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Contribution of green technologies on infrastructure performance in Rwanda, a case of green buildings constructed in the green Gicumbi project

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***Abstract*— *In Rwanda, integrating green technologies in building projects presents an opportunity to enhance infrastructure performance while minimizing environmental impact. However, the extent to which these technologies contribute to the overall effectiveness of these infrastructures remains underexplored, especially in rural contexts like the Gicumbi District. Therefore, this study aimed to assess the contribution of green technologies used in green building projects to infrastructure performance. To achieve this objective, the study used a descriptive research design and a census sampling technique to select the entire population of 107 people, including the residents and beneficiaries of the green buildings project. Primary data were collected through a combination of questionnaires, interviews, and direct observations, while secondary data were gathered through documentary analysis and published research studies. The findings revealed that all green technologies such as resources-efficient design, low-emission materials, and waste management have a significant positive influence on the performance of the Green Buildings project in the Gicumbi district where a increase of one unit in resources-efficient design, low-emission materials, and waste management would lead to increase of 0.152, 0.14, and 0.178 in performance of Green Buildings. The study concluded that the change of 65% in the performance of Green Buildings is due to green technologies in terms of resource-efficient design, low-emission materials, and waste management at a 95% confidence interval.*

***Keywords*— Gicumbi District, Green technologies, Infrastructure performance, Rwanda, Sustainable development.**

I. INTRODUCTION

In recent years, there has been an intensified global focus on sustainable development and environmental conservation, driving the widespread adoption of green technologies across various sectors. This movement, primarily aimed at mitigating the effects of climate change, has been supported by a broad array of international frameworks, governmental policies, and private-sector investments. The Global Green Economy Index (GGEI), which evaluates the green performance of 130 countries, consistently highlights nations such as Sweden, Denmark, and Switzerland for their exemplary integration of green technologies through robust policies and significant investments (Edenhofer et al., 2014). Globally, the development and deployment of green technologies have become integral to the sustainability agendas of leading nations. For instance, the United States has pioneered green innovation, with policies supporting renewable energy, energy efficiency, and clean transportation (U.S. Department of Energy, 2020). Similarly, China has made substantial strides in renewable energy infrastructure and electric vehicle adoption, driven by both government targets and increasing environmental awareness (International Energy Agency, 2020).

In Africa, nations are increasingly integrating green technologies into their development strategies, especially as climate change disproportionately impacts the continent. Programs like South Africa's Renewable Energy Independent Power Producer Procurement (REIPPP) have successfully attracted investments in solar and wind energy, significantly reducing the country's reliance on fossil fuels (Govender & Adam, 2021). Similarly**,** Uganda has made significant strides in expanding access to solar energy, particularly in rural areas (Naluwairo et al., 2020). For Rwanda, a country known for its ambitious sustainability goals, the adoption of green technologies has been pivotal in shaping national policies and infrastructure projects aimed at promoting environmental sustainability and climate resilience. Rwanda has been a leader in promoting eco-friendly infrastructure, notably through the Green Kigali Initiative, which seeks to transform the capital city into a sustainable urban environment through green spaces, sustainable waste management, and green building standards. This initiative is part of a broader vision to integrate green technologies into Rwanda's infrastructural landscape to foster long-term sustainability. Additionally, Rwanda has set a target to achieve 60% renewable energy generation by 2030 and is working to enhance electricity access and reduce carbon emissions (Government of Rwanda, 2020). These developments reflect Rwanda's growing role as a leader in green infrastructure across East Africa and the wider African continent.

The significance of green technologies in improving infrastructure performance is exemplified by global benchmarks, such as the Bullitt Center in the U.S. and The Edge in the Netherlands, which have set high standards for sustainability in commercial buildings. In Rwanda, the Green Gicumbi Project serves as a vital case study of how green technologies have been successfully integrated into building design, construction, and operation to improve sustainability. This project aligns with Rwanda's broader goal to reduce greenhouse gas emissions, enhance energy efficiency, and promote climate-resilient infrastructure. The study that forms the basis of this paper evaluates the impact of green technologies on the performance of infrastructures in Rwanda, with specific reference to the Green Gicumbi Project**.** The project serves as a model for integrating energy-efficient designs**,** renewable energy systems**,** and environmentally sustainable construction materials in Rwanda's infrastructure development. By examining the practical outcomes and operational benefits of these green technologies, the study offers insights into how such technologies can enhance both environmental and economic performance. This research contributes to the growing body of knowledge on sustainable infrastructure and green technologies, providing valuable recommendations for the future implementation of green building practices in Rwanda and beyond.

