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DEPARTMENT OF CIVIL ENGINEERING

OPTION OF CONSTRUCTION TECHNOLOGY

EXPLORING GREEN BUILDING TECHNOLOGY FOR GREENEER TOMORROW

CASE STUDY: KIGALI /RWANDA

Submitted in partial Fulfilment of the requirements for the award of Advanced diploma in Construction technology

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Under the guidance of

Eng. RUKUNDO Emmanuel

Kigali, October 2024

DECLARATION

I hereby declare that the present work, **Exploring green building technology for greener tomorrow** is my research. I understand the nature of plagiarism and I am aware of the university policy on this. The work provided in this project, unless otherwise referenced, is the research of my own work and has been not submitted by others elsewhere for any other degree of qualification.

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Signature………………………….

CERTIFICATE

This research project entitled **Exploring green building technology for greener tomorrow** prepared by NSHIMIYIMANA IMFURA Henry Steven in partial fulfilment of the requirements for award of advanced diploma (A1) in civil engineering /construction technology has been examined and approved by

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DEDICATION

I dedicate this final year project to:

- To my Almighty God
- To my parents
- To my lecturers
- To my friends
- To my classmates
- To all who helped me to complete this project
- To my supervisor: Eng. Emmanuel RUKUNDO

ACKNOWLEDGEMENTS

To write a project, many people must be involved, whose titles are not disclosed on the book's cover but who are real, important contributors to the process. This final year effort, though, could never have achieved recognition without their support and guidance.

That is why I would like to express my gratitude to every member of the ULK Polytechnic. Especially thanks go to the Department of Civil Engineering for this finished project. Without my supervisor, Eng. Emmanuel RUKUNDO, this project would not have been accomplished. I sincerely appreciate their friendly and helpful assistance.

Additionally, I would like to extend my sincere gratitude to all the lecturers and board members who did their utmost to assist me in providing students studying construction technology with my comprehensive intellectual baggage. I am appreciative to my family, friends, and other special supporters for helping me with my education all the way from the beginning to this point.

ABSTRACT

This project, titled "**Exploring Green Building Technology for a Greener Tomorrow"** addresses the environmental challenges posed by traditional construction methods, which often result in high energy consumption, waste generation, and resource depletion. The research explores green building technologies such as energy-efficient systems, rainwater harvesting, and the use of recycled materials like steel, glass, and plastic to promote sustainable construction practices.

A case study from Kigali, Rwanda, is presented to demonstrate the real-world application of these technologies. The research methodology involved data collection through surveys, interviews with construction professionals, and performance tests comparing green and conventional buildings. The study aimed to assess the impact of green building technologies on reducing waste, lowering energy consumption, and conserving natural resources. Results showed that water consumption was reduced by 30%, power usage by 40%, and solar energy systems provided up to 25% energy savings. Additionally, improvements in natural lighting and air ventilation resulted in a 20% and 15% enhancement in indoor environmental quality, respectively.

The findings reveal that green building technologies significantly reduce the environmental impact of construction while offering cost-saving benefits. However, challenges such as higher initial costs and the need for increased awareness among stakeholders persist. The study concludes that adopting these technologies is essential for a sustainable future in construction and recommends further research to explore their long-term benefits and incorporation into Rwanda's construction policies.

Keywords: Green building technology, Sustainable construction, Energy efficiency, Water efficiency, Recycled materials, Solar energy systems, Rainwater harvesting, Natural lighting, Indoor air quality, Conventional building

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LIST OF ABBREVIATIONS

%: Percentage

BIPV - Building-Integrated Photovoltaics

BREEAM - Building Research Establishment Environmental Assessment Method

EE - Energy Efficiency

EEP - Energy Efficiency Percentage

EMS - Environmental Management System

EPD - Environmental Product Declaration

GB - Green Building - Green Building Technology

GBC - Green Building Council

GHG - Greenhouse Gas

HVAC - Heating, Ventilation, and Air Conditioning

IAQ - Indoor Air Quality

LCA - Life Cycle Assessment

LED - Light Emitting Diode (for energy-efficient lighting)

LEED - Leadership in Energy and Environmental Design

NZEB - Net Zero Energy Building

PV - Photovoltaic (for solar panels)

RWH - Rainwater Harvesting

ULK: Kigali Independent University

VOC - Volatile Organic Compounds

WEP - Water Efficiency Percentage

WMS - Waste Management System

LIST OF APPENDICES

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Background of study

Construction has been a fundamental human activity since ancient times, evolving from simple shelters to complex structures. Early construction relied on natural materials like wood, stone, and clay. As civilizations advanced, so did building techniques, leading to the development of concrete, steel, and glass. (Ching, F. D. K. (2014)

Using construction materials like steel, concrete, and glass has significant environmental impacts, including high energy consumption, CO2 emissions, and resource depletion. Green building technology mitigates these effects by incorporating recycled materials, enhancing energy efficiency, and adopting sustainable practices. This approach helps create more environmentally friendly and sustainable buildings.

Green building technology began as a response to the increasing awareness of the environmental and health impacts of traditional building practices. In the 1970s, during the global energy crisis, there was a significant push towards energy conservation and efficiency in buildings.

Green building technology in Africa began as a response to the continent's unique environmental challenges, including water scarcity, energy shortages, and the effects of climate change, as well as the construction industry's impact on the environment. Influenced by global trends and sustainability frameworks, several African countries developed policies and launched pilot projects to demonstrate the benefits of green building. (Wilkinson, S., & Schulte, K. W. (2009)

In 2017, Rwanda Housing Authority in collaboration with the Global Green Growth Institute, the Building Construction Authority (BCA) of Singapore, Rwanda Green Building Organization (RwGBO), and other stakeholders, initiated the development of the Green Building Minimum Compliance System (GBMCS).

Green building technology in Rwanda aims to create sustainable, energy-efficient, and environmentally friendly buildings to address local environmental challenges, such as deforestation and water scarcity. It promotes the use of renewable energy, water conservation, and sustainable materials, leading to lower operational costs, improved health, and increased climate resilience.

