Sustainability in the construction sector: A case study review on the implementation of sustainability practices on Building Construction projects

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…………….

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Introduction

The construction sector is one of the sectors that directly impact man's basic needs of life, and as such, the industry will continue to exist if there is humankind. The catch is that it must utilize natural resources for the construction sector to survive. However, this sector involves construction and destruction within its processes from the conception to the utilization stage. Now, the construction industry has consumed up to 40% of the total energy produced, emitted 35 to 40% of carbon dioxide emissions (Noha Ahmed, 2021), and had a heavy impact on natural resources. Resources are utilised from extraction of land onto which these infrastructure developments are placed, as construction in the form of sand, aggregates to mention a few, or as raw materials for manufacturing building materials, tools and equipment. Based on these effects, it is important that the construction industry adopts sustainable practices at all stages of the construction process. (Wen B, 2020)

Since 1994, when the concept of sustainable construction was conceived, the construction sector has steadily transitioned from rudimentary construction to more critically assessed construction.
The concept was notably intellectualized after Agenda 21 on sustainable construction thanks to the adoption of the Sustainable construction proposal at the World summit for sustainable construction in Johannesburg in 2002 (United Nations, 2002) coupled with the UN sustainable development Goals approved for implementation in 2015.

Several studies have been conducted and defined sustainability in differently according to the parameters for which their studies focus on.
Sustainability focuses on protecting both the natural and built environment resources to ensure the future generations in the next century or so have proper continuity of natural resources. Sustainability can be defined in several ways as the development, commitment, and management of a healthy built environment through prudent use of resources while adhering to ecological principles. (Oladukun M G, 2020)

Since then, several countries and professionals have been involved in the path toward sustainable development within the construction sector. Studies have shown positivity towards sustainability practices by some companies in the UK; however, most of them have not engaged them within their businesses. (Myers, 2005)

Several studies have looked at blockades and influencers of sustainable building from previous studies and several interviews. Various Ideas like sustainable construction materials and construction design concepts have been developed in efforts to promote sustainability through themes of climate change reconciliation, low carbon emission, green buildings, and technology. (Hakkinen, 2009), (Chen Y, 2010).

Measurement of sustainability within the construction industry has proven to be rather difficulty and this is attributed to the fact that different construction projects are faced with several uncertainties from time to time across the lifecycle of the project. And on top of that, there are limited tools available to measure sustainability performance. (Wagner Cezar Lucato, 2018) In order to ensure to come to some semblance of quantifying sustainability performance, several studies have been done to come up with indicators that can be used to help measure sustainability within the construction sector. (Guangdong Wu, 2018) (Moawiah Alnsour, 2022).

These sustainability indicators have been categorised in different perspectives following the ecological principles. These aspects include environmental, economic, and social aspects.
Within the environmental aspect, the sustainability indicators are focused on considering selection of materials that are renewable, waste management through minimization, recycling, and proper waste disposal and general land use in a bid to reduce negative impacts on the environment. It also promotes responsible extraction of resources at lower recuperation rates to enable optimal regeneration for future use. In other wards environmental sustainability considers protecting the ecosystem from destruction and or extinction by through efficient and economical use of non-renewable resources.in addition, factors like efficient use of water and energy, and pollution issues

are considered as well. As for the renewable resources, an ecological balance is ensured. (Fernández-Sánchez, 2010)
Economically, Businesses and other developments benefit through the ever increase in buying power on the market, which means constant production and consumption. This often does not consider the environmental impact it creates on natural resources. Therefore, the economic sustainability especially in the construction sector principally focuses on increasing efficiency in utilisation of resources used in the construction industry. It promotes creation of jobs for labour intensive kinds of construction. It fosters support in encouraging choosing environmentally friendly suppliers and contractors. And thus some of the indicators for the economic perspective revolve around efficient production and consumption, employability, profitability and the lifecycle costing (Fernández-Sánchez, 2010) (Rong Hui Chen, 2015)

the social perspective, looks at the dealing with the needs of the community, stakeholders involved in the construction process to ensure their needs are properly met to satisfaction. The principles behind this social aspect are to improve the quality of humankind through poverty alleviation in the form of job employment, protecting and promoting healthy and safe working environment for human health, Improving and enhancing skills through offering trainings. (Fernández-Sánchez, 2010)

In addition, studies involving sustainable indicators have shown different strategies on how to make achieve and deliver sustainable construction projects. However, more needs to be done on evaluating the sustainability during the execution phase of the project. And as such, it is imperative to ascertain the practicality and implementation of sustainable practices on construction projects most especially during the execution phase, and the practicality and influence of the sustainability indicators. Also, to note, construction companies and or projects are not mostly focused on the sustainability output or even maintaining a certain level of sustainability performance through consistent monitoring and control for example ensuring optimum use of sustainable construction materials.
Making these assessments in countries like Germany is substantial to ascertain yardstick measures and derive ways to guide other countries and professionals developing in this field to enhance development.

Research Objective

Based on the above, it is safe to assume that construction professionals are aware of the need to embrace sustainable construction. The main focus of study will be assessing the practicality of implementing sustainable indicators through a case study approach to ascertain the sustainability of construction projects during the construction execution phase.

The Specific research objectives for the study will include.

1) Ascertaining sustainable indicators for construction projects through literature review
2) Develop a framework tool to assess the identified sustainable methods and practices based on the sustainable indicators.
3) Application of the framework tool on a case study project to assess practicality of implementation on a construction project.

Methodology

This research will mainly be quantitative and qualitative. The data and information will be attained through extensive literature review and using.
The proposed case study project, EUREF campus in Berlin Schoneberg will be used to validate the proposed framework tool. Questionnaires/interviews with construction professionals on the case study project in Germany will be used.

Time scale

The project timelines will be executed as reflected in the Gantt chart below.

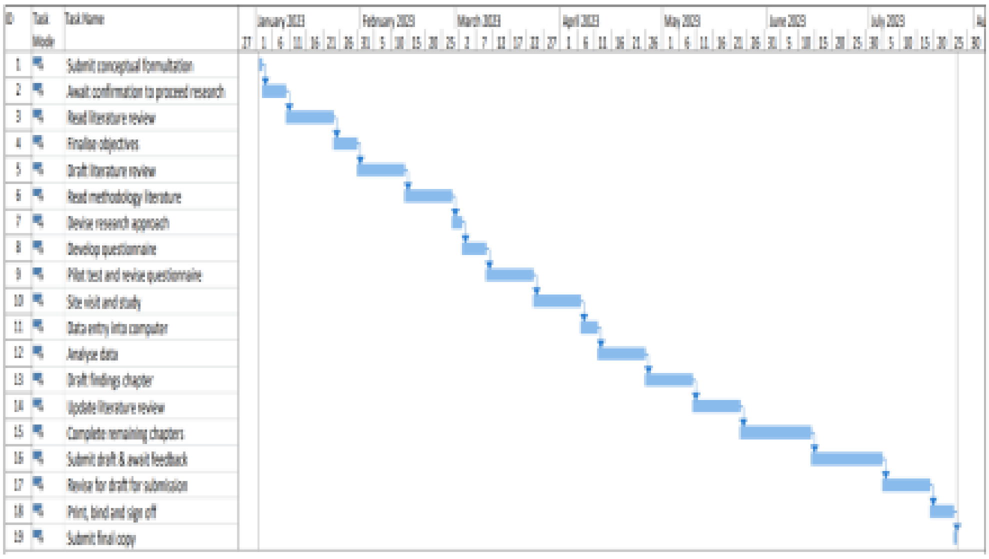

Figure 1; Time scale for the research project

Resources

The study will be done with the help of several literature content acquired from the university library, public databases, company information, and e-books.

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Abstract

The global population growth of young adults is increasing tremendously, which ultimately means more demand for basic needs like shelter (housing) and infrastructure, by extension. Several studies have been conducted concerning sustainable construction and sustainability, mainly focusing on the design phase, sustainable materials, and technologies. More needs to be done in the construction phase of construction projects, yet implementation of all other elements happens during this stage, particularly material utilization. This study assessed the sustainable practices implemented during construction, designed and proposed a performance assessment tool for real-time sustainability performance tracking. Case studies were then used to check the assessment tool's functionality and applicability during the construction.

Key words: sustainable construction, construction phase, sustainability indicators, sustainable practices

Table of Contents

Abstract .... **VIII**

Table of Contents .... **IX**

Table of Figures .... **XI**

List of Tabulations .... **XII**

List of Abbreviations .... **XIII**

List of Symbols .... **XV**

1. Introduction **16**

2. Literature Review **18**

2.1. Sustainability Concept 18

2.2. Construction Phase of a Project 21

2.3. Aspects of Sustainability on Construction Projects 26

2.4. Barriers and Enablers to sustainability 33

2.5. Sustainable Indicators for Construction projects 36

2.5. SDGs and the Construction sector: 39

2.6. Chapter summary 42

3. Methodology **44**

3.1. Research Design and Approach 44

3.2. Research Questions 45

3.3. Case study Selection 45

4. Case study and Frameworks **46**

4.1. Existing Frameworks 46

4.2. Case studies 52

4.3. Chapter summary 53

5. Proposed Framework tool Development **56**

5.1. Identification of Key Sustainable indicators for the Framework 56

5.2. Design of the Framework tool 58

6. Results and Analysis 71

6.1. Current Sustainable Practices Implemented based on the Case Study Project. 71

6.2. Current Assessment Methods for Current Sustainable Practices Based on Case Studies. 80

6.3. Performance Assessment of the Proposed Framework................................ 82

6.4. Discussion on the Implications and Limitations of the Study 91

7. Conclusion and Recommendations.. 92

Declaration of Authorship.. 93

References 94

Table of Figures

Figure 1: SDGs supported by the construction sector. (By Author). 39
Figure 2: Part 1 of the sustainability assessment framework tool. (By Author). 58
Figure 3: part 2 of the sustainability assessment framework tool continued. (By Author) 59
Figure 4: sustainability assessment framework tool final part. (By Author) 60
Figure 5: showing the different types of construction activities to be selected as circled in red. (By Author) 60
Figure 6: showing selection type 0-5. (By Author) 61
Figure 7: showing selection options for noise pollution levels. (By Author). 62
Figure 8: showing selection option 'Yes', 'No' and 'N/A' for qualitative information. (By Author). 63
Figure 9: showing selection type in percentages 0 up to 100%. (By Author). 64
Figure 10: showing extracted figures from the material tracker. (By Author). 65
Figure 11: the different selections for the renewable materials. (By Author). 66
Figure 12: different energy systems. (By Author). 67
Figure 13: selections for the recyclable materials used. (By Author). 67
Figure 14: showing details within the material tracker. (By Author). 68
Figure 15: showing selection for lightings used. (By Author). 69
Figure 16: showing tools and equipment being used. (By Author). 70
Figure 17: Skanska hierarchy of control adapted (By Author). 75
Figure 18: HCC site training programs adapted (By Author). 77
Figure 19: Skanska performance evaluation part 1. (By Author). 82
Figure 20: Skanska performance evaluation continued. (By Author). 83
Figure 21: Skanska performance evaluation continued. (By author). 83
Figure 22: HCC Performance evaluation part 1. (By Author). 84
Figure 23: HCC Performance evaluation continued. (By Author). 85
Figure 24: HCC Performance evaluation score. (By Author). 85