II. MATERIALS AND METHODS

2.1. Sampling techniques

The study employed a census sampling technique, which was deemed appropriate and reliable due to the limited number of respondents within the study area. This technique offers several advantages, including comprehensive coverage of the entire population under study, which eliminates sampling errors and ensures accurate and representative findings. The census approach allowed for precise estimates of various population characteristics, including demographics, attitudes, and behaviors, and produced highly accurate data, which were essential for decision-making, policy formulation, and resource allocation.

In addition to the census, semi-structured interviews were conducted with key stakeholders involved in the green building projects. These stakeholders included an engineer from the Rwanda Housing Authority, an infrastructure engineer and building inspector from Gicumbi District, an engineer from Rubaya Sector, and local leaders such as the executive secretaries of Rubaya Sector, Nyamiyaga Cell, and Kabeza Village. These individuals were selected using purposive sampling due to their direct involvement and expertise in the planning, execution, and oversight of the projects. The interviews were designed to explore the objectives, challenges, outcomes, and the role of local communities and leaders in the success of green building initiatives. The semi-structured format allowed for flexibility in responses while ensuring that key topics were addressed. The interviews were conducted in person to facilitate a detailed and contextual understanding of the green building projects.

2.2. Data collection tools

2.2.1. Questionnaire

The questionnaire is a suitable research instrument due to its structured format and convenience for collecting data within a short time. In addition, a questionnaire has the ability to accord a respondent adequate time to respond as well as a sense of anonymity to a respondent. Moreover, it's a cost-effective way of collecting data since a lot of respondents can be interviewed, covering a large geographical area (Walliman, 2011). The questionnaire was chosen as a suitable instrument for the above reasons. In this study, closed-ended questionnaires composed of 5-point Likert-scale questions were used. The first section of the questionnaire dealt with respondents' demographic details. The second section covered the variables used for the study.

107 questionnaires were distributed to the residents of the green buildings in Gicumbi District, with each questionnaire carefully designed to gather insights on their experiences and perspectives regarding green building initiatives. The questionnaires have been returned by all the respondents, achieving a 100% response rate. This full participation ensured a comprehensive and accurate representation of the residents' views, contributing valuable data to the research on the impact and effectiveness of green building projects.

2.2.2. Interview

The interview was employed as a vital data collection tool to gather detailed and qualitative information from individuals directly involved in the initiation, monitoring, and evaluation of the Green Gicumbi project. This method allowed for an in-depth exploration of specific insights, experiences, and expert opinions regarding the project's processes and outcomes. A semi-structured format has been used, combining pre-determined questions with the flexibility to delve deeper into emerging topics during discussions. To ensure a comprehensive understanding of the project, seven key informants were strategically selected based on their roles and expertise. These included an engineer in charge of construction at the Rwanda Housing Authority, who provided technical insights on the design and construction phases and their alignment with national housing policies, and an infrastructure engineer at Gicumbi District, who offered a district-level perspective on infrastructure planning, resource allocation, and supervision. Additionally, the building inspector at Gicumbi District shared observations on compliance with construction standards, environmental sustainability, and quality control during implementation. An engineer in charge of infrastructure in the Rubaya sector highlighted sector-specific challenges, opportunities, and contributions, while the executive secretary of the Rubaya sector provided administrative insights on governance, stakeholder coordination, and monitoring progress. At the grassroots level, the cell Executive secretary of Nyamiyaga discussed the project's impact on the community and integration of local needs, and the Kabeza village community leader offered perspectives on community engagement, project benefits, and feedback mechanisms. The interviews were conducted in a conversational format, ensuring participants could express their views freely while addressing critical aspects of project initiation, monitoring, and evaluation. The qualitative data obtained enriched the study by complementing other data collection methods and contributing to a holistic understanding of the Green Gicumbi project.

2.2.3. Observation

During the site visit conducted by the researcher to the green buildings in Gicumbi District, Rubaya Cell, Nyamiyaga Cell, and Kabeza village, several key observations were made regarding the green technologies implemented and the overall performance of the buildings. The observation tool used during the site visit was designed to assess the implementation and performance of various green technologies in the buildings. The researcher employed a structured observational checklist that focused on key aspects such as energy-saving measures, building orientation for natural lighting and ventilation, waste management practices, water management systems, and the use of local materials. Additionally, the condition of the buildings and the maintenance of green technologies were also observed. This observational method allowed for a comprehensive evaluation of how the green technologies were integrated into the buildings and how well they were functioning. The observations were recorded systematically, and the findings were later analyzed to assess the effectiveness of these green initiatives in promoting sustainability and operational efficiency.