1.1 Problem statement

Despite the urgent need for sustainable development, the construction industry in many developing countries, including Rwanda, continues to rely heavily on traditional building practices that are resource-intensive and environmentally damaging. This results in high energy consumption, significant carbon emissions, and substantial waste generation, which exacerbate climate change and deplete natural resources. (Belloni, K. (2011)

There is a critical need to explore and implement green building technologies that can mitigate these environmental impacts by promoting energy efficiency, resource conservation, and the use of sustainable materials. This project aims to address these challenges by investigating the potential of green building technology to create a more sustainable and resilient built environment in Rwanda, providing practical solutions for a greener tomorrow.

In Rwanda, the adoption of green building technology remains limited despite the country's commitment to sustainable development and environmental conservation. The construction industry predominantly uses conventional building methods, which lead to high energy consumption, significant greenhouse gas emissions, and extensive resource depletion.

This lack of widespread implementation of green building practices results in buildings that are not energy-efficient or environmentally friendly, exacerbating the nation's environmental challenges such as deforestation, water scarcity, and climate change. (Ahmed, V. (2014)

This project aims to explore the barriers to the adoption of green building technology in Rwanda and propose viable solutions to promote sustainable construction practices, ultimately contributing to a greener and more resilient built environment.

1.3 Objectives of the

1.3.1 Main objective

The project aims to identify and evaluate effective green building technologies to reduce energy consumption, waste, and carbon emissions while ensuring economic feasibility and integration into existing practices.

1.3.2 Specific objectives

- Conduct cost-benefit analyses to determine the financial implications and long-term benefits of green building technologies.
- Identify challenges to the widespread adoption of green building technologies and propose solutions.
- Investigate the use of recycled and low-impact materials in construction projects.
- Evaluate strategies to enhance water efficiency and improve indoor environmental quality in green building projects

1.4 Research question

- What are the cost implications and economic benefits of implementing green building technologies?
- How do these technologies impact energy consumption, waste production, and carbon emissions?
- Which sustainable materials are most viable for use in construction, and what are their benefits?
- How can water-saving technologies and design innovations be effectively implemented in buildings to improve indoor environmental quality and occupant health

1.5 Scope and limitation of the study

this project aims to explore the potential of green building technologies to contribute to a sustainable and environmentally friendly construction industry in Rwanda. Key areas of investigation include energy efficiency, renewable energy integration, sustainable materials, water efficiency, and indoor environmental quality.

This study is limited by the availability of data on green building technology in Rwanda, particularly in terms of local implementation and cost analysis. Additionally, the research faced constraints in accessing advanced performance metrics for long-term environmental benefits due to the relatively recent adoption of these technologies

1.6 Significance of the study

This project is important to different members of societies.

1.6.1 Personal significance

This project provides an opportunity to gain practical knowledge and skills about green building technology.

It prepares me to be a leader in sustainable engineering, capable of addressing the challenges of climate change and resource depletion.

1.6.2 Society's significance

- Protects the Environment: By reducing pollution and conserving natural resources, green building technology helps minimize the environmental impact of construction.
- Fights climate Change: Green buildings use energy more efficiently, reducing the carbon footprint and making structures more resilient to extreme weather events like storms and heatwaves, which are worsened by climate change.
- Improves Quality of Life: Green buildings provide healthier indoor environments with cleaner air, better ventilation, and natural lighting, creating more comfortable and productive spaces for people to live and work in.
- The adoption of green building technologies creates new jobs in construction, design, and manufacturing, while also helping businesses save on energy costs, leading to economic growth and new investment opportunities

1.6.3 Academic significance

This document will be published in ULK library and serve as reference for further reading to students pursuing their studies, and any other that could benefit their uses in construction field.

1.7 Organization of the study

This research will be divided into five main chapters to provide information about exploring green building technology for greener tomorrow.

CHAPTER 1: General Introduction

This chapter deals with the introduction, problem statement, research objectives, research questions, scope of the research, significance of the research, and finally, the organization of the study.

CHAPTER 2: Literature Review

This chapter provides all the details and theories concerning the green building its history, component of green building and benefits with challenges and barriers and materials used in green buildings.

CHAPTER 3: Research data and analysis procedure

This chapter discusses the methods and procedures used, defines the instruments employed in the investigation, and describes the techniques used to collect all the necessary data.

CHAPTER 4: Results and Discussions

This chapter presents the analysis and interpretation of the findings.

CHAPTER 5: Conclusion and Recommendations

This final chapter presents the conclusions and recommendations, summarizing the outcomes of the research.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This literature review begins with briefly description on evolutions of sustainable construction when it started from 1990 after we see the emergencies of green certification system, we go through components of green building like energy efficiency, water efficiency, and sustainable materials and resources after we discussed about benefits and challenges of green building, we concluded by eco-friendly materials used in sustainable construction.

2.1 Evolution of sustainable construction practice

The history of green building from 1990 to 2024 represents a remarkable journey towards sustainability, marked by key milestones, technological advancements, and shifting global priorities. This essay explores the significant developments year by year, highlighting how green building has evolved from a nascent concept into a critical component of modern construction practices. Kibert, C. J. (2016).

1990-1999: Early Foundations

In the early 1990s, awareness began to grow among architects, engineers, and environmentalists regarding the environmental impact of buildings. The recognition of resource depletion, energy inefficiency, and pollution spurred discussions on sustainable construction practices. This period laid the groundwork for the emergence of the modern green building movement, setting the stage for future advancements. Smith, J. (2010)

1993: Formation of USGBC

A pivotal moment in the history of green building occurred with the establishment of the U.S. Green Building Council (USGBC) in 1993. Founded to promote sustainability in building design, construction, and operation, USGBC provided a framework for developing standards and certifications that would define green building practices globally. (U.S. Green Building Council. (2018)

1998: Introduction of LEED

The launch of the Leadership in Energy and Environmental Design (LEED) rating system by USGBC in 1998 marked a significant milestone. LEED provided a comprehensive framework for assessing the sustainability of buildings based on criteria such as energy efficiency, water conservation, indoor environmental quality, and materials selection. This introduction laid the foundation for a standardized approach to green building certification. Yudelson, J. (2008)

2000-2009: Expansion and Recognition

During the early 2000s, LEED certification gained international recognition, influencing sustainable building practices beyond the United States. Governments worldwide began to recognize the importance of sustainable construction and started offering incentives, tax credits, and subsidies to promote green building projects. This decade saw a gradual shift towards mainstream adoption as more developers and corporations embraced sustainable building initiatives. Cole, R. J., & Larsson, S. (2016)

2010-2019: Mainstream Adoption and Policy Influence

The 2010s marked a significant acceleration in the adoption of green building practices. Sustainability became a central consideration in building design and construction, driven by economic incentives, regulatory requirements, and growing societal awareness of environmental issues. LEED underwent several updates during this period, with versions like LEED Version 4 (2013) and LEED Version 4.1 (2018) focusing on performance-based outcomes, lifecycle assessment of building materials, and enhanced sustainability criteria.