List of Tabulations

Table 1; Showing identified Key sustainable indicators. (adapted by Author) 56

List of Abbreviations

HCC	Hindustan Construction Company
ISO	International Organization for Standardization
WECD	World Commission on Environment and Development
UN	United Nations
SDG	Sustainable Development Goals
ROI	Return on Investment
LEED	Leadership in Energy and Environmental Design
BREEAM	Building Research Establishment Environmental Assessment Method
IMF	International Monetary Fund
EU	European Union
LCC	Life Cycle Costing
LCA	Life Cycle Analysis
BIM	Building Information Modelling
EUI	Energy Use Intensity
HVAC	Heating Ventilation and Air Conditioning
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
VOC	volatile organic compound
PPE	Personal Protective Equipment
CPSA	Construction Project Sustainability Action
GRI	Global Reporting Initiative
LED	Lighting Emitting Diode
IEA	International Energy Agency
WEF	World Economic Forum
LTAR	Lost Time Accidents Rate
UK	United Kingdom

PSOP	Proactive Safety Observation Program
HSE	Health, Safety, and Environment
GHG	Green House Gases
ICE	Institution of Civil Engineers
LGBTQ	Lesbian, Gay, Bisexual, Transsexual and Queer
D.G.	Diesel Generator
IPCC	Intergovernmental Panel on Climate Change
GWP	Global Warming Potential
C& D	Construction and Demolition

List of Symbols

₹	Indian rupee currency

1. Introduction

The global population growth of young adults is increasing tremendously, which ultimately means more demand for basic needs like shelter (housing) and infrastructure by extension (IMF, 2023). Consequently, this places the construction sector at the forefront of supporting these needs and hence the sector's growth to meet the growing needs. Inadvertently, the need to cater for these basic needs in the different sectors (food, shelter, water, air, and clothing) has generally affected the environment as we know it and a climate change shift. The construction industry alone has consumed up to 40% of the total energy produced, emitted 35 to 40% of carbon dioxide emissions (Noha Ahmed, 2021), and heavily impacted natural resources. In other words, the construction sector is widely recognized as one of the most significant contributors to global greenhouse gas emissions and environmental degradation. Resources are utilized from the extraction of land onto which these infrastructure developments are placed, as construction in the form of sand and aggregates, to mention a few, or as raw materials for manufacturing building materials, tools, and equipment. As a result, there is growing concern about the sustainability of the construction industry and the need for it to adopt more sustainable practices. It is from such concerns that the UN came up with strategies to counter the general impacts on the environment through sustainable measures within the UN sustainable development goals (United Nations, 2002).

In the construction industry, sustainability has become a critical aspect worldwide, with increasing concerns about construction activities' environmental, social, and economic impacts. As one of the significant contributors to environmental degradation and resource depletion, the construction sector is under increasing pressure to adopt sustainable practices to mitigate its negative impacts. Construction professionals and researchers are developing ways to play their part in ensuring sustainability is achieved. Efforts have been placed into ideas like green construction, renewable energies, lifecycle studies, optimization through BIM and lean construction. In a bid to make construction projects more profitable, sustainable, and efficient, these structures are playing into ensuring sustainability is achieved within the construction sector. Studies indicate that the majority of the research has been tailored towards improving the designs either architecturally, structurally, energetically or through sustainable materials (Georgescu, et al., 2022). In addition, sustainability systems have been created to undertake the responsibility of ascertaining the sustainability of construction projects, such as LEED and BREEAM, to mention a few.

More studies have approached sustainability barriers and provided recommendations for implementations within the construction industry. However, more must be done to highlight the impact of sustainability of construction projects within the other construction phases. Granted, the earlier stages of the project phase are critical in painting and directing the sustainability of the project and its overall outcome as a construction product for utilization, but also, project phases like the construction execution phases are equally necessary to be checked to ensure the overall performance towards sustainability Afterall it is the actual construction process that will define the outcome of the construction project.

Research Aims and Objectives

Given the information provided, it could be reasonably inferred that construction professionals were aware of the importance of adopting sustainable construction practices. The focus of the study was to assess the practicality of implementing sustainable indicators through a case study approach to ascertain the sustainability of construction projects during the construction execution phase.

The Specific research objectives for the study included:

a) Ascertaining sustainable indicators for construction projects through an extensive literature review on the general sustainability indicators applicable within the construction industry. It was from these indicators that crucial performance indicators suitable for assessment were identified.

b) Developing a framework tool that could be used to assess the identified practicality of implementation of sustainable practices based on the sustainable indicators.

c) Application of the framework tool on the case study project to determine whether the practicality of implementation on a construction project was achievable.

2. Literature Review

This chapter provides a brief background on sustainability origin concepts, a review of relevant literature on sustainability in the construction sector, an overview of the execution phase of construction projects, barriers and implementation practices involved, and sustainability indicators in construction.

2.1. Sustainability Concept

As aforementioned, the concept of sustainability stemmed from Its development in the Brundtland’s Report of 1987, our common future, which defined *sustainable development* as "development that meets the needs of the present without compromising the ability of the future generations to make their own needs". This definition was published in 1889 by the United Nations World Commission on Environment and Development and has been used as a guiding factor in several studies and practices concerning sustainability. However, the definition of sustainable development was redefined by the EU strategy on sustainable development to be "a long-term vision for sustainability where economic growth, social cohesion and Environmental Protection work together and are mutually supporting". (EU, 2023).

Several researchers have devised different ways of defining sustainable construction development from this background. Opoku et al. defined *sustainable construction* as an infrastructure development that meets the present desires without compromising the future generations' abilities to meet their own. (D.G.J. Opoku, 2019). Aghazadeh et al. defined *sustainability* in construction "as the development in which three key factors of the environment, the economy, and the society are balanced, thereby providing solutions against traditional development patterns". (Ebrahim Aghazadeh, 2021)

Overall, *sustainability* in the construction sector can be defined as adopting practices that minimize construction activities' negative environmental, social, and economic impacts while maximizing positive outcomes. It involves considering the entire life cycle of a construction project, including design, planning, construction, operation, maintenance, and eventual demolition or reuse. The aim is to balance environmental protection, social responsibility, and economic viability.

The environmental dimension of sustainability in the construction sector focuses on reducing resource consumption, minimizing pollution, and mitigating climate change. Construction activities consume vast natural resources, including energy, water, and raw materials. They also generate substantial waste, including construction debris, packaging materials, and demolition waste (Koker, 2019). Addressing these challenges requires adopting sustainable practices such as energy-efficient design, renewable energy integration, water conservation measures, waste reduction and recycling, and sustainable materials selection. several factors involved in environmental sustainability include rapidly renewable materials, renewable energy technologies, recycled materials, increase of recycled contents, protection of on-site soils, reuse of top soils and rock materials, vendors using materials with recycled content, proper handling, storage and disposal of hazardous and toxic materials (Koker, 2019), materials based on life-cycle assessment, minimized construction wastes, waste reduction goals during construction, specified materials for location, and use green landscape retrofit techniques, increase of durability, and finally increase of recyclability.

Social sustainability can be defined as reflection through meeting and managing the needs of the sectors and several stakeholders. (Essam Almahmoud, 2015). Notwithstanding the increased concern in social sustainability, there is still limited knowledge and information for the social sustainability assessment, as well as inadequate social sustainability indicators to perform an appropriate quantitative assessment (Tamara Popovic, 2018). According to (Merlina Missimer, 2017), the vast and growing array of concepts, methods and tools in the sustainability field implied a need for a structuring and coordinating framework, including a unifying and operational definition of sustainability.

The social dimension of sustainability in the construction sector recognizes the importance of promoting social well-being, equity, and community engagement. (James Pocock, 2016). Construction projects can impact local communities, including the workforce, residents, and other stakeholders. However, (Qian Zhang, 2019) highlighted that the key stakeholders involved in construction needed to be well identified for social sustainability to be well planned and executed; otherwise, it would hinder communication and collaboration. As far as the construction industry was concerned, (Essam Almahmoud, 2015), noted that the major stakeholders involved were clients, contractors, suppliers, investors, and local communities.

Another aspect of social sustainability is equality, or in other words, ensuring fair labour practices. There must be minimal or, better yet, no gaps between different groups. (Tamara Popovic, 2018) noted that diversity in gender, age, race, and skills, among others, was acknowledged as vital in enhancing strength within the human social system.

The third aspect of sustainability within the construction sector involved health and safety measures for workers. (Laura Monalban-Domingo, 2018) highlighted that health and safety were considered among the prominent social sustainability criteria in the construction sector and involved practices such as site inductions, signage placements, safety access creations, communication of hazards, working hours and definition of breaks in between works, provision of safe water, provision of personal protective gear and equipment, among others.

(Md Uzzal Hossain, 2018), noted that other aspects involved in social sustainability included the creation of employment opportunities, employee or project staff training, career development opportunities and community engagement, especially in the decision-making process were the critical aspects of social sustainability in construction. Overall, the main drive in implementing social sustainability practices within the construction sector is focused on improving the quality of human life, increasing knowledge and skill training. (James Pocock, 2016).