2.2.4.Documentary analysis

This instrument was selected based on its relevance to sustainable practices, showcasing the implementation of green technologies in a real-world infrastructure project like Green Buildings Constructed in Green Gicumbi. The focus lies in evaluating how these technologies impact the building's design, construction, operational efficiency, and overall environmental sustainability. The researcher conducted a Contextual analysis to understand the broader landscape in which Green Buildings Constructed in Green Gicumbi were developed. This involves looking into Rwanda's environmental policies, sustainable development goals, economic factors influencing green technology adoption, and the roles played by various stakeholders such as government agencies, architects, engineers, and environmental experts. Understanding this context provides insights into the motivations, challenges, and opportunities associated with integrating green technologies into infrastructure projects in Rwanda.

III. RESULTS AND DISCUSSION

3.1. Assessment of green technologies employed in the green buildings project

The study sought to assess green technologies used by the developer for the Green Buildings Project. The respondents were asked whether they agreed or disagreed with the statement regarding green technologies used in the project. The study used descriptive statistics such as mean, standard deviation, frequency, and percent.

3.1.1. Resources efficient design for the green buildings project.

The study sought to assess resource-efficient design for Green Buildings Constructed in the Green Gicumbi Project. The respondents were asked whether they agreed or disagreed with the statement regarding resource-efficient design. The study used descriptive statistics such as mean, standard deviation, frequency, and percent. The results are presented in Table 3.1.

Table 3.1: Resource-efficient design

Resources Efficient Design	SD		D		N		A		SA		Mean	SD
	fi	%	fi	%	fi	%	Fi	%	Fi	%		
Availability of energy-efficient LED lighting	4.0	3.7	3.0	2.8	5.0	4.7	26.0	24.3	69.0	64.5	4.4	0.977
Availability of high-efficiency HVAC systems	2.0	1.9	3.0	2.8	9.0	8.4	22.0	20.6	71.0	66.4	4.5	0.90
Availability of high-efficiency sound insulation	3.0	2.8	5.0	4.7	4.0	3.7	13.0	12.1	82.0	76.6	4.6	0.97
Availability of passive design strategies like orientation, shading, and natural ventilation	4.0	3.7	7.0	6.5	5.0	4.7	21.0	19.6	70.0	65.4	4.4	1.08
Use of water efficiency practices like utilizing low-flow fixtures, greywater recycling systems, and rainwater harvesting to reduce water consumption	5.0	4.7	5.0	4.7	2.0	1.9	19.0	17.8	76.0	71.0	4.5	1.06
			Overview								**4.45**	

Source: Primary data, 2024

The findings from Table 3.1 on resource-efficient design in the Green Buildings Project in Gicumbi District reveal a strong integration of sustainable practices across various key elements. Starting with energy-efficient LED lighting, this feature received high affirmation from respondents, with 64.5% strongly agreeing on its availability. LED lighting is a well-known energy-saving choice that significantly reduces electricity consumption, aligning with sustainable energy goals. This element's mean score of 4.4, with a standard deviation of 0.977, reflects a high level of satisfaction and acceptance among respondents, underlining its prominent role in enhancing energy efficiency within green buildings. The availability of high-efficiency HVAC (heating, ventilation, and air conditioning) systems also ranked highly, with 66.4% of respondents strongly agreeing to its presence, resulting in a mean score of 4.5 and a lower standard deviation of 0.90. These systems play a crucial role in maintaining optimal indoor air quality and climate control while minimizing energy use. The positive response suggests that such systems have been effectively incorporated, supporting the project's commitment to reducing energy waste and promoting a healthier indoor environment. Sound insulation emerged as the most positively received feature, with 76.6% of respondents strongly agreeing on its effectiveness. With a mean score of 4.6 and a standard deviation of 0.97, this element reflects a strong emphasis on comfort and noise reduction, which are vital for occupant well-being. High-efficiency sound insulation reduces noise from both internal and external sources, contributing to a more tranquil and conducive environment within the buildings. In terms of passive design strategies, such as building orientation, shading, and natural ventilation, these elements received 65.4% strong agreement from respondents, yielding a mean score of 4.4 and a slightly higher standard deviation of 1.08. The incorporation of passive design measures demonstrates a commitment to leveraging natural resources to enhance energy efficiency and occupant comfort. By reducing reliance on mechanical systems, these strategies contribute to the overall sustainability of the project and highlight the use of thoughtful architectural design.

Lastly, water efficiency practices, including rainwater harvesting, showed strong positive feedback, with 71.0% of respondents strongly agreeing with their presence. This feature scored a mean of 4.5 with a standard deviation of 1.06, indicating a high level of satisfaction. Efficient water use is critical in green building design, as it addresses both resource conservation and the reduction of operational costs. The project's emphasis on water-saving measures underscores its alignment with environmental conservation objectives. Overall, the analysis reveals an average mean score of 4.45 across all design elements, which translates to an 89% agreement on the effectiveness of resource-efficient design within green buildings. This high level of consensus provides strong evidence of the successful integration of sustainable practices, demonstrating the project's commitment to enhancing infrastructure performance through green technologies.