The adoption of the Paris Agreement in 2015 further underscored global commitments to reducing greenhouse gas emissions and combating climate change. This landmark agreement influenced green building policies worldwide, reinforcing the integration of energy-efficient technologies, renewable energy sources, and resilient design principles in building projects. (U.S. Green Building Council. (2018)

2020-2024: Challenges and Innovations

The year 2020 brought unprecedented challenges with the COVID-19 pandemic, highlighting the importance of indoor air quality, health-focused design, and flexible building layouts in green buildings. The pandemic accelerated trends towards healthier indoor environments, adaptive reuse of spaces, and the integration of smart technologies for monitoring and controlling building operations.

Looking towards 2024 and beyond, green buildings continue to evolve with advancements in sustainable materials, resilient design practices, and efforts towards achieving carbon neutrality. Emerging technologies such as digital innovations, artificial intelligence (AI), and the Internet of Things (IoT) are enhancing building performance and energy efficiency, further driving the adoption of green building practices globally (U.S. Green Building Council. (2021)

In Rwanda Green Building Organization (RWGBO) was established and officially launched in November 2016, in partnership between Rwanda Institute of Architects and Rwanda Housing Authority. It will function as the catalyst of change for sustainability of buildings and communities in the country.

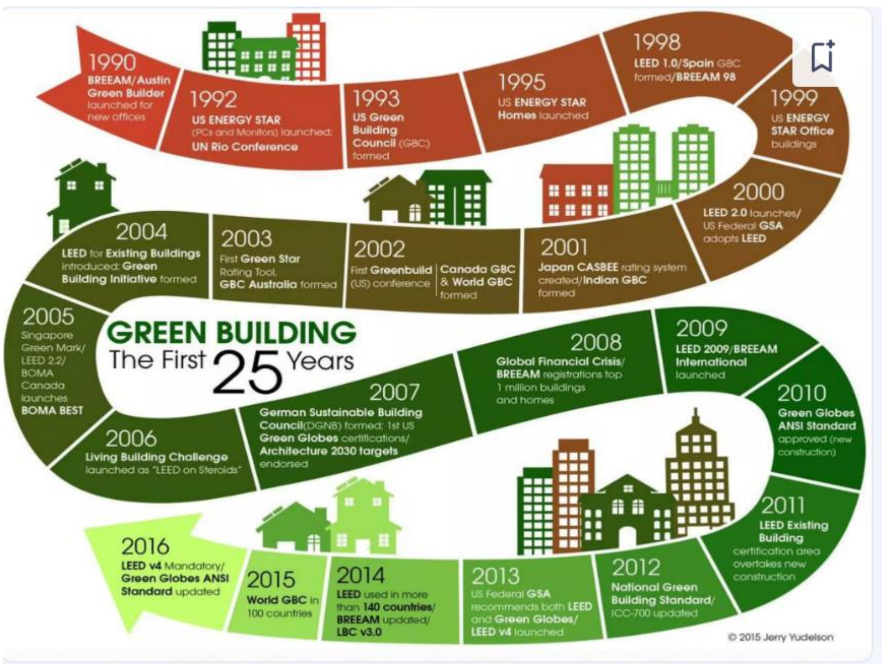

Figure 2. 1 Green building history

2.2 Emergence of green building certification systems

There are many programs available for green building certification. Some are worldwide and others are only available in certain countries. Not all programs will work for all buildings or projects. The design team will need to look at each program carefully to determine what is best for the project.

Figure 2. 2 Green building certifications

- **LEED**

program is administered by the Green Building Certification Institute. It has been around for about 20 years and has been a big part of the market shift that has made green building as popular as it is today. Certification is available for many types of projects, including homes, existing buildings, new construction, retail and core and shell projects. Levels of certification range from certified to platinum

LEED CERTIFICATION LEVELS

Figure 2. 3 Leed certification levels

- **Energy Star**

is offered through the Department of Energy and the Environmental Protection Agency (EPA). To qualify, buildings must be at least 15% more energy efficient than traditional construction. Certification lasts for one year.

- **BREEAM**

is an international program for sustainable buildings and infrastructure projects. It includes new construction, existing buildings, and refurbishment projects.

- **Green Globes**

is offered through the Green Building Initiative and consists of three categories: new construction, existing buildings, and interiors. The process includes an online survey, a third-party site assessment, and a post assessment.

- **Living Building Challenge**

is a certification program based on a building's performance over a twelve-month period. It includes certification of the building's materials and construction methods. Once the data has been submitted, projects are subject to an audit to confirm their certification.

National Green Building Standard

The National Green Building Standard comes from the National Association of Home Builders and is for residential properties only. Certifiable projects include single family homes, multi-family projects, and mixed-use developments. It has several levels of certification, ranging from Bronze to Emerald. All scores are validated, and an independent inspection is performed once the project is complete.

- **WELL Building Standard**

focuses on the overall impact of buildings on health and wellbeing and focuses on seven core concepts. It was awarded by the International WELL Building Institute. Here are the seven core concepts of the WELL Building Standard:

- Air
- Nourishment
- Light:
- Fitness
- Comfort
- Mind

2.3 Component of green building

According to Environmental Protection Agency (EPA). There is main 7 aspects on which green buildings are judged to measure their sustainability. Being environmentally friendly with your building project can happen in many ways. Same obvious like saving energy, while others focus more than on human aspect such as maintaining good air quality.

2.3.1 Energy efficiency& Renewable energy

When people think of "green" buildings, they often think of energy first. Creating an energy-efficient building begins during design and can be interpreted in many ways. Green building design reduces energy consumption by using lightweight materials like bamboo, cool roofs to lower cooling demands, natural lighting, green roofs, and high-grade insulation. Energy-efficient windows and renewable energy sources like solar, wind, hydropower, geothermal, and biomass further enhance sustainability and efficiency.