The economic dimension of sustainability in the construction sector emphasizes the importance of long-term economic viability and financial responsibility. Sustainable construction applies a sustainable approach which is cyclic, and as such, it efficiently integrates several principles such as value for money, maximum output with minimum input, stakeholder partnerships, human quality of life, and integration of short-term return with long-term benefits to improve and deliver the best quality of life. Sustainable construction practices can lead to cost savings through energy efficiency, reduced operational expenses, and optimized use of resources. Moreover, sustainable buildings often have higher market value, lower maintenance costs, and improved occupant satisfaction.

In addition, the transition to sustainable practices can stimulate innovation, create new business opportunities, and enhance the competitiveness of construction companies in a rapidly changing market. Several economic indicator factors include reduced resource consumption, energy savings, resource reuse, maximum utilization of non-renewable resources, energy efficiency, water efficiency, extraction efficiency, optimal artificial light, operation efficiency, appropriate technology, efficient use of renewable resources, design systems for ease of maintenance and operation, and maximum utilization of natural light, water recycling system.

2.2. Construction Phase of a Project

The execution phase of a construction project, also known as the construction phase or implementation phase, is the stage during which the actual construction work takes place. It follows the planning and design phases and precedes the completion and handover of the project. The execution phase involves the building or infrastructure's physical construction, installation, and assembly according to the approved design and specifications.

During the execution phase, key characteristics and various activities are carried out, including:

a) Mobilisation: The execution phase begins with mobilising resources, including workforce, equipment, and materials, to the project site. Construction teams are assembled, contracts are finalised, and work schedules are established.

b) Procurement and Logistics: The execution phase involves procuring and managing the necessary construction materials, equipment, and supplies. It also includes coordinating deliveries, inventory management, and timely availability of on-site resources.

c) Site Preparation: The project site needs to be prepared before construction activities commence. It includes clearing the site, setting up temporary facilities (e.g., site offices and storage areas), and ensuring proper access, utilities, and safety measures.

d) Construction Activities**:** The construction phase is one of the lifecycle phases of a construction project, and it involves a physical building process. Construction activities are carried out according to the project plans, specifications, and applicable building codes and regulations. These activities during the construction stage have a close association with environmental impacts such as waste generation and pollution. They include:

i. ***Setting out*** can be defined as a process through which information is extracted from a construction design drawing and then profiled, marked, or marked onto the construction site to work as a control for the construction project. This activity, also known as marking, is one of the first construction activities to define the position, area, shape, and size of a building on the plot/site to use as a reference. Before beginning construction, this activity ensures that the workers know the legal boundaries set for construction.
   This activity, when properly executed, helps the project avoid Construction costs and delays, legal battles, and disputes. In addition, setting out also helps to place structures at the correct levels and in their rightful positions and alignments as designed to for example roads, and adjacent building, among others. (Chudley R, 2007)
ii. ***Excavation*** can be defined as a process of removing earth, soil, rock, or other materials to create a cavity in the ground. On a construction project, this activity can be through earthwork, trenching, retaining walls and shafts, tunnelling, and the ground basements. Depending on the type of structure to be constructed, excavation can be done using machinery, tools or even explosives. (R, 1994)
iii. ***Concreting*** can be defined as placing concrete on a designated or within prefabricated formwork on a construction site to achieve a concrete structural element. Concrete is a heterogeneous mixture of cement, fine aggregates (sand), coarse aggregates and water. Sometimes admixtures like fast setting, and retarders, among others, are added based on the conditions required to achieve the concreting objective. Concrete is one of the most long-lasting, affordable, and durable artificial products. However, its production comes at a high environmental cost during its production mainly with raw material production and acquisition.
iv. ***Carpentry*** can be defined as a construction activity involving using timber and or wood to assemble, construct and repair wooden structures. Carpentry can be categorized into different fixes, such as; (1) preparation of formwork and shuttering for concrete works to slabs, stairs, lift shafts, walls, beams and columns, among others, before concrete is cast, (2) in timber framed constructions like roofs, walling, flooring among others and finally as final fixes in the form of doors and window installations, shelving, facades, terraces, among others.

Tools and materials used in carpentry. The essential critical tools used within carpentry are the circular saw, Compound mitre saw, Power drills, hammers, Reciprocating Sawzall, and table saws, among others. Moreover, the primary materials are timber and wood. Timber as a construction material is considered a naturally eco-friendly construction material because it has a very significant low embodied carbon footprint when compared to other construction materials making it sustainable. However, it can only be sustainable if properly sourced and disposed of at the end of its lifecycle.

v. ***Masonry*** can be defined as the laying of stones, bricks, and blocks on top of each other in alternating positioning with or without the need to cohere them with bonding elements like mortar. Just like concrete, masonry works also impact a lot on the environment particularly in material acquisition and utilization.

vi. ***Welding*** is a construction fabrication process that uses heat and/or pressure to bind or join materials together. It is mainly done on metals. However, elements like thermoplastic and wood can be fused as well through welding. Welding is one way to fabricate construction elements, and it is economical in both the fabrication process and material and equipment acquisition. Welding can be done through several processes in construction. (1) Stick welding, which involves the use of welding rods and sticks that contain the filler material and flux o enable bonding; (2) Gas metal arc welding, which involves the use of a welding gun with an electrode wire that produces heat utilizing an electric arc in order to weld; (3) Hyperbaric welding that uses same principles as stick welding but underwater; Others include but not limited to gas welding, submerged arc welding, solvent welding, among others. Among other factors that make unsustainable, the welding processes play a big part in sustainability. (Mehta, 2019)

Conventional welding processes like arc welding have been known to be less sustainable in comparison with advanced welding processes. Moreover, this is because, socially and environmentally speaking, they are a health hazard due to the undesirable fumes caused by shielding gas/ flux economically through material wastage, more energy consumed during the process, and general requisition for enormous resources. However, for sustainable options, hybrid welding processes have been proven to be better at attaining sustainability parameters in the form of minimal resources, minimum wastage, maximum environmental benefits, high process efficiency, maximum cost saving and minimum energy consumption. (Mehta, 2019)

vii. The process of finishing or completing the construction entails adding the final details and elements to a structure, making it ready for use. This involves various tasks such as glazing, flooring, painting, wallpapering, and plastering, among others. While these activities primarily focus on enhancing the aesthetic appeal, they also play a significant role in ensuring the safety and functionality of the final construction product.

viii. The construction projects are classified functionally in projects' different categories that are Infrastructure construction, which mainly comprises roads, railways, tunnels, highways, and bridges, industrial construction projects, which entail industries, factories, pipelines and other manufacturing plants, and finally, building construction which is most common and involves residential and commercial building construction projects.. (Mahdi, 2015)

e) ***Project Management and Coordination***: Effective project management is crucial during the execution phase to ensure efficient coordination of various activities, subcontractors, and suppliers, monitor progress, manage risks, and address any issues or changes that may arise. It includes regular communication with stakeholders, scheduling, cost control, and monitoring of project milestones and deliverables.

f) ***Quality Control and Assurance***: Monitoring and ensuring the quality of materials, craft, and compliance with building codes, regulations, and industry standards. Conducting inspections, tests, and certifications to verify compliance and rectify any deficiencies or deviations from the project specifications.

g) ***Health and Safety***: The execution phase prioritizes the health and safety of workers and stakeholders involved in the construction project. Safety protocols and practices are enforced, and regular safety inspections and training sessions are conducted to minimize the risk of accidents and ensure a safe working environment.

h) Environmental Considerations involves Implementing environmental management practices to minimize the project's impact on the environment. It may include waste management, pollution control, erosion and sedimentation control, and energy efficiency measures.

i) ***Stakeholder Communication***: Maintaining effective communication with stakeholders, including the project owner, architects, engineers, subcontractors, suppliers, and local authorities. Providing regular updates, addressing concerns, maintaining positive relationships, and ensuring alignment with project requirements.

j) ***Progress Monitoring and Reporting***: Regular monitoring of project progress, including tracking timelines against project schedule, costs, and resource utilization, is essential during the execution phase. Project reports and updates are generated to provide stakeholders with timely information on the project's status, potential risks, and any necessary adjustments to the construction schedule or budget.

k) ***Project Documentation***: Accurate and comprehensive documentation is maintained throughout the execution phase. It includes recording project progress, change orders, materials delivered, site conditions, inspections, and other relevant information. Documentation is a reference for future project maintenance, legal purposes, and post-construction evaluations.

l) ***Change Management***: Managing any changes or modifications to the design, scope, or specifications that may arise during the construction phase. Evaluating the impacts of changes, obtaining approvals, and implementing the necessary adjustments.

m) ***Handover and Closeout***: At the end of the execution phase, the completed project is handed over to the client or owner. It involves final inspections, testing, and verifying compliance with contractual obligations. Closeout activities are also carried out, such as finalizing financial aspects, resolving outstanding issues, and archiving project documents.

2.3. Aspects of Sustainability on Construction Projects

Sustainability on construction projects focuses on implementing sustainable practices throughout the lifecycle project. For example, during the design phase, the form of meticulous material selection for the project, eco-friendly project design or green design, and design layout of the permanent facility to gain from natural light, ventilation, and solar energy, among others. Most of these practices done during the design phase have a powerful influence on the overall sustainability achievement of construction projects.

During the construction phase, several factors are considered to attain sustainability, including waste management, site energy efficiency use, management and emissions control, material selection and management, water management and efficiency use, indoor air quality management, and community and social aspects. These practices are often employed; however, benchmarks for ascertaining their performance are often difficult to quantify.

2.3.1. Construction and Demolition Waste Management.

Construction and demolition wastes come from construction, renovation activities and demolition of buildings, roads, and bridges. This waste, commonly known as construction and demolition (C&D) waste, includes a wide range of materials such as damaged glass, plastics, steel, excess mortar, excess concrete, broken blocks and bricks, grass, excavated soil, wood, and various types of scrap like formwork and shuttering timber and boards. (Tahir Noor, 2020,).

Sustainability efforts in the context of C&D waste management focus on how these waste materials are handled and processed. It is crucial to address this aspect of construction to minimize the environmental impacts associated with waste disposal and to maximize resource efficiency.