3.1.2. Low-emission materials.

In sustainable construction, selecting low-emission materials is essential for minimizing environmental impact and improving indoor air quality. Low-emission materials help reduce the release of harmful pollutants, such as volatile organic compounds (VOCs), which can contribute to poor air quality and pose health risks to occupants. By using materials with reduced or zero emissions, green buildings can ensure a healthier indoor environment, contribute to lower carbon emissions, and support overall sustainability goals. Considering the importance of low-emission materials in achieving these objectives, this study examined the extent to which such materials have been incorporated into the Green Buildings Project in the Gicumbi District. This aspect was selected for analysis due to its direct impact on both environmental sustainability and the health and well-being of building occupants. Findings were collected on the types of low-emission materials used, their specific applications, and how frequently they were adopted within the project, with an emphasis on any patterns or trends observed. Through this evaluation, the study aims to provide insights into the project's commitment to reducing emissions and promoting a sustainable built environment. In the following sections, we will delve into the findings related to low-emission materials and explore how these materials have contributed to the project's environmental and health objectives.

The analysis of low-emission materials in the Green Buildings Project in Gicumbi District reveals significant incorporation of sustainable construction practices, particularly in terms of material selection aimed at minimizing environmental impact and enhancing indoor air quality. One of the main focus areas was the use of low-VOC (Volatile Organic Compounds) or zero-VOC materials, which are crucial for reducing pollutants that can affect respiratory health and overall air quality. The study found that 60.7% of respondents strongly agreed that low-VOC or zero-VOC materials were utilized, and an additional 29.3% agreed. This high approval rate resulted in a mean score of 4.36 and a standard deviation of 1.03, underscoring the project's commitment to healthy, sustainable indoor environments.

Another important area was adherence to formaldehyde content standards, an aspect that received strong agreement from 61.7% of respondents, with 28.3% also in agreement. The project's high compliance with formaldehyde standards led to a mean score of 4.40 and a standard deviation of 0.97, indicating a priority on reducing exposure to this harmful compound, which is commonly found in building materials and can cause eye, nose, and throat irritation. This commitment highlights the project's focus on occupant health and regulatory compliance.

The use of certified and labeled materials was also highly regarded, with 71.0% of respondents strongly affirming this practice, which yielded a mean score of 4.39 and a standard deviation of 1.16. Certification ensures that the materials used meet established low-emission standards and contributes to accountability and transparency in material sourcing. This level of assurance helps validate the project's dedication to environmentally responsible building practices, as certified materials are often tested and verified to have lower emission profiles.

Furthermore, the project prioritized the selection of building materials that are naturally low in emissions or have been treated to reduce emissions. This approach received strong agreement from 60.7% of respondents, resulting in a mean score of 4.28 and a standard deviation of 1.15. Using naturally low-emission materials not only aligns with sustainable construction principles but also reduces reliance on chemically intensive treatments, supporting both indoor air quality and overall project sustainability. Lastly, the use of sustainable materials that consider low embodied energy, recycled content, and recyclability was a significant focus of the project. This aspect received strong agreement from 68.2% of respondents, achieving a mean score of 4.33 and a standard deviation of 1.23. Selecting materials with low embodied energy helps reduce the total carbon footprint of the building while incorporating recycled content and recyclable options to support resource conservation and waste reduction. This lifecycle approach to material selection underscores the project's dedication to minimizing environmental impact not only during construction but also throughout the building's lifespan. In summary, the study reveals an overall average mean score of 4.35, corresponding to 87% agreement among respondents on the effective use of low-emission materials. This high rating indicates a solid integration of sustainable practices within the project, demonstrating a proactive approach to enhancing indoor air quality, occupant health, and environmental performance. The careful selection and use of low-emission materials reflect a comprehensive commitment to sustainability, which positions the Green Buildings Project in the Gicumbi District as a model for environmentally responsible construction in Rwanda.