2.3.2 Water efficiency

Water efficiency is just as important as energy efficiency. And just like energy efficiency, conserving water can happen anywhere from the construction process to the way the completed structure uses water (especially in landscaping).

During the construction phase, green buildings conserve water by minimizing evaporation, using brooms instead of hoses, and implementing efficient irrigation and rainwater harvesting systems. Post-construction, water efficiency focuses on installing water-saving appliances, low-flow fixtures, drip irrigation, drought-resistant landscaping, and utilizing rainwater and greywater for non-potable uses.

2.3.3 Waste reduction

Reducing waste to make a building greener doesn't necessarily have to do with any "waste" produced within the building during occupancy. Rather, it has to do with the waste generated during the construction process or even future demolition. This aspect of sustainability can also include reducing waste and pollution from landscaping and even emissions from heavy machines needed for building.

To reduce waste in green buildings, use sustainable materials like earth bags or prefabricated components, and promote onsite recycling through source separation. Modular construction also minimizes waste and emissions during the construction phase.

2.3.4. Environmentally Preferable Building Materials & Specifications

Of course, a green building wouldn't be anything without the green building materials used. Luckily, there are dozens of choices for sustainable materials! Building recycled steel or even an existing item like a shipping container can reduce the need for reprocessing of the steel, saving energy and reducing emissions. You can even build green with something as crazy as tire bales.

Other Examples of green building materials include bamboo, cork, and wool. Additionally, wood obtained from certified sustainable forests is also suitable for a green building project.

2.3.5 Toxic reduction

Reducing toxins within a structure can happen in a variety of ways. From the chemicals used to make indoor furnishings flame retardant to the glues and finishes used on building materials, many traditionally toxic items can be replaced with greener options.

Using DfE-certified products in construction reduces toxins and ensures good indoor air quality by focusing on human health, environmental safety, and ingredient safety. Examples include using mercury-free lighting, formaldehyde-free cabinetry, and low VOC paint, alongside proper mechanical ventilation systems.

2.3.6 indoor air quality

The chemicals used in older, traditional building methods can leech out of the finished structure and affect air quality. If bad enough, this can lead occupants to develop "sick building syndrome." Sustainable materials such as bamboo are great for air quality because they absorb ⅔ more CO_2 and produce 30% more O_2 than regular wood.

Besides using sustainable materials like bamboo, air filtration, ventilation, and moisture control can be used to achieve the following: Protect occupant health, promote comfort and productivity, Enhance the house's durability.

2.3.7 smart growth and sustainable development

It isn't enough to just *be* a green building. Sustainable buildings will continue to develop their sustainability and environmental impact over time. This could include dealing with storm water runoff or even occupant waste in a new, sustainable way. Green buildings will need to adapt over time to changing and ever tightening regulations.

The EPA's smart growth program advocates for sustainable communities, smart transportation, and location efficiency by situating buildings within or near existing communities. This approach improves air quality, conserves energy, promotes efficient land use, and enhances public health.

2.4 Benefit of green building technology

Green building technology offers numerous benefits, extending beyond environmental protection to include economic, social, and health advantages.

- **Environmental Benefits**

Green buildings lower greenhouse gas emissions through energy-efficient designs and renewable energy. They conserve resources by using sustainable materials and reducing water and energy consumption. Additionally, green roofs and urban spaces support local biodiversity and improve ecosystems.

- **Economic Benefits**

Green buildings reduce energy and water bills through efficient technologies, increasing long-term savings. They also boost property value and attract higher rents due to growing demand for sustainability. Additionally, lower operating and maintenance costs contribute to overall financial benefits.

- **Social Benefits**

Green buildings enhance occupant health through improved air quality, natural lighting, and comfort, boosting productivity and well-being. They promote community engagement by incorporating shared spaces and foster social equity by providing affordable, sustainable housing.

- **Health Benefits**

Green buildings improve indoor air quality with low-emitting materials and better ventilation, reducing health risks. They incorporate natural lighting and biophilic design to boost mental well-being and reduce stress. Additionally, efficient insulation and climate control enhance overall comfort for occupants.

- **Resilience and Adaptability**

Green buildings enhance climate resilience with flood-resistant materials and stormwater management, helping them withstand extreme weather. They also futureproof by incorporating adaptable designs that can evolve with technological advancements and changing needs, ensuring long-term sustainability.

- **Innovation and Economic Growth**

Green buildings stimulate innovation by driving advancements in sustainable materials, technologies, and design. They also create jobs across various sectors, from construction and design to the manufacturing and maintenance of green technologies.

2.5 Challenges and barriers of green building technology

Despite the numerous benefits of green building technology, several challenges and barriers can hinder its widespread adoption and implementation. Understanding these obstacles is crucial for developing strategies to overcome them and promote sustainable construction practices. Key challenges and barriers include:

- **High Initial Costs**

Green building technologies typically involve higher upfront investments due to costs for sustainable materials and energy-efficient systems, which can deter developers. Additionally, perceived financial risks regarding ROI and long-term performance may restrict access to funding for these projects.

- **Lack of Awareness and Education**

Limited awareness among developers, architects, and contractors about the benefits of green building technologies can create resistance to sustainable practices. Additionally, a lack of training programs in the construction industry contributes to a shortage of skilled professionals who can effectively implement and maintain these practices.

- **Regulatory and Policy Barriers**

Different regions often have confusing and inconsistent green building rules, making it hard to adopt sustainable practices. Plus, getting permits for green building projects can be complicated and take a long time, which leads to delays and higher costs.

- **Technological and Technical Challenges**

Using advanced green building technologies, like smart systems and renewable energy, can be technically difficult, requiring careful planning and expert knowledge for them to work well together. Additionally, worries about the long-term performance and reliability of these new technologies, including issues with maintenance and effectiveness, can discourage their use.

- **Market and Economic Barriers**

The demand for green buildings can be low if buyers and renters aren’t willing to pay more for eco-friendly features, making developers less likely to invest. Also, incentives like tax credits and grants can help encourage green building, but without these, there’s less reason to choose sustainable options.

2.6 Materials designer or conceptional demand used in green building technology.

Using green building materials is a crucial step towards sustainable development and creating a greener future. They not only conserve natural resources but also promote healthier living environments and reduce overall construction costs through improved efficiency and durability.

These materials have little to no negative impact on the environment during production and use. Here are some examples of green building materials.