One of the key strategies employed to tackle C&D waste is the principle of "reduce, reuse, and recycle." The aim is to reduce the overall generation of waste by ensuring accurate material quantity estimations with precise measurements. This helps to avoid unnecessary excess material usage and subsequent waste generation. Additionally, materials like timber can be efficiently utilized to achieve maximum productivity, reducing the need for additional resources. (Jose-Luis Galvez-Martos, 2018)

Another approach is the emphasis on reusing materials whenever possible. Reusable materials, such as salvaged timber, bricks, or fixtures, can be collected, sorted, and stored for future use in construction projects. This promotes resource conservation and reduces the demand for new materials.

For materials that cannot be reused, recycling is an essential step. C&D waste can be sorted and sent to recycling facilities where materials like concrete, metal, and plastics can be processed and transformed into new products or used as raw materials for other industries. Recycling reduces the extraction of virgin resources and helps close the material loop, contributing to a more circular economy.

Proper waste management practices for C&D waste also involve considering the disposal of hazardous or controlled materials. These materials, such as asbestos, lead-based paints, or certain chemicals, require special handling to ensure they do not pose environmental risks. Compliance with regulations and appropriate disposal methods are crucial in safeguarding the environment and human health.

2.3.2. Energy Efficiency and Management during construction

Considering the array of prospects and options available, ensuring efficient energy management, and controlling emissions are vital for promoting sustainable progress. Energy efficiency in design entails creating structures with energy-efficient lighting, heating, ventilation, and air conditioning systems. Energy efficiency during construction can be achieved through diverse strategies, including the incorporation of energy-efficient HVAC and lighting systems. (Anisah, 2017), and renewable energy sources such as solar or wind energy. Reducing greenhouse gas emissions and other air pollutants caused by the combustion of fossil fuels is another energy management approach (Jeong Tai Kim, 2018).

The focus of construction site energy management plans is to improve the collection of construction equipment, choose alternative sources of temporary power and fuel supply at the site, and optimize construction operations. The utilization of fuel-efficient and hybrid technology in construction equipment fleets has allowed contractors to utilize cleaner energy instead of relying solely on conventional diesel-powered machinery.

Numerous sustainable approaches can be employed to optimize construction site operations. One such example is the utilization of appropriately sized construction equipment for specific tasks, which helps avoid inefficiencies associated with oversized equipment such as safety concerns and limited mobility. This approach brings benefits like fuel cost savings, reduced operational and maintenance expenses, as well as decreased noise and particulate emissions. In addition to implementing idling control systems, further reduction in machine idling can be achieved by improving material handling and unloading logistics and fostering better coordination between contractors and suppliers to minimize delivery queues.

Furthermore, implementing balanced earthwork solutions can effectively minimize the need to transport and relocate excavated soils to external locations. By incorporating GPS technologies into existing heavy equipment fleets for soil volume assessments, significant advancements can be made. This can be accomplished by reducing laborious efforts and fuel consumption, as well as minimizing the number of passes required for precise grading. For example, (Mostafa M. Shehata, 2012) indicated that employing GPS technologies for earthmoving operations could enhance time saving up to 18.57%, productivity by approximately 42% and generate cost savings up to 20% compared to conventional systems.

Finally, and perhaps most importantly, efficient temporary buildings (such as project offices, fabrication shops, storage warehouses, and worker camps) that integrate computerized system management technologies such as motion sensors for site lighting and HVAC control systems can cut energy consumption.

2.3.3. Water Efficiency and Use

As the population continues to grow and water availability faces constraints in various regions, the need for water conservation is becoming an increasingly pressing issue. (Fatma S. Hafez, 2023). Water management involves adopting waste reduction, reuse, and recycling measures to minimize water wastage and enhance efficiency. In addition to addressing water conservation, it is important to consider the energy implications associated with water usage throughout the entire process. This includes the energy resources required for activities such as water acquisition, pumping, treatment, transportation, and storage. By implementing sustainable practices, such as stormwater discharges and erosion prevention techniques, it is possible to reduce the energy footprint associated with water management.

Water consumption and quality reconstruction focus on employing ecologically friendly methods and technologies that help maintain water quality while reducing reliance on potable water sources. This involves exploring alternative water sources and utilizing them for non-potable purposes whenever possible. By implementing water-efficient technologies and practices, such as water-saving fixtures, rainwater harvesting systems, and greywater treatment systems, it becomes feasible to reduce potable water consumption while ensuring water quality is preserved. (Ludimilla de Oliveira Zeule, 2020)

In construction sites, various measures can be taken to effectively manage water without increasing usage. Installing water screens around the perimeter of the work site helps prevent runoff and ensures water stays within the construction area, reducing water loss. Using sweepers equipped with vacuums allows for efficient cleaning of the site without requiring additional water. Furthermore, choosing environmentally adapted vegetation for landscaping helps minimize water requirements by selecting plants that are well-suited to the local climate and require less irrigation.

Moreover, on-site water capture and reuse can significantly contribute to water conservation efforts. Treated greywater, which includes water from sinks, showers, and laundry, can be collected and treated for reuse in non-potable applications such as toilet flushing or irrigation. Stormwater runoff can also be captured and treated on-site to be utilized for various non-potable needs, such as sewage conveyance, vehicle washing, or landscape irrigation. By maximizing the use of captured water and reducing reliance on fresh potable water sources, construction sites can significantly reduce their water footprint and contribute to overall water conservation efforts.

2.3.4. Material Selection and Management

Sustainable material management practices involve minimizing environmental impacts and maximizing efficiency. These practices encompass various strategies, such as developing comprehensive materialistic plans, implementing automated material tracking systems, and reducing excessive stockpiling of materials.

In addition, through creating materialistic plans that consider the specific delivery locations, construction projects can optimize logistics and minimize transportation-related emissions. Efficient material delivery processes contribute to improved site productivity, as materials are readily available when needed, reducing delays and idle time.

Furthermore, by implementing automated material tracking systems, project teams can effectively monitor and manage material usage, ensuring proper inventory control and minimizing the risk of damage or loss.

Sustainable material selection is another essential aspect of material management during construction. It involves choosing materials with a low environmental impact, such as recycled or locally sourced materials, while reducing the use of materials with high embodied energy. By opting for materials with low embodied energy, such as wood, bamboo, or natural stone, projects can minimize the carbon footprint associated with construction. Additionally, utilizing recycled materials like recycled steel or glass helps reduce the demand for virgin resources and promotes circular economy principles.

Prefabrication and pre-assembled construction elements are gaining popularity in sustainable material selection due to their environmental benefits. Prefabricated components are manufactured off-site under controlled conditions, resulting in reduced waste generation during the construction phase. This approach minimizes material waste and optimizes resource utilization, contributing to overall sustainability goals.

2.3.5. Indoor Air quality during construction

The implementation of effective indoor air quality practices during the construction phase and prior to occupancy is of utmost importance. These practices play a critical role in ensuring the long-term performance of HVAC systems, as well as the comfort and health of both construction workers and future occupants. While the exact costs associated with poor indoor air quality can be challenging to quantify, its consequences have significant social implications.

One of the key concerns with inadequate indoor air quality is its potential to cause illnesses and health issues. Poor air quality can lead to respiratory problems, allergies, and other health conditions among the individuals exposed to it. Moreover, compromised indoor air quality can have detrimental effects on productivity and occupant well-being. It can result in decreased work efficiency, increased absenteeism, and general discomfort, all of which can have a negative impact on overall occupant satisfaction and performance.

Furthermore, poor indoor air quality can lead to additional operational and maintenance costs. Contaminants present in the air can adversely affect the performance of HVAC systems, leading to reduced efficiency and increased energy consumption. This, in turn, can result in higher utility bills and maintenance expenses. Additionally, addressing and remedying indoor air quality issues can require specialized services and treatments, adding further financial burden.

To address these challenges, sustainable construction practices emphasize strategies aimed at improving indoor air quality. These strategies focus on reducing or eliminating sources of air pollutants, ensuring the integrity and cleanliness of HVAC systems, and preventing potential pathways for contamination (Anisah, 2017). By minimizing the emission of pollutants from building materials, paints, adhesives, and other sources, indoor air quality can be significantly improved.

Absorptive materials commonly used in construction, such as insulation, carpeting, and ceiling tiles, have been identified as potential sources of air pollutants. These materials have the capacity to absorb and retain substances like chemical spills, moisture, and even odors. Over time, if not properly addressed, these trapped pollutants can contribute to poor indoor air quality, leading to unpleasant odors and the growth of hazardous molds. Therefore, it is essential to address these materials appropriately, ensuring they are clean and free from contaminants to maintain a healthy indoor environment.

2.3.6. Community and Societal dimensions

During construction, social issues encompass a wide range of opportunities that can have a substantial impact on project performance and have long-term consequences for the surrounding communities (James Pocock, 2016) (Qian Zhang, 2019). During the construction phase of a project, community social responsibility and stakeholder engagement programs ensure that the project team is actively involved in understanding and responding to the needs and expectations of various stakeholders. By engaging with stakeholders, including residents, businesses, government authorities, and community organizations, construction projects can establish effective lines of communication and build positive relationships.

Through stakeholder engagement, the project team can gather valuable insights and feedback on issues that directly impact the community. This includes concerns related to noise pollution, traffic management, lighting, environmental impacts, and other aspects associated with the construction process (James Pocock, 2016. By actively listening to stakeholders' perspectives and addressing their concerns, project teams can work towards minimizing negative impacts and maximizing positive outcomes for the community.

Additionally, community social responsibility programs ensure that construction projects are carried out in a manner that respects the social and cultural fabric of the community. This involves implementing measures to mitigate disruptions, promote safety, and minimize inconveniences caused by construction activities. It may include measures such as implementing construction schedules that consider peak traffic hours, providing clear and timely communication to stakeholders about project updates and potential disruptions (James Pocock, 2016, and ensuring the well-being of the community throughout the construction process.

Moreover, these programs foster transparency and accountability by keeping stakeholders informed about project milestones, progress, and any challenges faced. This helps to build trust and confidence within the community, as stakeholders feel engaged and included in the decision-making process.