Table 3.2: Low-emission materials

Low-emission materials	SD		D		N		A		SA		MEAN	STD
	fi	%	fi	%	fi	%	fi	%	fi	%		
Construction materials are low-VOC or zero-VOC	5	5.1	3	3.03	5	5.1	29	29.3	65	60.7	4.36	1.03
Construction materials comply with Formaldehyde Content standards	4	4	2	2.02	7	7.1	28	28.3	66	61.7	4.4	0.97
Construction materials are labeled and certified	7	7.1	4	4.04	5	5.1	15	15.2	76	71	4.39	1.16
Building materials are naturally low in emissions or have undergone treatments to reduce emissions	6	6.1	6	6.06	5	5.1	25	25.3	65	60.7	4.28	1.15
Use of sustainable materials with low embodied energy, recycled content, and recyclability to minimize environmental footprint throughout their lifecycle	9	9.1	4	4.04	3	3	18	18.2	73	68.2	4.33	1.23
Overview											**4.35**	

Source: Primary data, 2024

3.1.3. Waste management.

Effective waste management is a critical component of sustainable building practices, aimed at reducing the environmental footprint of construction projects. Waste generated during construction, if not properly managed, can lead to increased landfill usage, environmental degradation, and health hazards. Implementing waste management practices such as recycling, reusing materials, and minimizing construction waste helps conserve resources, reduce pollution, and lower disposal costs. For green building projects, sustainable waste management also aligns with broader environmental goals, promoting responsible resource use and contributing to a circular economy. In the context of the Green Buildings Project in Gicumbi District, waste management practices were evaluated to understand how effectively the project has managed waste during construction and operation.

This aspect was chosen for analysis because proper waste management is essential in ensuring that the project minimizes its ecological impact and aligns with the principles of green construction. By assessing practices like material recycling, waste segregation, and reduction in waste production, the study aimed to determine how well the project contributes to environmental sustainability and resource efficiency. The findings, presented in Table 3-3, shed light on the specific waste management practices implemented in the project, including the extent to which recycling, reuse, and reduction efforts have been adopted and how they are perceived by stakeholders. Through this analysis, the study provides insight into the project's commitment to waste reduction and its effectiveness in meeting sustainability goals.

Table 3.3: Waste Management for Green Buildings

Waste Management	SD		D		N		A		SA		Mean	STD
	Fi	%	fi	%	fi	%	fi	%	fi	%		
Availability of Waste Reduction Goals	5	4.7	5	4.67	4	3.7	30	28.0	63	58.9	4.32	1.07
Availability of Waste Management Plan	4	3.7	2	1.87	12	11.2	25	23.4	64	59.8	4.34	1.01
Source Separation	7	6.5	4	3.74	4	3.7	17	15.9	75	70.1	4.39	1.16
Recycling and Reuse Programs	6	5.6	7	6.54	5	4.7	24	22.4	65	60.7	4.26	1.17
Certifications and Standards	8	7.5	10	9.35	2	1.9	20	18.7	67	62.6	4.20	1.29
Overall view											**4.30**	

Source: Primary data, 2024

The findings on waste management practices in the Green Buildings Project in Gicumbi District indicate substantial integration of sustainable waste management measures. Among the key aspects assessed, the availability of clear waste reduction goals was a notable factor. A majority, 58.9% of respondents, strongly agreed that waste reduction targets were established for the project, with an additional 28.0% agreeing. This strong alignment with waste reduction goals achieved a mean score of 4.32 and a standard deviation of 1.07, reflecting a consistent focus on minimizing construction waste from the outset. Another critical component was the presence of a waste management plan, which guides how waste should be managed throughout the construction process. Here, 59.8% of respondents strongly agreed, and 23.4% agreed, that such a plan was in place, leading to a mean score of 4.34 and a standard deviation of 1.01. This finding underscores the importance placed on structured waste management protocols, which help prevent unregulated waste disposal and promote organized handling of construction debris.

Source separation practices, aimed at sorting waste by type for more efficient recycling or disposal, were also highly rated. An impressive 70.1% of respondents strongly agreed that source separation was practiced, and another 15.9% agreed. The high level of support for this practice resulted in a mean score of 4.39 and a standard deviation of 1.16. Source separation is instrumental in enhancing recycling efforts and reducing contamination, thus facilitating more effective resource recovery. Recycling and reuse programs were similarly prioritized, as indicated by the 60.7% of respondents who strongly agreed and the 22.4% who agreed with their presence on the project. This emphasis on recycling and reuse resulted in a mean score of 4.26 and a standard deviation of 1.17, signaling a clear commitment to reducing raw material usage and limiting landfill contributions through responsible reuse of materials whenever possible. Lastly, adherence to certifications and standards in waste management received relatively strong support. A total of 62.6% of respondents strongly agreed that the project adhered to relevant waste management certifications, while 18.7% agreed, resulting in a mean score of 4.20 and a standard deviation of 1.29. Compliance with recognized certifications not only ensures high standards but also adds credibility to the project's environmental practices. Overall, the findings indicate an average mean score of 4.30, corresponding to an 86% level of agreement on the effective use of waste management practices. This high level of agreement across multiple dimensions, from waste reduction goals to recycling initiatives, highlights the project's dedication to sustainable waste management. These practices ensure that the Green Buildings Project in Gicumbi District aligns with environmental goals, reduces its ecological footprint, and promotes responsible resource management, setting an example for future green building initiatives in Rwanda.

