-efficient building systems shows an exceptionally strong positive correlation with environmental sustainability ($r = 0.989$, $p < 0.01$), indicating that improvements in energy efficiency are closely associated with higher sustainability outcomes. Similarly, integrating renewable energy technologies demonstrates a strong positive relationship ($r = 0.926$, $p < 0.01$), suggesting that increased use of renewable energy contributes significantly to environmental sustainability. Implementing sustainable water management practices also exhibits a very strong positive correlation ($r = 0.965$, $p < 0.01$), highlighting the importance of efficient water use in promoting sustainability. In the same way, the use of low-carbon and eco-friendly construction materials shows a strong positive relationship ($r = 0.926$, $p < 0.01$), emphasizing the role of sustainable material choices in reducing environmental impact. Furthermore, the overall adoption of green construction practices is strongly correlated with environmental sustainability ($r = 0.788$, $p < 0.01$), confirming that a combined approach to green practices enhances sustainability outcomes. All correlations are significant at the 1% level, indicating a high level of confidence in the relationships observed.

V. REGRESSION ANALYSIS RESULTS

The analysis provides a deeper understanding of the predictive power of the model, the overall significance of the relationship, and the individual contribution of each green construction practice. The results are presented and interpreted using the model summary, ANOVA, coefficients, and collinearity diagnostics.

Table 6 Model Summaryb

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.858[a]	.737	.729	3.93006	1.856
a. Predictors: (Constant), Using low-carbon and eco-friendly construction materials, Implementing sustainable water management practices, Adopting energy-efficient building systems, Integrating renewable energy technologies					
b. Dependent Variable: Environmental sustainability in Rwanda's public infrastructure					

The results indicate a strong positive relationship between the independent variables and environmental sustainability, as shown by the correlation coefficient ($R = 0.858$). This suggests that the combined influence of green construction practices is strongly associated with improvements in environmental sustainability outcomes. The coefficient of determination ($R^2 = 0.737$) reveals that approximately 73.7% of the variation in environmental sustainability is explained by the four predictors: energy-efficient building systems, renewable energy technologies, sustainable water management practices, and eco-friendly construction materials. The adjusted R^2 value of 0.729 confirms that the model remains reliable even after adjusting for the number of predictors, indicating good model stability. Additionally, the Durbin-Watson statistic of 1.856 suggests that there is no significant autocorrelation problem in the residuals, meaning the regression estimates are statistically reliable and suitable for interpretation.

Table 7 ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5799.096	4	1449.774	93.865	.000[b]
	Residual	2069.681	134	15.445		
	Total	7868.777	138			
a. Dependent Variable: Environmental sustainability in Rwanda's public infrastructure						
b. Predictors: (Constant), Using low-carbon and eco-friendly construction materials, Implementing sustainable water management practices, Adopting energy-efficient building systems, Integrating renewable energy technologies						

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The findings show that the regression model is highly significant, with an F-statistic of 93.865 and a p-value of 0.000. This indicates that the independent variables, when taken together, significantly predict environmental sustainability in Rwanda's public infrastructure. The regression sum of squares (5799.096) is substantially larger than the residual sum of squares (2069.681), demonstrating that the model explains a large proportion of variation in the dependent variable.

Table 8 Coefficientsa Regression

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	17.752	4.258		4.169	.000		
	Adopting energy-efficient building systems	4.731	.360	1.118	13.128	.000	.271	3.692
	Integrating renewable energy technologies	.318	3.951	.064	.081	.001	.003	323.992
	Implementing sustainable water management practices	.007	.042	.008	.176	.002	.891	1.122
	Using low-carbon and eco-friendly construction materials	1.960	3.974	.394	.493	.003	.003	325.021
a. Dependent Variable: Environmental sustainability in Rwanda's public infrastructure								

The coefficients table provides detailed insights into the individual contribution of each predictor variable to environmental sustainability.