- **Recycled steel**

Recycled steel is a type of material that doesn't lose its properties when recycled. As you know that steel is the most recycled material in the world. More steel is recycled each year than plastic, paper, aluminum and glass all combined.

Using recycled steel in the building process, you know for a fact that is will be strong and durable. It's a massive saver in energy costs too.

Steel as scrap

Figure 2. 4 Steel scrap

- **Bamboo**

Bamboo is a type of plant that grows back quickly within only 3-5 years. It is 100% biodegradable, antibacterial and Eco-friendly if not chemically processed. Having said that, bamboo makes a perfect choice in the construction world. Bamboo has high strength because of its fibers running

Figure 2. 5 Bamboo

- **Clay brick**

Clay brick is a natural material made from water and clay from the earth. It is entirely recyclable, entirely Earth-friendly, and it doesn't release any toxic chemicals when in the landfill.

Clay brick is an energy-efficient material. In the summer, it keeps a house cooler, and in the winter traps the warmth for a more extended period.

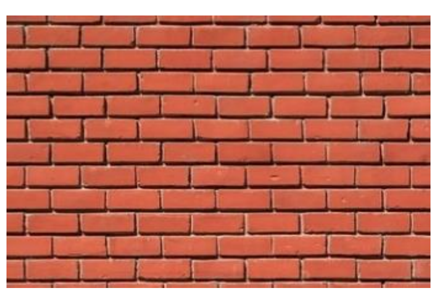

Figure 2.6 Clay Brick

- **Timber Crete**

Timber Crete is an Eco-friendly building material made of sawdust and concrete mixed together. The sawdust replaces components within the concrete that are most energy-intensive to produce - which makes timber Crete a green material. It is lighter than concrete or clay, and therefore much easier for transport. Timber Crete can be used in the form of blocks, bricks and pavers.

A better insulator than brick, clay or concrete, highly fire-resistant, very long-lasting

Figure 2. 6 Timber Crete

- **straw bales**

The straw material is also typically sourced from farmers who are burning off their straw after harvest. Rather than have the straw release its embodied carbon back into the atmosphere when destroyed, which contributes to increasing carbon emissions, repurposing this waste by-product into compressed ceiling and wall panels instead ensures that it retains its carbon content in the most eco-friendly way possible.

Figure 2. 7 Straw bales

Reclaimed, Recycled and sustainable wood.

Probably one the most used type of building material and for a reason. It is aesthetically pleasing, easy to use, and it feels like nature indoors. Reclaimed or recycled wood has a much lower environmental impact than harvesting new timber.

Being surrounded by a natural material like wood, it significantly increases overall wellbeing.

Figure 2. 8 woods after use

Precast concrete

While concrete tends to be a factor in CO2 emissions created at construction sites, it is still a much-needed material. That’s where precast concrete comes to play. Precast concrete is factory-made in exact measurements and then shipped to the construction site.

Figure 2. 9 Precast concrete

Recycled plastic

In 2021, the total world population created 139 million tons of single-use plastic with most of it ending up in landfills or polluting waterways. With new advancements in construction and technology, we can now recycle plastic to create building materials, such as plastic sheets, bricks and lumber.

Recycled plastic is a durable and robust material, great at sound retaining. Creating this green circle in using what we already have will significantly reduce the waste in the long run.

Figure 2. 10 Recycled plastic house.

- **Plant-Based Polyurethane Rigid Foam**

Plant-based polyurethane rigid foam uses a mixture of bamboo, hemp and kelp that is great wall insulation. This improved rigid is also good for furniture and even surfboards.

It's excellent at protecting against mould and pests, as well as sound insulation and heat resistance.

Figure 2. 11 Plant based polyurethan rigid foam.

- **Cob**

Cob is a mud mixture made from natural materials such as soil, straw, sand and lime. Cob most frequently appears in the construction of residential buildings or as a replacement for concrete structures. Making of cob is inexpensive and produces less CO_2 than producing concrete.

Figure 2. 12 Cob

- sheep’s wool

  Sheep's wool is entirely natural and eco-friendly material that can be regrown quickly. Wool is best known for being used for cosy warm blankets and sweaters. But it also plays a role as an outstanding home insulator - with its fibers forming millions of tiny air pockets that trap air. Usually, you can see wool incorporated in the ceiling, walls or attics.

Figure 2. 13 sheep's wool

- Hempcrete

  Hempcrete is a mixture of sand, hemp fibers and lime. It is typically used for construction and insulation. Blocks made of hempcrete are super-lightweight and easy to work with.

Figure 2. 14 Hempcrete

CHAPTER THREE: MATERIALS AND METHODS

3.0 Introduction

This chapter outlines the methods and procedures used in collecting and analyzing data for the research study on exploring green building technology for a greener tomorrow. The chapter discusses the research design, population, sample size, sampling procedure, research instrument data gathering procedure, data analysis and interpretation, ethical considerations and limitation of the study.

The research aims to investigate various green building technologies and their effectiveness in promoting sustainable construction practices the study will follow an analytical approach to evaluate the impact of these technologies on environmentally sustainable energy efficiency and cost effectiveness in building industry.

3.1 Description of study area

The City of Kigali is the capital of Rwanda and is located at Rwanda's geographical heart. Occupying an area of 730km2. The City of Kigali is composed of three Districts Gasabo, Kicukiro and Nyarugenge. Gasabo is the largest district by geographical area at 429.3km2, followed by Kicukiro (166.7km2) and Nyarugenge (134km2). The City of Kigali population is 1.7 million.