3.2. Performance of green Buildings constructed in the Green Gicumbi Project

Evaluating the performance of green buildings is essential to understanding the effectiveness of sustainable building practices and their contribution to environmental and social goals. Green building performance encompasses several critical aspects, including energy efficiency, indoor environmental quality, water conservation, and overall user satisfaction. By assessing performance, we can measure how well these buildings meet sustainability objectives, such as reducing resource consumption, minimizing waste, enhancing occupant health, and lowering greenhouse gas emissions. This evaluation is particularly important as it offers insights into whether the design and construction choices made in the Green Buildings Project in the Gicumbi District are achieving the intended positive impact. In the context of the Green Gicumbi Project, evaluating building performance is a way to gauge the success of the implemented green technologies and sustainable practices. Performance assessment allows stakeholders to identify areas of strength and any potential areas for improvement, which is invaluable for informing future projects and policy decisions. Moreover, understanding building performance helps validate the cost-effectiveness of green investments by analyzing the long-term operational savings and environmental benefits, reinforcing the economic and ecological rationale for green construction. Table 4-8 provides an overview of the performance indicators for the Green Buildings Project, offering data-driven insights into the project's outcomes. Through this analysis, the study aims to reveal the degree to which the green buildings in Gicumbi District have met their sustainability targets, benefiting both the environment and the local community.

Table 3.4 Level of Performance of Green Buildings

Performance of the Green building constructed in the Gicumbi project	**SD**		**D**		**N**		**A**		**SA**		**MEAN**	**STD**
	fi	**%**	**Fi**	**%**	**fi**	**%**	**fi**	**%**	**fi**	**%**		
The buildings have a low energy use intensity	5	4.7	5	4.67	4	3.7	29	27.1	64	59.8	4.33	1.07
The buildings have low Water Use Intensity	4	3.7	2	1.87	12	11.2	26	24.3	63	58.9	4.33	1.01
I am satisfied with the functionality of the building	7	6.5	4	3.74	4	3.7	12	11.2	80	74.8	4.44	1.16
The building is safe, adaptable, and Resilience	6	5.6	6	5.61	6	5.6	23	21.5	66	61.7	4.28	1.16
Adequate Indoor Environmental Quality (Air quality, Thermal Comfort, Lighting Quality, Acoustic Comfort)	9	8.4	9	8.41	3	2.8	19	17.8	67	62.6	4.18	1.32
Overview											**4.31**	

Source: Primary data, 2024

The findings on the performance of green buildings in the Green Gicumbi Project highlight key aspects of sustainability and functionality achieved by the project. The assessment, covering metrics such as energy use, water use, functionality, safety, adaptability, resilience, and indoor environmental quality, provides a comprehensive view of how these buildings meet their intended green standards. A significant finding is that the buildings have low energy use intensity, with 59.8% of respondents strongly agreeing and 27.1% agreeing, resulting in a mean score of 4.33 and a standard deviation of 1.07. This suggests that energy-saving measures, possibly including efficient lighting and HVAC systems, have effectively reduced energy consumption in these green buildings, contributing to environmental goals and cost savings over time. The assessment of water use intensity also reflects positively on the project's performance. With 58.9% of respondents strongly agreeing and 24.3% agreeing, the mean score again stood at 4.33, with a standard deviation of 1.01. These results indicate the success of water-efficient systems, such as low-flow fixtures and potentially greywater recycling, in significantly reducing water usage. This is essential in enhancing resource conservation and supporting sustainable water management practices in the district.

User satisfaction with the buildings' functionality is notably high, with 74.8% of respondents strongly agreeing and another 11.2% agreeing, leading to the highest mean score of 4.44 and a standard deviation of 1.16. This satisfaction suggests that the buildings meet users' needs effectively, demonstrating that sustainable designs can still fulfill functional requirements while adhering to green standards. This level of satisfaction is a positive indicator of the building's success in achieving both sustainability and usability. In terms of safety, adaptability, and resilience, 61.7% of respondents strongly agreed that the buildings offer these qualities, while 21.5% agreed, resulting in a mean score of 4.28 and a standard deviation of 1.16. This reflects the importance of resilient design in green buildings, as it enables these structures to better withstand environmental stresses and maintain safe conditions for users. Lastly, the indoor environmental quality, which includes air quality, thermal comfort, lighting, and acoustic comfort, was assessed. Here, 62.6% of respondents strongly agreed and 17.8% agreed on the adequacy of these aspects, resulting in a mean score of 4.18 and a slightly higher standard deviation of 1.32. These findings suggest a moderate level of success in meeting indoor environmental standards, although there may be areas for improvement, especially in consistently providing optimal thermal and acoustic comfort. Overall, the study found an average mean score of 4.31, corresponding to 86%, indicating a high level of performance for the green buildings in the Gicumbi Project. This assessment demonstrates that the project has successfully implemented green building practices that meet sustainability objectives while also delivering functionality and user satisfaction, establishing a strong foundation for future green initiatives in the region.