International projects often encounter additional social challenges, particularly related to fostering cohesion within the workforce and the hiring of expatriate workers. Project teams need to possess cultural awareness and understanding in order to effectively manage a diverse workforce. It is crucial to continuously monitor interactions between workers from different cultural backgrounds to cultivate an inclusive work environment that respects and responds to the diverse needs of the workforce.

In the case of hiring expatriates, it is important to exercise caution and provide them with training in dispute resolution, active listening, and cultural sensitivity prior to their deployment. This helps to foster open communication and better collaboration among workers, leading to improved overall project performance.

When undertaking international projects, it is also essential to evaluate the trade-offs between equipment-intensive and labor-intensive approaches. This assessment allows for a better understanding of various factors such as safety, productivity, local employment opportunities, skills training, and other sustainability aspects, particularly in regions with high levels of local unemployment.

2.4. Barriers and Enablers to sustainability

To study the implementation practices for sustainability, a preamble into the barriers and drivers of sustainable building were identified as:

2.4.1. Government Policy and Legislation

Government influence, policies and regulations have played an essential role in shaping and creating the structure and direction of communities, societies, and organizations. Several researchers have attributed the weakness in government regulations, policies, and support, building code legislations and overall government commitment to sustainable construction practices as a barrier to effective implementations of sustainable construction practices. (Aussama Khalil, 2021).

On the plus side, Government initiatives in drafting sustainability policies within other legislations that support the economic, social and environmental aspects towards sustainability whilst pledging commitment and ensuring enforcement of these regulations and policies would be a step toward ensuring sustainability implementation and practice. Government incentives such as monetary enticement, tax holidays, and partnership initiatives, among others, have been known to be some of the ways in which different sectors and businesses have been motivated by governments to ensure adherence and cooperation to government agenda sustainability (Ali Karji, 2019). Such initiatives were tried and presented success in improve sustainability in the Spanish construction industry (Reverte, 2015).

2.4.2. Unforeseen Financial Implication

To a more significant extent, clients investing in construction projects expect a financial gain from their investments. For investors to be willing to invest in sustainable construction projects, there must be some semblance of profitability. This phenomenon makes finances one of the most influential and significant challenges in implementing sustainable construction practices. Sustainable construction involves using non-traditional techniques or improved technologies that often need more performance information due to limited previous experience, inadequate testing, and inspection, to mention a few.

These technologies can be considered high risk, which in turn can potentially yield incurring higher investment costs in construction projects (Hwang B.G and Tan, 2012).

In addition, the higher costs pertaining to the use of sustainable practices are primarily experienced in the form of initial capital cost, which usually goes up to about 25%. As a result of these unforeseen costs, Potential low profits and non-monetary payback in investment, these become daunting to clients and potentially cause a hindrance to invest in sustainable practices. (Abidin, 2010)

However, in the same spectrum, some of the new sustainability technologies like Lifecycle costing (LCC) and design solutions involved in BIM, Artificial Intelligence, to mention a few have also proven to be instrumental in improving the overall performance in ensuring sustainability within the construction phase. Lifecycle costing (LCC), which is a tool used in assessing the total performance of assets over time, including their acquisition, operating, maintenance and disposal costs helps clients and contractors a like to establish the value of the assets invested in. These can include materials, tools and equipment used in the construction, hence justifying the need for an investment.

In addition, the LCC also plays a vital role in environmental sustainability assessment in construction by providing sustainable alternatives to construction processes like type of resources to use. (Davis Langdon Management Consulting, 2014). Whereas for Building Information Modelling (BIM) technologies, improvement in project's quality, ensuring maximum collaboration, to mention a few, reduction in time wastages and other expenditures prove a boast in financial leverage. (Yu Cao, 2022)

2.4.3. Stakeholder Management and Engagement

The role of the client in implementing sustainable construction practices can be expressed firstly in the desire for a sustainable structure. This can be of significant influence as everyone within the team has to and would be working towards ensuring achieving the client's need on the project. And as such, a commitment on the part of the client would be necessary to implement the sustainable practices. (Alfredo Serpell, 2013) (Lipika Swarup, 2011).

Effective community engagement tends to have a positive impact on the overall sustainability of the project (Islam Bouzguenda, 2019), and continued cooperation, communication between communities, decision makers and other stakeholders reduces the chances of project failures.

2.4.4. Knowledge and Awareness of Sustainability

Knowledge and awareness of sustainable practices within the construction sector have been repeatedly reported as a barrier to sustainable construction practices. This has been expressed in the form of professionals' unawareness of sustainable construction, the lack thereof or inadequacy of professional knowledge concerning sustainable construction, the potential benefits and detriments to the application and misapplication of sustainable practices. (Ofori Ametepey, 2015)

Sustainability is a very ambiguous word and can often get lost in the meaning and interpretation of its understanding. This predicament can hinder sustainability implementation and or cause misguided intent on actionable deliverables concerning achieving sustainability, especially when the interpretation of what sustainability is to the individual stakeholders in the construction (Abidin, 2010). The construction sector involves several players and professionals (engineers, architects, contractors, facility managers, and project managers). It consequently means different interpretations and knowledge awareness of sustainability and the practices involved, depending on their professions, among other backgrounds.

Many a times, stakeholders are unaware of sustainable technologies, methods of installation, materials, and product information (Alsanad, 2015). Knowledge and competencies about the use and execution of these practices outside their remit can be noticed, thus, affecting the use of the unaware sustainable practices.

In addition, for sustainable practices to be implemented within the construction phase, they must have been highlighted within the project brief, either as a form of design during the phase or as a technical specification, for example, in the form of energy-efficient systems, and indoor air quality, among others.

2.5. Sustainable Indicators for Construction projects

Numerous research studies have been conducted concerning sustainability indicators that can be used within the construction sector. (Laura Monalban-Domingo, 2018) (Gholamreza Heravi, 2015), (Siew R. Y., 2016) (bregroup.com, 2023) (Sareh Rajab, 2022) (Ludimilla de Oliveira Zeule, 2020). These research studies, among many others, contributed to understanding sustainability in the construction sector. The sustainable indicators highlighted below were identified within the research studies and provided a comprehensive framework for evaluating the performance of construction projects during the execution phase.

a) ***Energy Efficiency***: Indicators related to energy efficiency measure the project's performance in reducing energy consumption and promoting energy conservation. Examples include energy use intensity, energy savings percentage, use of renewable energy sources, and reduction in greenhouse gas emissions. It includes tracking energy consumption, implementing energy-saving measures, and monitoring the use of energy-efficient equipment, lighting systems, and HVAC systems. It can be expressed as energy consumed per square meter or energy intensity per unit of construction work.
b) ***Water Conservation***: Indicators for water conservation focus on measuring the project's efforts in reducing water consumption and preserving water resources. This indicator focuses on the efficient use of water resources during the execution phase. It involves monitoring water usage, implementing water-saving measures, and tracking the use of water-efficient technologies and systems. It measures water consumption, water recycling and reuse, and the implementation of water-efficient practices, such as the use of low-flow fixtures and rainwater harvesting systems.
c) ***Waste Management***: This indicator assesses the effectiveness of waste management practices. Indicators for waste management assess the project's performance in minimizing waste generation, promoting recycling and reuse, and reducing waste sent to landfill. It measures the amount of waste generated, the percentage of waste diverted from landfills, and the implementation of recycling programs. Examples include waste diversion rate, percentage of recycled materials used, waste reduction targets, and hazardous waste management practices.

d) ***Sustainable Material Use***: Indicators related to sustainable material use evaluate the project's efforts to select environmentally friendly and resource-efficient materials. This can include metrics such as the percentage of sustainable materials used (e.g., certified wood, recycled content), embodied carbon or energy of materials, monitoring the use of low-emission materials, and environmentally preferable material sourcing practices like promoting the use of locally sourced materials to reduce environmental impacts.

e) ***Indoor Environmental Quality***: This indicator assesses the project's efforts to ensure a healthy indoor environment for occupants during the execution phase. It includes monitoring air quality, tracking the use of low-emitting materials, and implementing proper ventilation and thermal comfort measures. It can be measured using parameters such as air exchange rates, acoustic performance, volatile organic compound levels, and lighting levels.

f) ***Worker Health and Safety***: Indicators related to worker health and safety evaluate the project's efforts in ensuring a safe and healthy working environment. This can include metrics such as tracking safety incidents, monitoring compliance with health and safety regulations, and the availability of personal protective equipment (PPE) (Laura Monalban-Domingo, 2018). In addition, worker training hours, and promoting worker training and welfare programs.

g) ***Stakeholder Engagement***: This indicator evaluates the level of stakeholder engagement and participation during the execution phase. (Laura Monalban-Domingo, 2018)Indicators for stakeholder engagement assess the project's efforts to involve and communicate with stakeholders, including workers, local communities, and project partners It assesses the inclusion of stakeholders in decision-making processes (Merlina Missimer, 2017), the effectiveness of communication channels, and the establishment of mechanisms to address stakeholders' concerns and feedback. This can include metrics such as the frequency of stakeholder meetings, community satisfaction surveys, worker feedback mechanisms, and the integration of stakeholder input into decision-making processes.

h) ***Collaboration and Partnerships***: Indicators related to collaboration and partnerships assess the project's efforts to engage and collaborate with external organizations, suppliers, and contractors to enhance sustainability. This can include metrics such as the number of sustainable supplier partnerships, joint initiatives for knowledge sharing, and the use of sustainability criteria in contractor selection.

i) ***Compliance with Sustainability Standards***: This indicator measures the extent to which the project complies with sustainability standards, certifications, or green building rating systems such as LEED (Leadership in Energy and Environmental Design) or BREEAM (Building Research Establishment Environmental Assessment Method). Compliance is assessed based on specific criteria and performance metrics set by the chosen standard or certification system.

j) ***Innovation and Research***: This indicator encourages adopting innovative and research-based practices during the execution phase. This can include metrics such as the number of sustainable innovation ideas implemented, participation in research and development projects, and lessons learned documentation. It measures the implementation of new technologies, materials, and techniques that enhance sustainability and the project's contribution to research and development in the construction sector.

k) ***Community Impact***: This indicator assesses the project's impact on the local community during the execution phase through fuelling the community’s economy either directly or indirectly. (Low Sui Pheng, 2019) It includes metrics such as job creation, community engagement activities, mitigation of construction-related disruptions, and the project's contribution to the social and economic well-being of the community. (Essam Almahmoud, 2015)

l) ***Greenhouse Gas Emissions*** This indicator measures the project's carbon footprint during the execution phase. It involves tracking and reducing greenhouse gas emissions associated with construction activities, including energy use, transportation, and material production.

m) ***Biodiversity and Ecosystem Protection***: This indicator assesses the project's efforts to protect and enhance biodiversity and ecosystems. It includes tracking measures to preserve natural habitats, minimize ecosystem disruption and promote ecological restoration during the execution phase.

n) ***Financial Performance Indicators*** for financial performance evaluate the project's economic sustainability. It can include metrics such as the return on investment (ROI) of sustainable features or technologies, cost savings from energy or water efficiency measures, and the cost-effectiveness of sustainable practices compared to conventional alternatives.