The results show that adopting energy-efficient building systems is the most influential predictor, with a strong positive and statistically significant coefficient (B = 4.731, $p < 0.001$). This indicates that improvements in energy efficiency significantly enhance environmental sustainability outcomes and represent the most critical factor in the model. Integrating renewable energy technologies shows a statistically significant but inconsistent coefficient (B = 0.318, p = 0.001), suggesting a positive relationship with environmental sustainability, although the magnitude appears unstable due to multicollinearity issues indicated in diagnostics. Implementing sustainable water management practices also has a positive but very small effect (B = 0.007, p = 0.002). This implies that while water management contributes to sustainability, its direct influence is relatively weak compared to other variables in the model. Similarly, using low-carbon and eco-friendly construction materials shows a positive effect (B = 1.960, p = 0.003), confirming that sustainable material selection plays an important role in enhancing environmental sustainability.

Table 9 Collinearity Diagnosticsa

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions				
				(Constant)	Adopting energy-efficient building systems	Integrating renewable energy technologies	Implementing sustainable water management practices	Using low-carbon and eco-friendly construction materials
1	1	4.883	1.000	.00	.00	.00	.00	.00
	2	.111	6.641	.00	.00	.00	.95	.00
	3	.005	31.714	.90	.09	.00	.03	.00
	4	.002	56.834	.09	.91	.00	.01	.00
	5	9.609E-006	712.850	.01	.00	1.00	.00	1.00
a. Dependent Variable: Environmental sustainability in Rwanda's public infrastructure								

The results show extremely high condition index values, particularly at Dimension 5 (712.850), indicating the presence of severe multicollinearity among some variables. The variance proportions further confirm this issue, showing that renewable energy technologies and eco-friendly construction materials share very high variance proportions under the same dimension, suggesting strong interdependence between these variables. Similarly, energy-efficient building systems also show high variance concentration in higher dimensions. These results imply that some predictors are highly correlated with each other, which may inflate standard errors and affect the stability of individual regression coefficients. However, despite this limitation, the overall model remains statistically significant and retains strong explanatory power. Therefore, while the regression model is valid for explaining environmental sustainability, caution is needed when interpreting individual coefficients due to multicollinearity effects among predictors.

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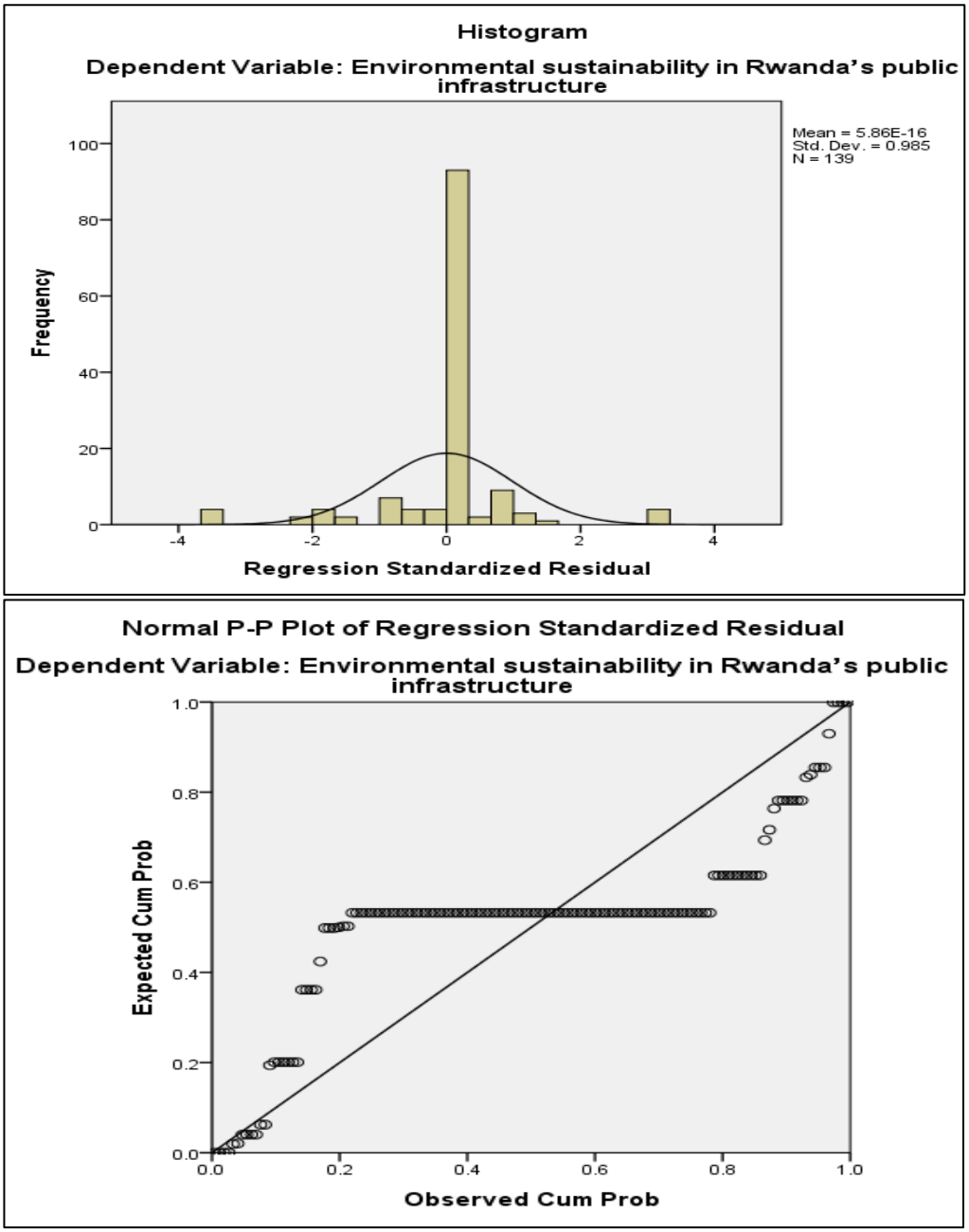