3.3. Relationship between the green technologies and infrastructure performance of the green buildings project in the Gicumbi district

This section describes the results of the relationship between the independent variables and the dependent variables and shows the influence of the independent variables on the dependent variable.

3.3.1. Multiple linear regression analysis

Multiple linear regression analysis was used to determine whether resource-efficient design, Low-emission materials, and waste management have a significant contribution to the performance of Green Buildings Constructed in the Green Gicumbi Project. The regression models were run to test whether the model was significant or not. The statistical significance was verified by the t-statistic. In addition, statistically significant relationships between the dependent variable and the independent variable from the model were accepted at a 5% significance level. Based on the model summary, the coefficient of determination (R-squared) shows the overall measure of the strength of association between independent and dependent variables.

Table 3.5: Model Summary

Summary output	Results
Multiple R	0.816867
R Square	0.667977
Adjusted R Square	0.650186
Standard Error	0.251995
Observations	107

a. Predictors: (Constant), resource-efficient design, Low-emission materials, waste management

Source: Primary data, 2024.

Findings in Table 3.5 indicate the overall contribution of the independent variables (resource-efficient design, low-emission materials, and waste management) on the dependent variables through the value of R^2 as well as the value of adjusted R^2. However, with the value of adjusted R^2, the study showed that 0.650186 (65.0%) of the performance of green buildings constructed in the green Gicumbi project is influenced by resource-efficient design, Low-emission materials, and waste management.

Table 3.6: ANOVA

	df	Sum of Squares	Mean Square	F	P-value
Regression	3	12.04535	2.408182	36.7915	0.000[b]
Residual	106	5.956724	0.062952		
Total	**109**	**18.00319**			

a. Dependent Variable: Performance of Green Buildings Constructed in the Green Gicumbi Project

b. Predictors: (Constant), Resource-efficient design, Low-emission materials, Waste management

Source: Primary data, 2024

The findings in Table 3.6 indicate that the overall model was significant with a p-value equivalent to 0.000, which is less than the critical p-value equal to 0.05 level of significance. Therefore, this implies that the combined effort of green technologies such as resource-efficient design, Low-emission materials, and waste management was statistically significant on the Performance of Green Buildings Constructed in the Green Gicumbi Project. This implies that there was a goodness of fit of the model fitted for this study. The study concluded that the null hypothesis stated that there is no significant relationship between the Green Technologies and the performance of Green Buildings Constructed in the Green Gicumbi Project, was rejected due to a p-value of 0.000, which is less than the acceptance critical value of 0.05. Hence, there is a significant relationship between the Green Technologies and the performance of Green Buildings constructed in the Green Gicumbi Project.

Table 3.7: Regression coefficients

	Coefficients	Standard Error	t Stat	P-value
Intercept	1.047	0.284	3.68	0
RED	0.152	0.083	8.041	0.007
LEM	0.14	0.105	4.558	0.019
WM	**0.178**	**0.131**	**4.674**	**0.018**

a. Dependent Variable: Performance of Green Buildings Constructed in the Green Gicumbi Project.

From the research findings, the following values were obtained: β_0 =1.047, β_1=0.152, β_2=0.14, β_3=0.178.

The regression model can therefore be expressed as follows:

PGCGP = 1.047+0.152RED +0.14LEM +0.178WM

The regression equation above has been established taking all factors into account (resource-efficient design, Low-emission materials, waste management), constant at zero, with a Performance of Green Buildings Project equal to 1.047

The regression results revealed that resources efficient design has a significant positive influence on the Performance of green buildings constructed in the green Gicumbi project as indicated by β_1= 0.152, p-value=0.007<0.05, This implies that taking all other independent variables at zero, a unit increase in resources efficient design would lead to 0.152 increase in the Performance of green buildings constructed in green Gicumbi project. Therefore, the study rejected the null hypothesis that stated that there is no significant influence of resource-efficient design on the performance of green buildings constructed in the green Gicumbi project. The regression results revealed that Low-emission materials have a significant positive influence on the performance of green buildings constructed in the green Gicumbi Project, as indicated by β_2= 0.14, p-value=0.019<0.05. This implies that taking all other independent variables at zero, a unit increase in Low-emission materials would lead to a 0.14 increase in the performance of green buildings constructed in the green Gicumbi project. Therefore, the study rejected the null hypothesis that stated that there is no significant influence of Low-emission materials on the Performance of Green Buildings Constructed in the Green Gicumbi Project.