2.5. SDGs and the Construction sector:

The construction phase of projects presents a crucial opportunity to align with and contribute to specific Sustainable Development Goals (SDGs) outlined by the United Nations. This section explores the relationship between SDGs and the construction phase, highlighting how sustainable construction practices can address and support the achievement of these goals.

Figure 1: SDGs supported by the construction sector. (By Author).

2.5.1. SDG 3: Good Health and Well-being:

SDG 3 focuses on ensuring healthy lives and promoting well-being for all individuals. Although the direct relationship between SDG 3 and the construction sector may not be apparent during the construction phase, there are indirect ways in which the sector can contribute to this goal. For instance, the construction sector can prioritize the health and safety of construction workers by implementing stringent safety protocols, providing proper training and protective equipment, and ensuring safe working conditions. This can help reduce accidents, injuries, and occupational health hazards, promoting the well-being of construction workers. Additionally, sustainable construction practices that prioritize indoor air quality, natural lighting, and noise reduction can contribute to creating healthier and more conducive built environments for occupants. (Zhi-Jiang Lui, 2020)

2.5.2. SDG 6: Clean Water and Sanitation:

SDG 6 emphasizes the availability and sustainable management of water and sanitation for all. The construction sector plays a crucial role in water management, particularly during the construction phase. Sustainable construction practices can be implemented to minimize water consumption, promote water conservation, and prevent water pollution. Construction sites can implement measures such as rainwater harvesting, wastewater treatment, and erosion control to reduce water usage and prevent the contamination of water bodies. Additionally, the construction sector can contribute to improving access to clean water and sanitation facilities in communities by integrating water-efficient plumbing systems and constructing appropriate sanitation infrastructure. Gourbran, 2019)

2.5.3. SDG 7: Affordable and Clean Energy:

During the construction phase, sustainable construction practices promote SDG 7 by incorporating energy-efficient design principles and renewable energy technologies. This includes optimizing building envelope insulation, utilizing energy-efficient HVAC systems, integrating solar panels or wind turbines for on-site energy generation, and implementing smart energy management systems. By prioritizing energy efficiency and clean energy sources, the construction sector can reduce reliance on fossil fuels, lower greenhouse gas emissions, and contribute to affordable and clean energy access. (Zhi-Jiang Lui, 2020)

2.5.4. SDG 8: Decent Work and Economic Growth:

SDG 8 focuses on promoting sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. The construction sector is a significant source of employment and economic activity. During the construction phase, the sector can contribute to SDG 8 by providing job opportunities, promoting fair and inclusive labor practices, and ensuring decent working conditions for construction workers. This includes paying fair wages, providing training and skill development opportunities, and adhering to labor regulations and standards. Sustainable construction practices can also stimulate economic growth by fostering innovation, promoting local procurement and supply chains, and supporting the development of a skilled workforce.

2.5.5. SDG 9: Industry, Innovation, and Infrastructure:

The construction sector is directly linked to SDG 9, since it involves the development of infrastructure and drives innovation in the industry. Sustainable construction practices support this goal by integrating innovative and environmentally friendly construction techniques and materials. This may include the use of prefabrication and modular construction methods, adoption of green building certifications, implementation of digital technologies for efficient project management, and promoting sustainable transportation systems in construction logistics. By fostering innovation and sustainable infrastructure development, the construction sector can contribute to economic growth, job creation, and resilient infrastructure. (Gourbran, 2019)

2.5.6. SDG 11: Sustainable Cities and Communities:

Sustainable construction practices such as designing buildings and infrastructure with a focus on environmental, social, and economic sustainability have an influence on SDG 11. This involves incorporating principles of urban planning, promoting mixed land use, enhancing accessibility, ensuring adequate green spaces, and improving waste management systems. By prioritizing sustainable urban development, the construction sector can create inclusive, safe, resilient, and sustainable cities that enhance the quality of life for residents.

2.5.7. SDG 12: Responsible Consumption and Production:

Sustainable construction practices during the construction phase contribute to SDG 12 by promoting responsible consumption and production patterns. This includes adopting measures to reduce waste generation, promoting recycling and reuse of construction materials, optimizing material usage through efficient planning, and implementing sustainable procurement practices. By prioritizing responsible consumption and production, the construction sector can minimize the environmental impact associated with resource extraction, construction waste, and excessive material consumption. (Kofi Agyekum, 2021)

2.6. Chapter summary

Sustainability in the construction sector referred to the integration of environmentally friendly practices, social responsibility, and economic viability throughout the lifecycle of a construction project. It involved considering the impacts of construction activities on the environment, society, and the economy, with the aim of creating long-lasting, resource-efficient, and socially equitable structures.

The construction phase of a project section highlighted its criticality in a construction project since it was where the plans and designs were translated into physical structures, and highlighted encompassed activities such as site preparation, material sourcing, construction and assembly, transportation, and waste management. It required effective project management, coordination, and collaboration among various stakeholders to ensure the construction activities were executed efficiently, safely, and following the project requirements.

However, several barriers and enablers that affected the implementation of sustainability in the construction sector were identified and these included Government policy and legislation, unforeseen financial implications, stakeholder management and engagement, knowledge, and awareness of sustainability. These barriers needed to be addressed through government support, financial strategies, stakeholder engagement, and knowledge dissemination to enable effective implementation of sustainable practices in the construction sector.

The different sustainability indicators provided insights into effective strategies, best practices, and areas for improvement. They contributed to the body of knowledge on sustainable construction and provide guidance for industry professionals, project managers, and policymakers in enhancing and assessing sustainability performance during the construction phase.

In addition, the construction phase of projects provided a significant opportunity to align with specific SDGs. Through sustainable construction practices, such as energy-efficient design, innovative infrastructure development, sustainable urban planning, and responsible consumption and production, the construction sector could actively contribute to the achievement of SDGs 3, 6, 7, 8, 9, 11, and 12. By addressing the unique challenges and opportunities during the construction phase, the sector could promote sustainable development, enhance environmental performance, and contribute to a more sustainable and resilient future and hence the need to study different approaches to ensuring sustainable practices and performances during the construction phase of projects.

3. Methodology

This chapter presents the methodological approach that was followed to meet the objectives of this research. This chapter discusses the research methodology, research approach, the data collection and sampling strategy and the interview process used for the research study. The study follows a mixed approach of qualitative and quantitative research. The chapter presents the methodological steps that were followed to develop the new assessment tool.

3.1. Research Design and Approach

The research design consists of the complete structure of execution of the research study. There were several evaluation techniques that could help in assessing the sustainability of a construction project using assessment frameworks and tools (Patrick V. Mangili, 2019). These involved.

a) Framework assessment based on indicators, which used performance indicator metrics to measure progress, performance and provide parameters for recognizing areas that require improvement.
b) Lifecycle assessment which involved assessing the environmental life cycle, social life cycle assessment and life cycle costing techniques. Unlike the other techniques, this assessment method was quite complex, time consuming and presenting uncertainty in quality of data especially when the data could not be available when required.
c) Comparative analysis. This assessment involved the study of the ratio of financial and social benefits to the related environmental effects. This assessment method was more considered rather simplified, and ideal for comparative study.

Based on the above descriptions, it was safe to conclude that, the indicator method of assessment was considered best for attaining the objectives of the research given its simplicity, practicality, the time constraint, availability and quality of data, and singularity of the study.

3.2. Research Questions

The focus of study was to ascertain the sustainability of construction projects and assess the practicality of implementing sustainable indicators during the construction phase of a construction project. The sub questions that the research study was addressing were the following based on case studies.

1) What were the current sustainable practices being implemented during construction phase?
2) How were these practices being assessed to ascertain project performance?
3) Could a proposed framework help ascertain sustainability performance of construction projects?

3.3. Case study Selection

Based on the type of research, there were high levels of uncertainty on the type of data that was to be collected hence was the researcher's ability to influence behavioural occurrences, and the degree of attention paid to current phenomena had to be considered while choosing an acceptable research method (Richard Fellows, 2022). In addition, the primary research was initially answering a "how" question. Second, the researcher has little to no influence over behavioural events with interviewees choices, making it impossible to change the pertinent behaviours.

Finally, because this research focused on contemporary occurrences, and factual data was a necessity, then case study approach was observed to be the most recommended as a research technique, according to (Richard Fellows, 2022) since "a "how" question was being addressed." Based on the above, the case studies were selected based on the project’s consideration and inclusion of sustainability concerns, level of experience, diversity of scope, and ease of access to project data involved in construction.

4. Case study and Frameworks

This section identifies the existing frameworks that have been done previously in relation to the implementation of sustainability practices on construction projects. It also defines the case studies selected for this research.

4.1. Existing Frameworks

Several researchers have proposed frameworks for assessing and implementing sustainability in construction. For the purposes of this study, a few were selected owing to the objectives of this study.

4.1.1. Framework 1: José Fernando de Carvalho Ferreira

According to José Fernando de Carvalho Ferreira (Ferreira, 2016) the framework proposed by Sikdar in 2003 was utilized which consisted of seven dimensions and three hierarchical levels. This framework addressed and overcame some of the limitations associated with the widely adopted Triple Bottom Line (TBL) framework. In Sikdar's framework, the first hierarchical level, which was one-dimensional, aligned with the TBL and included the social, economic, and environmental dimensions. The second hierarchical level, which was two-dimensional, combined the one-dimensional levels. Lastly, the tridimensional level which encompassed aspects that simultaneously promote economic, social, and environmental development. The model's logical structure comprised seven dimensions, each containing one or more themes. These themes included economic indicators, social indicators, environmental indicators, economic and environmental indicators, social and environmental and finally social and economic indicators.