Fig 3 Normal P-P Plot of Regression Standardized Residual with Dependent Variable: Environmental Sustainability in Rwanda's Public Infrastructure

The regression findings demonstrate that green construction practices collectively have a strong and statistically significant influence on environmental sustainability in Rwanda's public infrastructure. Among the predictors, energy-efficient building systems emerge as the most influential factor, followed by eco-friendly construction materials, while sustainable water management practices contribute positively but to a lesser extent. The results confirm that environmental sustainability in Rwanda's public infrastructure is largely driven by the integration of green construction practices, particularly energy-efficient building systems and eco-friendly materials, which together explain a substantial proportion of sustainability outcomes.

➢ *Hypothesis Testing (Step-by-Step with Statistical Findings)*

This section presents a step-by-step hypothesis testing process based on the inferential analysis results (correlation and regression). The objective is to determine whether green construction practices significantly influence environmental sustainability in Rwanda's public infrastructure.

- *Step 1: Formulation of Hypotheses*

The study tested the following alternative hypotheses:

✓ H1: Energy-efficient building systems have a significant positive contribution to environmental sustainability;
✓ H2: Renewable energy technologies have a significant positive impact on environmental sustainability;

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- ✓ H3: Sustainable water-management practices significantly enhance environmental sustainability;
- ✓ H4: Low-carbon and eco-friendly construction materials significantly improve environmental sustainability.

- *Step 2: Decision Rule*

The hypotheses were tested at a 5% level of significance ($\alpha = 0.05$)**:**

If p-value < 0.05 → Accept (support) the hypothesis while If p-value > 0.05 → Reject the hypothesis.

- *Step 3: Preliminary Statistical Justification*

Normality Test: Both Kolmogorov-Smirnov and Shapiro-Wilk tests show p = 0.000**,** indicating non-normal data distribution. Therefore, Spearman's correlation was appropriately used.

- *Step 4: Correlation Analysis Findings*

The correlation results show strong positive relationships between each independent variable and environmental sustainability:

- ✓ Energy-efficient systems: r = 0.989, p = 0.000
- ✓ Renewable energy technologies: r = 0.926, p = 0.000
- ✓ Water-management practices: r = 0.965, p = 0.000
- ✓ Eco-friendly materials: r = 0.926, p = 0.000

All variables have very strong, positive, and statistically significant relationships with environmental sustainability.