The vision of the City of Kigali is to become "The Centre of Urban Excellence in Africa

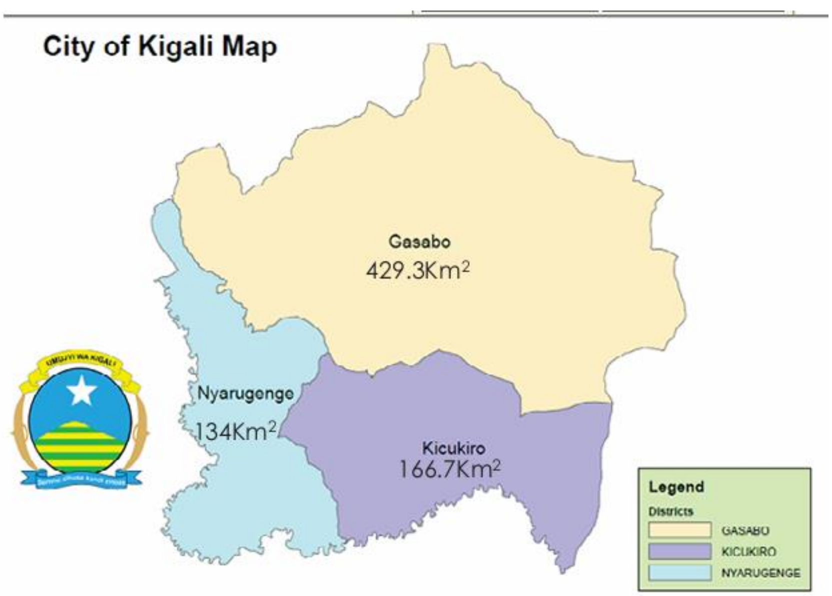

Figure 3. 1 Kigali city map

3.2 Research design

This research design for this study is analytical and comparative, as it involves evaluating the feasibility and effectiveness of various green building technologies. the design will allow for a systematic examination of different sustainable construction practices including renewable energy system, eco-friendly building materials and energy efficient designs. By comparing these technologies, the study aims to identify the most effective solutions for promoting environmentally sustainable, reducing energy consumption and enhancing cost efficiency in the building industry. This approach facilitates a detailed and controlled analysis of the impact of green building technologies on creating a greener tomorrow.

3.3 Research population

This target population for this study includes professionals and stake holder in the construction industry in Rwanda. This includes architects, engineers' builders, government, builders' government officials, renewable energy providers, policy makers environmental organization and representatives from green building certification bodies.

3.4 Sample size

The sample size of this study explore of green building technology will be determined based on availability of participants and resources. a lager sample size will allow for more robust data analysis and interpretation.

Based on accessible population a sample size of 50 can be a target these includes the clients (consumer of the green building projects), engineers and architecture and student of civil engineering to help to collect data

3.4.1 sampling procedure

Sampling procedure involves selecting representative data points from various stages of construction and operation to asses' sustainable performance. The key stakeholders are government officials like ministry of infrastructure and Rwanda housing authority, Architects and engineers, Builders and contractors, Academic Researcher, Non-governmental organizations (NGOs), Residents and building users.

3.5 Research instrument

The research instrument for this study will be a questionnaire that includes both closed-ended and open-ended questions. The questionnaire will be used to gather data on the participants' knowledge, opinions, and experiences related to exploring green building technology for a greener tomorrow, with a case study in Kigali, Rwanda

3.5.1 Choice of research instrument

The questionnaire was chosen for its efficiency in collecting both quantitative and qualitative data, standardizing responses for reliable analysis and providing participants with the flexibility to share detailed thoughts. It ensures confidentiality and is cost effective, making it deal foe exploring green building technology.

3.5.2 validity and reliability of instrument

Ensuring the validity and reliability of the questionnaire is crucial for the integrity and credibility of this study on exploring green building technology for a greener tomorrow.

Validity

To ensure the validity of the questionnaire, pilot testing will be conducted with a small, representative sample of the target population. This process will help identify any ambiguities, biases, or misunderstandings in the questions. Feedback from the pilot test will be used to refine and improve the questionnaire, ensuring that it accurately measures the variables of interest. Additionally, the questionnaire will be reviewed and validated by experts in the field of green building technology, materials science, and sustainability. Their insights will help confirm that the questions are relevant, comprehensive, and aligned with the study's objectives.

Reliability

Reliability will be established by ensuring consistency and stability in the questionnaire responses. The pilot test will also serve to assess the internal consistency of the questionnaire. Any items found to be inconsistent or unclear will be revised or removed to improve reliability. Furthermore, the questionnaire will be designed to minimize variability in responses that could result from different interpretations of the questions. Clear instructions and well-defined terms will be provided to ensure that all respondents understand the questions in the same way.

3.6 Data gathering procedure.

Data for this study will be gathered through a questionnaire distributed to selected stakeholders in the green building sector, either in person or online. Participants will complete the questionnaire at their convenience, and responses will be securely recorded and stored. A clear timeline and reminders will ensure a high response rate. Collected data will be analyzed using statistical methods to identify patterns and trends, providing insights into green building technology.

3.7 Data analysis & interpretation

The data analysis for this study on exploring green building technology for a greener tomorrow will involve both descriptive and inferential statistical methods to provide comprehensive insights.

Descriptive Statistics

- **Frequencies and Percentages:** These will be used to summarize the questionnaire responses, providing an overview of how many participants support various green building technologies and their perceived benefits.
- **Means and Standard Deviations:** These measures will be calculated for continuous variables to describe the average levels and variability of support for different green building technologies among participants.

Inferential Statistics

- **Correlation Analysis:** This will identify relationships between variables, such as the correlation between the implementation of green building technologies and improvements in energy efficiency or environmental impact.
- **Regression Analysis:** This method will be used to predict the factors influencing the adoption of green building technologies. By examining variables such as cost, perceived benefits, and regulatory support, the analysis will highlight key predictors and barriers to adoption.

Interpretation

The results from both descriptive and inferential analyses will be interpreted to draw meaningful conclusions about green building technology adoption. Patterns and trends identified will provide insights into the current state and potential future developments in the field. The findings will be compared to existing literature to validate and contextualize the results, contributing to the broader understanding of how green building technologies can foster a greener tomorrow.

3.8 ethical considerations

Ethical considerations for study include obtaining written informed consent from participants and ensuring the confidentiality and anonymity of their data. Participant's rights and privacy will be protected allowing them to withdraw at any time without consequence. The research will follow established ethical guidelines and standards, with ethical approval sought from relevant committees. This approach ensures the integrity and validity of the findings on green building technology.

3.9 limitation of the study

There are various obstacles to the Kigali, Rwanda study on green construction technology. Reliance on self-reported data and potential biases in participant selection could compromise the validity and generalizability of results. The study's scope and depth may be limited by time and resource constraints, and its concentration on Kigali limits its applicability to other places. When interpreting the results, these considerations need to be considered.