José Fernando de Carvalho Ferreira’s study developed a model for sustainability indicators (SI) specifically designed for the largest Portuguese companies. The research revealed that the developed model was applicable since most indicators could be calculated for at least one company. It also identified an existing gap between the availability and quality of both financial and non-financial data, which had implications for the indicators and the resulting conclusions drawn from them. The main limitations identified included variations in methods, limited data consolidation, omissions, and inconsistencies. Despite those limitations, there was a certain degree of agreement among companies regarding certain aspects that need to be sustained. Many of the identified constraints could be attributed to the absence of regulations governing specific types of data. Consequently, it was essential to recognize and prioritize the use of Sustainability indicators and sustainability reports as valuable scientific tools rather than mere marketing instruments.

4.1.2. Framework 2: Excerpt from Robert et al

Based on an excerpt from Robert et al, (Robert V. Thomas, 2023), their research study proposed a conceptual framework for sustainable construction that could be considered a comprehensive list of specifications with indicators, criteria, and sub-criteria without replication under each pillar of sustainability, contributing to the objectives of sustainable construction. Their framework distinguished and separated indicators into four categories: socio-cultural, economic, technical, and environmental, to reduce the overlap and interconnectedness of the various criteria contrary to most other frameworks.

According to their research, the social-cultural indicators could be identified through (1) community participation that involved the creation of job opportunities that support and create a demand for the participation of unskilled labour within that community. Furthermore, this indicator could be measured by the utilisation level of these local resources (human). (2) Awareness was another indicator within the social-cultural perspective that could be measured by assessing stakeholders' practical awareness and overall knowledge of the sustainability concept. (3) Adaptability and satisfaction as an indicator within the social-cultural perspective looked at how flexible technology could be made to ensure that changing needs of the users would be addressed. The receptibility and acceptance to using flexible non-permanent fixed designs contrary to traditional measures indicate sustainability. Finally, (4) the social costs and benefits indicator refers to the ability of sustainable practices to contribute to additional benefits aside from the intended objectives of the construction project.

Within the economic sustainability spectrum, Robert et al. looked at the affordability of technological options necessary to achieve sustainability on a construction project. Their framework considered the following indicators to determine sustainability from an economic perspective. (1) Lifecycle cost optimisation that considered and measured initial raw material, transportation, and processing costs; operational and maintenance costs; and environmental and waste management costs; and studied the reuse/recycle potential of the technological option. (2) it looked at the feasibility of resources as an indicator of the affordability and ease with which the technological option for sustainability was to ensure sustainability. In other words, the easier the acquisition/access of sustainable technological resources, the more sustainable the option. And finally, (3) process duration, which considers the duration through which all processes necessary to make the technological option for sustainability were achieved. In other words, the shorter the duration implied, the more sustainable the option.

In the technological sustainability category, the sustainable indicators highlighted were (1) Strength which could be measured by assessing the potential strength of the technological option to meet specific standards for construction. (2) Durability could be identified by the time taken for the material or technological option to efficiently serve its specific functionality as specified by its codes.

Finally, in the environmental sustainability category, Robert et al. proposed (1) Environmental quality as an indicator for determining environmental sustainability by assessing the quality of air, water and noise generated due to technological practice. (2) Resource efficiency that assessed the way the materials, water, land and energy were utilised for maximum efficiency in order to ensure environmental sustainability. The efficiency of these elements could be determined in different ways, for example, land efficiency- by the amount of utilisation of the site premises, as well as by how much impact the construction process has had on the natural land through resource extraction processes, Energy efficiency through measuring overall energy requirement concerning embodied energy and operational energy, material efficiency through evaluating actual quantities of materials used in comparison to acquiring as well as how much of the material has been outsourced locally through the reuse/recycle process and finally water efficiency by the overall quantity required for the construction process, operational process to actual units consumed on the project.

4.1.3. Framework 3: Excerpt from Torres et al

Torres et al. conducted a study that identified 54 potential measures that project teams could apply during construction to improve the overall sustainability of their project. These Construction Phase Sustainability Actions were catalogued, categorized, and rated to aid project teams in their selection and implementation. Furthermore, a Construction Phase Sustainability Action screening tool was created to help projects identify relevant CPSAs for their projects based on project-specific sustainability priorities and compatible project characteristics.

Their research resulted in input- and output-oriented sustainability indicators for capital project building. The CPSA Implementation Index, for example, an input-oriented indicator that could be used to measure and track the level of work was required to implement selected CPSAs. In contrast, 59 output- and CPSA-oriented measures were calculated. A seven-step work procedure was also established to provide additional direction for project teams to integrate CPSA selection/implementation and accompanying research tools into capital project frameworks. Paperless Communication and Construction Documentation, Sustainable Temporary Facilities, and On-Site Power Source received additional implementation assistance. Owners and construction contractors will benefit from the conclusions of this study. (Torres, 2014)

Furthermore, several organizations have taken up the initiative to ensure sustainability adherence by coming up with criteria for the assessment in the sustainability performance of construction projects. These private organizations include BREAM (Building Research Establishment Environmental Assessment Method, LEED (U.S green building council), DGNB – Deutsche Gesellschaft für Nachhaltiges Bauen e.V.)]. During this study, these sustainable performances were to some extent incorporated/used as a guidance within/to develop this research's framework tool.

4.1.4. Framework 4: BREAM (Building Research Establishment Environmental Assessment Method)

BREEAM, or Building Research Establishment Environment Assessment system, is a sustainability performance assessment system developed by the BRE group (Building Research Establishment) that is used to guarantee projects meet sustainability targets while also maximizing time efficiency. BREEAM evaluates the design, specifications, construction, and use of a project building using established and recognized benchmarks. These metrics are used to investigate many sustainability categories such as reduced carbon emissions, low impact design, climate change adaption, ecological value, and biodiversity protection. When introduced early in the project, BREEAM achieves the best sustainability results of enhanced asset value after completion, minimizing risks, and less life cycle costs. (bregroup.com, 2023)

The BREEAM assessment method evaluates buildings based on a range of sustainability criteria, including energy and water use, materials and resources, pollution, health and well-being, and ecology. These criteria are organized into ten main categories:

a) Management - This category assesses how the building is managed, including its policies, procedures, and strategies for sustainability.

b) Health and Wellbeing - This category evaluates how the building supports the health and well-being of its occupants, including air quality, lighting, and comfort.

c) Energy - This category evaluates the energy performance of a building, including its heating, cooling, and lighting systems, as well as its renewable energy sources.

d) Transport - This category assesses the accessibility and sustainability of the building's transport links, including public transportation and cycling facilities.

e) Water - This category evaluates the water efficiency of the building, including its water consumption and management systems.

f) Materials - This category assesses the sustainability of the building's construction materials, including their environmental impact, durability, and recyclability.

g) Waste - This category evaluates the building's waste management practices, including its recycling and disposal systems.

h) Land Use and Ecology - This category assesses the impact of the building on the surrounding environment, including its use of land, biodiversity, and ecological features.

i) Pollution - This category evaluates the building's impact on air, water, and soil pollution, including its emissions and waste disposal practices.

j) Innovation - This category assesses any innovative or exceptional features of the building that go beyond the standard sustainability criteria.

The BREEAM assessment method uses a points-based system to evaluate buildings. Buildings earn points for their performance against each criterion, and the total number of points earned determines the level of certification, which ranges from Pass to Outstanding.

Overall, the BREEAM assessment method is widely recognized as a leading sustainability assessment method and certification scheme for buildings in the UK and internationally. It has been adapted for use in several other countries, including the USA, China, and Australia, to address local sustainability challenges and conditions.

4.1.5. Framework 5: DGNB

The DGNB Certification System is a comprehensive sustainability assessment method and certification scheme for buildings in Germany. It was developed by the German Sustainable Building Council (DGNB), a non-profit organization that promotes sustainable building practices and aims to reduce the environmental impact of buildings.

The DGNB Certification System evaluates buildings based on a range of sustainability criteria, including environmental, economic, and social aspects. These criteria are organized into six main categories, each with its own subcategories and specific criteria:

1. Ecology: This category assesses the environmental impact of the building, including its energy and water use, materials and resources, and overall environmental performance.

2. Economy: This category evaluates the economic viability of the building, including its life cycle cost analysis, cost efficiency, and return on investment.

3. Sociocultural and functional quality: This category assesses the usability, accessibility, and adaptability of the building, as well as its social and cultural impact.

4. Technical quality: This category evaluates the construction quality, durability, and building services of the building.

5. Processes: This category assesses the project management, stakeholder engagement, and innovation aspects of the building.

6. Site quality: This category evaluates the location, transport connectivity, ecology, and other aspects related to the site where the building is located.

The DGNB Certification System uses a points-based system to evaluate buildings. Buildings earn points for their performance against each criterion, and the total number of points earned determines the level of certification, which ranges from Bronze to Platinum.

The DGNB Certification System also provides guidance and support to building owners, architects, and engineers throughout the design and construction process, with the aim of improving the sustainability of buildings and reducing their environmental impact. This includes the use of best practices, innovative technologies, and sustainable materials and resources.

Overall, the DGNB Certification System is widely recognized as a leading sustainability assessment method and certification scheme for buildings in Germany and is increasingly being adopted in other countries as well.