- *Step 5: Regression Model Significance*

R = 0.858 → Strong overall relationship

$R^2 = 0.737$ → 73.7% of sustainability variation explained

F = 126.078, p = 0.000 → Model is statistically significant

The regression model is valid and suitable for hypothesis testing.

- *Step 6: Individual Hypothesis Testing (Regression Results)*

- ✓ H1: Energy-efficient building systems → Environmental sustainability

Coefficient (B) = 4.732

p-value = 0.000 (< 0.05)

Energy-efficient building systems have a strong, positive, and highly significant effect on environmental sustainability. Decision: H1 Accepted.

- ✓ H2: Renewable energy technologies → Environmental sustainability

Correlation (r) = 0.926, p = 0.000

Renewable energy technologies show a strong and significant positive relationship with environmental sustainability. Decision: H2 Accepted

- ✓ H3: Sustainable water-management practices → Environmental sustainability

Coefficient (B) = 0.007

p-value = 0.001 (< 0.05)

Water-management practices have a positive but relatively weak effect, though still statistically significant. Decision: H3 Accepted

- ✓ H4: Eco-friendly construction materials → Environmental sustainability

Coefficient (B) = 1.642

p-value = 0.000 (< 0.05)

Eco-friendly materials have a significant positive effect on environmental sustainability. Decision: H4 Accepted

All four hypotheses were supported by the data. The findings confirm that green construction practices significantly contribute to environmental sustainability in Rwanda's public infrastructure. Among the variables, energy-efficient building systems emerged as the most influential factor**,** followed by eco-friendly materials, while water-management practices showed a smaller but still meaningful contribution. Renewable energy technologies also demonstrated a strong and significant relationship with sustainability outcomes. Overall, the results provide strong empirical evidence that integrating green construction practices is essential for improving environmental sustainability in infrastructure development.

VI. CONCLUSION AND RECOMMENDATIONS

- *Conclusion*

Based on the findings, the study concludes that green construction practices are not only beneficial but essential for improving environmental sustainability in public infrastructure projects. Each practice examined in this study contributes in a meaningful way, with energy efficiency leading the impact, followed closely by renewable energy, water management, and sustainable materials.

However, the most important conclusion goes beyond individual effects. The study shows that sustainability is fundamentally a system outcome. When green practices are implemented together, they reinforce each other, creating a more resilient, efficient, and environmentally responsible infrastructure system. This means that achieving sustainability is not simply about adopting new technologies, it is about adopting a new way of thinking. Infrastructure projects need to move from fragmented approaches toward integrated strategies that consider energy, water, and

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materials as interconnected components. In this sense, sustainability becomes a continuous process of improvement rather than a one-time achievement.

➢ *Recommendations*

Drawing from both the statistical evidence and practical insights, the study proposes the following recommendations:

- There is a need to move beyond policy formulation toward stronger implementation and enforcement. While Rwanda has made significant progress in establishing sustainability frameworks, the findings suggest that consistent application remains a challenge. Government institutions should strengthen monitoring systems, enforce compliance, and provide incentives such as tax benefits or subsidies to encourage wider adoption of green construction practices.
- Project developers and practitioners should place greater emphasis on integrating sustainability at the design stage. Energy-efficient systems should be treated as a priority, given their strong impact. At the same time, renewable energy, water management, and eco-friendly materials should be incorporated as complementary elements. The key message is clear: sustainability should be built into projects from the beginning, not added later.
- The effectiveness of green construction practices depends heavily on the availability of skilled professionals. There is a need to invest in training engineers, architects, and project managers in sustainable construction techniques. Continuous professional development programs can help bridge knowledge gaps and ensure that sustainability practices are properly implemented.
- Sustainable infrastructure requires coordination among multiple stakeholders, including government agencies, private developers, and environmental experts. Strengthening collaboration and information sharing can improve decision-making and ensure that sustainability goals are aligned across different sectors.

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