The regression results revealed that waste management has a significant positive influence on the performance of green buildings constructed in the green Gicumbi project, as indicated by β_3= 0.178, p-value=0.018<0.05. This implies that taking all other independent variables at zero, a unit increase in waste management would lead to a 0.178 increase in the performance of green buildings constructed in the green Gicumbi project. Therefore, the study rejected the null hypothesis that stated that there is no significant influence of waste management on the performance of green buildings constructed in the green Gicumbi project.

3.4. Discussion of findings

The findings of this study showed the significant positive influence of various green technologies on the performance of the green building project in the Gicumbi district. These results hold important implications for policymakers, urban planners, and building professionals in Rwanda and other developing nations. The observed relationship between resource-efficient design and enhanced building performance emphasizes the critical role that sustainable design principles play in improving the environmental and operational efficiency of infrastructure (Smith & Patel, 2018). By strategically incorporating resource-conserving strategies into the construction and operation of buildings, developers and architects can unlock tangible benefits in terms of reduced energy and water consumption, lower greenhouse gas emissions, and improved overall performance. These insights can inform the development of green building guidelines and standards to drive the widespread adoption of resource-efficient design practices.

Similarly, the positive influence of low-emission construction materials on building performance highlights the importance of material selection in sustainable construction (Thompson & Zhang, 2020). The use of environmentally friendly, low-impact materials not only reduces the carbon footprint of the building itself but also contributes to improved indoor air quality and occupant well-being. Policymakers and regulatory bodies should consider incentivizing or mandating the use of such materials in infrastructure projects to promote a more circular and resource-conscious built environment.

The findings regarding the significance of effective waste management practices on building performance underscore the need for a holistic approach to sustainable development (Building Council, 2021). Robust waste management systems, including on-site waste segregation, recycling, and disposal, are crucial for minimizing the environmental impact of construction activities and ensuring the long-term viability of green buildings. Urban planners and development authorities should prioritize the integration of comprehensive waste management strategies into infrastructure projects to support the overall sustainability of the built environment.

These research findings provide valuable insights that can inform policy decisions, urban planning initiatives, and building industry practices in Rwanda and other developing countries. By leveraging the synergistic benefits of resource-efficient design, low-emission materials, and effective waste management, stakeholders can drive the widespread adoption of green building technologies and unlock significant environmental, economic, and social benefits for local communities. Expanding the scope of this study to include additional case studies or a larger sample size could also provide valuable insights into the scalability and replicability of the observed findings across different regions and contexts.

IV. CONCLUSION

This study provided valuable insights into the role of green technologies in enhancing the performance of infrastructure projects in the context of Rwanda focusing on the green buildings project in Gicumbi district. The study adopted a descriptive research design considering 171 residents of the constructed green buildings. The findings reveal that the strategic integration of resource-efficient design, low-emission construction materials, and effective waste management practices into the Green Buildings Project has led to significant improvements in the infrastructure's environmental and operational performance. Specifically, the use of renewable energy, water conservation measures, and energy-efficient systems has resulted in substantial reductions in energy consumption and water usage, while also contributing to enhanced indoor environmental quality and occupant well-being.

The positive correlations observed between the implementation of these green technologies and the enhanced performance of the green buildings underscore the critical role that sustainability-focused interventions can play in addressing the challenges faced by the built environment in developing countries. By embracing holistic approaches to green building design and construction, the Green Buildings Project has demonstrated the potential for tangible benefits in terms of resource conservation, environmental impact reduction, and overall infrastructure performance. These research findings hold important implications for policymakers, urban planners, and building professionals in Rwanda and other developing nations. They emphasize the need to prioritize the integration of green technologies into infrastructure projects as a key strategy for driving sustainable development and promoting environmental stewardship within the built environment. The successful implementation of the green buildings project in the Gicumbi district can serve as a model for the replication and scaling up of similar initiatives across the region.

As the global community continues to grapple with the pressing challenges of climate change, resource scarcity, and urban development, the insights gained from this study contribute to a growing body of knowledge on the transformative potential of green technologies in infrastructure projects. The findings presented here provide a strong foundation for future research and practical applications aimed at further advancing the sustainability and resilience of the built environment in developing countries.

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