CHAPTER FOUR: RESULT AND DISCUSSION

4.0 Introduction

This chapter presents the findings of the research on green building technology and its potential to contribute to a sustainable future. The data collected from case studies, surveys, and literature reviews are analyzed to evaluate the effectiveness of various green building technologies in reducing environmental impact, improving energy efficiency, and promoting resource conservation. The discussion section will explore the implications of these findings in relation to the objectives of the study, comparing current building practices with green alternatives and assessing the feasibility and benefits of adopting these technologies on a larger scale.

4.1 Green building technologies efficiency

4.1.1 Energy efficiency

Energy-efficient green buildings can typically achieve **20-30%** power savings compared to conventional buildings due to the use of LED lighting, energy-efficient HVAC, and smart energy management systems.

Example. If a conventional building consumes 200,000 kWh/year and a green building uses 150,000 kWh/year:

$$\text{Efficiency}= (200{,}000-150{,}000) *100\%)/200{,}000 = 25\%$$

4.1.2 Water efficiency

Green buildings with rainwater harvesting systems and low-flow fixtures generally save **30-50%** more water compared to conventional buildings.

Example**:** If a conventional building uses 100,000 liters/year and a green building uses 60,000 liters/year

$$\text{Efficiency} = (100{,}000-60{,}000) *100)/200{,}00 = 25\ \%$$

4.1.3 Environmental protection

Green buildings reduce carbon emissions and waste generation by **35-40%** through sustainable materials, waste recycling, and energy efficiency.

If a conventional building emits 100 tons of CO_2 annually and a green building emits 65 tons:

Efficiency = (100-65) *100)/100 = 35%

4.1.4 solar savings

Solar panels typically provide **20-40%** of a building's energy needs in green buildings.

Example: If solar provides 60,000 kWh out of a 200,000-kWh annual requirement:

Efficient (60,000 /200,000) * 100 = 30%

4.1.5 Natural lighting

Buildings designed with optimized natural light (large windows, skylights, daylight harvesting) reduce the need for artificial lighting by **50-75%** during daylight hours.

Example: If artificial lighting is required for 10 hours/day in a conventional building but only 4 hours/day in a green building

Efficiency = (10-4) *100)/10) = 60%

4.1.6 Air ventilation

Green buildings with natural ventilation systems or energy-efficient HVAC systems typically improve air quality and reduce energy consumption by **30-50%**

If conventional HVAC consumes 100,000 kWh/year and the green system uses 60,000 kWh/year

Efficiency = (100,000 – 60,000) * 100)/100,000 = 40%

Table 4. 1 Comparison of efficiency percentage between conventional and green buildings

Category	Conventional buildings	Green buildings	Efficiency
Water Usage (Liters/year)	100,000	60,000	40%
Power Usage (kWh/year)	200,000	150,000	25%
CO_2 Emissions (tons/year)	100	65	35%
Solar Energy Contribution (%)	0	30%	30%
Natural Lighting (hours/day)	10	4	60%
HVAC Energy Use (kWh/year)	100,000	60,000	40%

4.2 Case study: Example of Green building in Kigali

- **I &M BANK Building**

Is a building which is in Kigali on the 3540sqm. This is one of green certification building built in duration of 4 years. Where the construction phase started in 2019 and continued up to 2023 where it was inaugurated. they Sayed it costed around 24-25 billion Rwf.

During the construction they used materials bricks, concrete, window, aluminum helps to get embedded carbon of 51% and they also used local materials like granite from Nyagatare and Ruriba Bricks as they required in green buildings.

On energy efficiency they installed solar panels that can provide 200kw and about water saving they used plan being system (siphonic drainage) where they collect rainwater and re use it (photos during the visit is in appendixes)

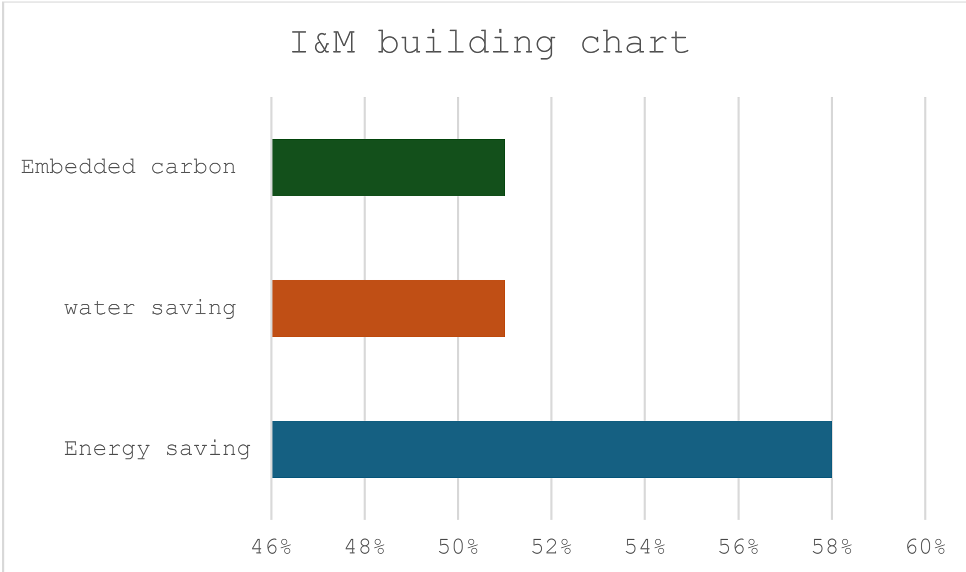

Figure 4. 1 I&M building chart

4.3 Survey and Interview Data Presentation

4.3.1 Survey Data Analysis

I carried out a survey with 50 people to understand their views on green building technologies in Kigali. The participants included civil engineering students, architecture students, engineers, and others working in construction. This mix of people helped give a clear picture of how green building technologies are understood and used in different areas of construction.

- **Familiarity with Green Building Technologies**

  The question was How familiar are you with green building technologies?

Table 4. 2 Response on familiarity with green building

Familiarity level	Percentage **%**
Very familiar	30%
Somehow familiar	50%
Not familiar	20%

A significant majority (80%) of respondents are at least somehow familiar with green building technologies. This indicates a general awareness within the sample, though 20% are not familiar, highlighting a potential need for increased education.

- **Involvement in Green Building Projects**

Question was Have you ever been involved in a green building project in Kigali?

Table 4. 3 Response on involvement in green building project

Response	Percentage
Yes	40%
No	60%

Only 40% of respondents have been involved in green building projects, suggesting a gap in practical experience with these technologies. This could point to a need for more project opportunities or increased engagement.

- **Belief in Environmental Impact Reduction**

Question was Do you believe green building technology can significantly reduce environmental impact in Kigali?

Table 4. 4 Response on belief in environmental impact

Response	Percentage %
Strongly agree	45%
Agree	35%
Neutral	10%
Disagree	10%

A majority (80%) of respondents believe that green building technology can significantly reduce environmental impact, either strongly agreeing or agreeing.

4.3.2 Interview Data Presentation

To gain deeper insights into the challenges and opportunities of green building technologies in Kigali, I conducted interviews with 50 participants. These interviews provided detailed answers on various topics such as challenges in adopting green building practices and personal experiences with sustainable construction. The most common responses were grouped into three main themes:

- **High cost** was mentioned by 20 participants (40%),
- **Lack of awareness** was mentioned by 15 participants (30%),
- **Positive outlook on future technologies** was mentioned by 15 participants (30%).

I represented these answers using a pie chart to show the distribution of these common theme.

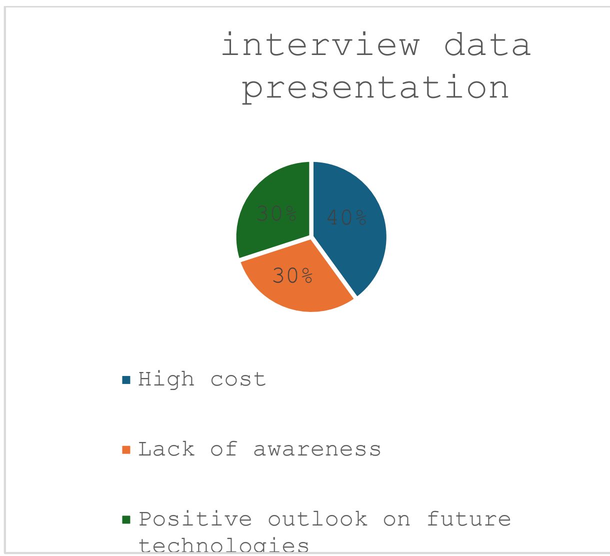

Figure 4. 2 Interview data presentation

4.4 Comparison Between Green Building Technology and Conventional Buildings

Table 4. 5 Comparison between Green building and conventional building

Aspect	**Green building**	**Conventional building**
Energy efficiency	Uses solar panels, energy-efficiency lighting and high-performance insulation to reduce energy consumption	Relies more on grid electricity, traditional lighting less efficiency insulation leading to high energy use
Water conservation	Incorporates rainwater harvesting systems and low fixture leading to water saving	Typically uses standard fixture with no water saving system resulting in higher water use
Environmental impact	Built with sustainable and recycled materials to reduce environmental impact on carbon footprint	Often uses conventional materials that contribute to more pollution, waste and higher carbon emmision
Cost	Higher initial costs but saves money long term with lower energy and water bills.	Lower initial costs but higher long-term expenses due to more energy and water usage.
Building Lifespan	Typically designed for a longer lifespan due to better materials and energy-efficient systems, reducing the need for frequent repairs.	May require more frequent maintenance and renovations due to less durable materials and systems.
Technological Integration	incorporates smart technologies like automated energy management and environmental monitoring systems.	Limited use of smart technologies, relying on older methods for energy and environmental management
Carbon Emissions	Significantly lowers carbon emissions through energy-efficient systems and sustainable materials.	Higher carbon emissions due to reliance on conventional energy sources and materials.

➢

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study explored how green building technologies can contribute to creating a more sustainable future. Through a case study of Kigali, Rwanda, and a detailed examination of technologies like rainwater harvesting, low-flow fixtures, energy-efficient systems, and the use of recycled building materials, we have shown how these practices help reduce environmental impact.

Our research, including surveys and interviews, revealed that there is growing awareness and interest in adopting green technologies in the construction industry. However, the adoption rate is still slow, especially in developing countries including Rwanda, due to challenges like cost, lack of expertise, and limited access to sustainable materials.

Thanks to the commitment of our leaders, projects like Vision City Phase 2, Kigali Green City in Kinyinya and Kigali green complex are set to implement green building practices. These initiatives not only reflect the growing awareness but also pave the way for a sustainable urban future, highlighting how leadership can drive the adoption of green technologies in our communities. (their photos are in appendix 2)

5.2 Recommendation

- Increase Awareness and Education: More awareness programs should be created to educate builders, architects, and civil engineers about the benefits of green building technologies. Educational institutions should also include these topics in their curriculum.
- Government Support and Incentives: Governments should provide financial incentives and policy support for builders who adopt green technologies.
- Training Programs: There should be more training opportunities for professionals in the construction field to learn how to implement green technologies effectively.
- Affordable Green Materials: Encourage the production and use of locally available, sustainable materials to lower the cost of construction and make green buildings more affordable for everyone.
- Partnerships and Collaboration: The construction industry should collaborate with environmental organizations and green technology companies to stay updated on the latest innovations and best practices**.**

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APPENDICES

Appendix 1

FINAL YEAR PROJECT DATA COLLECTING FORM

The following are Questionnaire that were distributed during our project of exploring green building technology for greener tomorrow.

❖ **Closed-ended Questions:**

1. How familiar are you with green building technologies?
    a. Very familiar
    b. Somewhat familiar
    c. Not familiar
2. Have you ever been involved in a green building project in Kigali?
    a. Yes
    b. No
3. Do you believe green building technology can significantly reduce environmental impact in Kigali?
    - Strongly agree.
    - Agree
    - Neutral
    - Disagree

❖ **Open-ended Questions:**

1. What are your thoughts on the current state of green building technology in Kigali?
2. Can you describe any personal experiences or projects involving green building technology?
3. What challenges do you think Kigali faces in adopting green building technologies?
4. How do you envision the future of green building technology in Kigali?

Appendix 2

Some photos of me during research and some green building project I managed to visit of green buildings.

I&M buildings

ULK hostels green building which is under construction.

Kigali green complex under construction in Kigali

Kinyinya site where the Kigali green city will be built.

Vision city phase 2 which will be built in Kigali.

Nyarutarama plaza green building in Kigali