4.2. Case studies

Hindustan Construction Company Limited, commonly known as HCC, was founded in 1926 and is headquartered in Mumbai, India. It operates in various sectors such as transportation, power, water, and infrastructure development. HCC has expertise in engineering, procurement, and construction services for infrastructure projects. The company is involved in the construction of highways, bridges, tunnels, dams, hydropower projects, and urban infrastructure. HCC has been involved in several significant projects in India and abroad. Some notable projects include the construction of the Bandra-Worli Sea Link in Mumbai, the Kolkata Metro, the Kishanganga Hydroelectric Plant in Jammu and Kashmir, and the Delhi Metro Rail Project. other milestones include India’s curvature dam 1977, metro station 1996, thermal power plant in 1956, largest hydroelectric power plant in 2007, India’s largest nuclear power plant in 2010, among others. (HCC, 2023)

Skanska was founded in 1887 and has its headquarters in Stockholm, Sweden. It is one of the world's largest construction and development companies, operating in Europe, North America, and other regions. Started as a maker of concrete the ideal foundation for everything that’s built to last and later grew to construct churches, roadways, and power plants. Skanska provides a wide range of construction and development services, including building construction, civil engineering, infrastructure development, commercial property development, and residential construction. Skanska has been involved in numerous high-profile projects globally. Some notable projects include the construction of the Karlatornet skyscraper in Gothenburg, Sweden, the renovation of the United Nations headquarters in New York City, and the development of the Elizabeth line (Crossrail) in London, UK. (Skanska, 2023)

Skanska places a strong emphasis on sustainability and has established itself as a leader in green construction practices. The company aims to minimize its environmental impact, promote social responsibility, and prioritize health and safety in its operations. Skanska operates in several countries worldwide, including Sweden, Norway, Finland, Denmark, the United Kingdom, the United States, Poland, and Czech Republic. It has a significant presence in both the European and North American markets. (Skanska, 2023)

4.3. Chapter summary

In this chapter, different frameworks were studied. Firstly, José Fernando de Carvalho Ferreira (Ferreira, 2016) described the utilization of Sikdar's framework to organize a model for sustainability indicators. Sikdar's framework consisted of seven dimensions and three hierarchical levels, addressing limitations of the widely adopted triple bottom line framework. The model comprised seven dimensions, each with themes representing significant sustainability issues in companies, monitored by sustainability indicators. The research focused on developing an SI model for the largest Portuguese companies. While most indicators were calculable, there was a gap in availability and quality of financial and nonfinancial data, affecting the indicators and resulting conclusions. Limitations identified included variations in methods, data consolidation, omissions, and inconsistencies. Despite that, companies showed agreement on certain aspects. The constraints were attributed to the lack of data regulation. The study emphasized the value of sustainability indicators and sustainability reports as scientific tools rather than marketing instruments.

Secondly, Robert et al proposed conceptual framework for sustainable construction which provided a comprehensive set of specifications, indicators, criteria, and sub-criteria under each sustainability pillar. It aimed to support the objectives of sustainable construction by assisting stakeholders in selecting and evaluating appropriate construction practices. The framework also offered flexibility to accommodate different situations while staying within the bounds of sustainability, making it suitable for universal adoption. However, the framework was still in the conceptual stage and required practical application and testing. One of its strengths was the clear distinction and separation of indicators into sociocultural, economic, technical, and environmental categories, reducing the overlap commonly found in other frameworks.

Thirdly, Torres et al. conducted a study that identified 54 potential measures that project teams might apply during construction to improve the overall sustainability of their project. These Construction Phase Sustainability Actions were catalogued, categorized, and rated to aid project teams in their selection and implementation. Furthermore, a Construction Phase Sustainability Action screening tool was created to help projects identify relevant CPSAs for their projects based on project-specific sustainability priorities and compatible project characteristics. Their research resulted in input- and output-oriented sustainability indicators for capital project building.

Fourthly, BREEAM, which is a widely recognized assessment system developed in the UK. It assesses the environmental performance of buildings and infrastructure projects. BREEAM evaluates various categories, including energy, water, materials, waste, pollution, health, and wellbeing. It provides a rating system that helps project teams improve sustainability performance. In addition, BREEAM assessment uses a similar approach, with projects assessed against a set of criteria grouped into categories such as energy, water, materials, waste, pollution, health, and wellbeing. Each criterion is assigned a weightage, and the project's performance in each criterion is evaluated and scored. The scores are then aggregated to calculate the final rating, which ranges from Pass to Outstanding.

Finally, The DGNB, which is a German-based system that focuses on holistic sustainability and covers various aspects, including environmental, economic, and sociocultural factors. It provides a comprehensive framework for assessing buildings and urban districts, considering criteria such as energy efficiency, resource conservation, indoor environmental quality, and social responsibility. DGNB assessment considers a wide range of criteria related to ecological, economic, sociocultural, technical, and process quality aspects. The assessment process involves a comprehensive evaluation of the project's sustainability performance using a point-based system. The project is scored against the criteria, and the accumulated points determine the final rating, which can range from Bronze to Platinum.

In contrast and addition to the above frameworks, the proposed framework tool designed in this study looked at how the eventual sustainability practices were performing during construction, so as to highlight where improvements would be required and for proper tracking and monitoring.

5. Proposed Framework tool Development

In this section, the methodological steps were taken to develop the assessment tool. Key sustainable indicators that served the objective of the research were identified, ranked, and then were used in the design of the framework tool.

5.1. Identification of Key Sustainable indicators for the Framework

Several indicators were observed to be vital and relevant for this study from the identified indicators within the literature review. The criterion for defining these sustainable indicators as key for this study was based on relevance to the construction phase of the project, frequency of acknowledgement as key by other studies (Wen-der Yu, 2018) and their applicability to the study. In addition, indicators whose performance was difficult to quantify were eliminated for this study, and those critical for the design phase were excluded. The identified vital indicators were categorized in the form of energy management, water management, waste management, material selection, recycling and reuse are highlighted as shown below.

Table 1; Showing identified Key sustainable indicators. (Adapted by Author)

No.	Indicators	Description
Environmental indicators		
Energy management	Energy use	The quantity of energy used in the construction process
	Renewable energy	The quantity of energy consumed from a renewable energy source (solar, wind)
Water management	Water consumption	Amount of water consumption during the construction process
	Recycling water	Amount of water consumption from recycling water used for construction activities

Waste management	Waste management	Amount of waste collected and delivered from the building site
	Material recycling/reuse	Quantity of recycled and/or reusable material for construction activities
Health and safety	Air pollution	Number of emissions arising from construction activities, equipment and machinery
	Water pollution	Amount of polluted water because of site construction activities during construction
	Nosie pollution	Amount of construction noise complaints received from the neighbours during construction
Social indicators		
Construction and public safety	Construction health and safety	The number of construction site worker injuries
	Local community safety	Number of injuries of people within the neighbourhood
Employee relations	Employee welfare	The level of employee well-being on site
	Employee training and development	Training hours for workers and sustainability during the construction
	Employee satisfaction and retention	The level of job satisfaction of employees during the project's construction
Local community	Invoked on local community	The level of community satisfaction during the construction phase through conducting a survey
	Social responsibility	Diverting non-hazardous construction and dedicated offsite fabrication,

		demolition, and excavation west of the project, when applicable, from landfills

5.2. Design of the Framework tool

The design of the framework tool was based on the key indicators that were selected from the general indicators identified by different studies and institutions. These key indicators were categorized under environmental and social perspectives. The social indicators involved in the social perspective were related to the project team members' and local community wellbeing. Whereas in the environmental perspective, the environmental indicators were related to environmental impacts.

SUSTAINABILITY ASSESSMENT FRAMEWORK TOOL	
Personal information	
Name	
Position	
Professional experience (years)	
Previous construction projects	
Previous project locations	
Primary areas of expertise	
Sustainability Implementation	
Construction project	
Project phase	
Construction activity	
Social perspective	
Health and safety	
No. Accident/incident reports	
Frequency of incident/accidents	
Noise reduction	
Decibels levels	
No. complaints	
Traffic management	
Timing of traffic during work	
No. traffic generated noise complaints	
No. road damages	
Availability of first respondent teams	
No. registered positive first respondent impacts	
Dust and air quality management measures in place	
Community participation	
Percentage no. local employees (as a fraction of total employees)	
Percentage of diversity inclusiveness (gender,age, race,... etc)	
Percentage of education and training opportunities	
Percentage of corporate social responsibility within the community	
Local procurement (can be materials, local restaurants support, ..etc)	

Figure 2: Part 1 of the sustainability assessment framework tool. (By Author).

Figure 2, *Figure 3*, *and Figure 4* showed the general outlook for the sustainability assessment framework tool that was developed to act as a tool for assessing sustainability during the construction phase of a project. Under the category of “Personal information”, the ‘name’, and ‘Position on the project’ required the respective fields for the respondent for accountability purposes. The other fields “professional experience’, ‘Previous construction projects’, ‘previous project locations’ and ‘Primary areas of expertise’ fields were required specifically for research purposes to confirm the respondents’ level of experience, knowledge, and awareness, as well as skills.

Waste disposal management plans in place	
Environmental perspective	
Material use efficiency	
Material Quantity required per unit workdone	0
Material Quantity used per unit workdone	0
Material Quantity waste generated per unit workdone	0
Reuse/recycleability	
Type of renewable materials reused	
Type of sustainable material used	
Percentage/volume of recycled content	
Percentage of renewable materials used (concrete, paint, timber,...etc)	
Percentage reduction in carbon footprint of the mix	
Waste reduction	
Waste generated per unit of workdone	
Percentage/volume of waste generated that is repurposed	
Percentage/volume of waste recycled	
Percentage/volume of waste diverted to landfill	
Energy efficiency use	
Type of tools and equipments used	
Other types of tools and equipment used	
Type of energy systems used	
Other types of energy systems used	
Reference energy performance benchmark	
Last maintenance of the tools used	
Any heating and cooling equipment used	
Type of lighting used	
Reduction in energy consumption per unit workdone	
Percentage of renewable resources energy used over the total energy used	
Reduction in fuel consumption per unit material transported	
Reduction in lighting energy consumption per unit workdone	
Water conservation/ efficiency use	
Percentage/ volume reduction water consumption per unit workdone	

Figure 3: part 2 of the sustainability assessment framework tool continued. (By Author)

Percentage water used from recycled sources over the total water used	
Reduction in water consumption during cleanup, transportation	
Sustainability performance	silver

Figure 4: sustainability assessment framework tool final part. (By Author)

The sustainability implementation section, the ‘construction project’ required to define the current project from which the research was being studied, the ‘project phase’ field required to define the current project phase status. For purposes of this study, the project phase that was targeted was the construction/execution phase. And the last field within this section was the ‘construction activity’ which required selecting the type of activity that the respondent was responsible for. As shown in *Figure 5*, the options to choose from were ‘concrete works’ and ‘painting works.

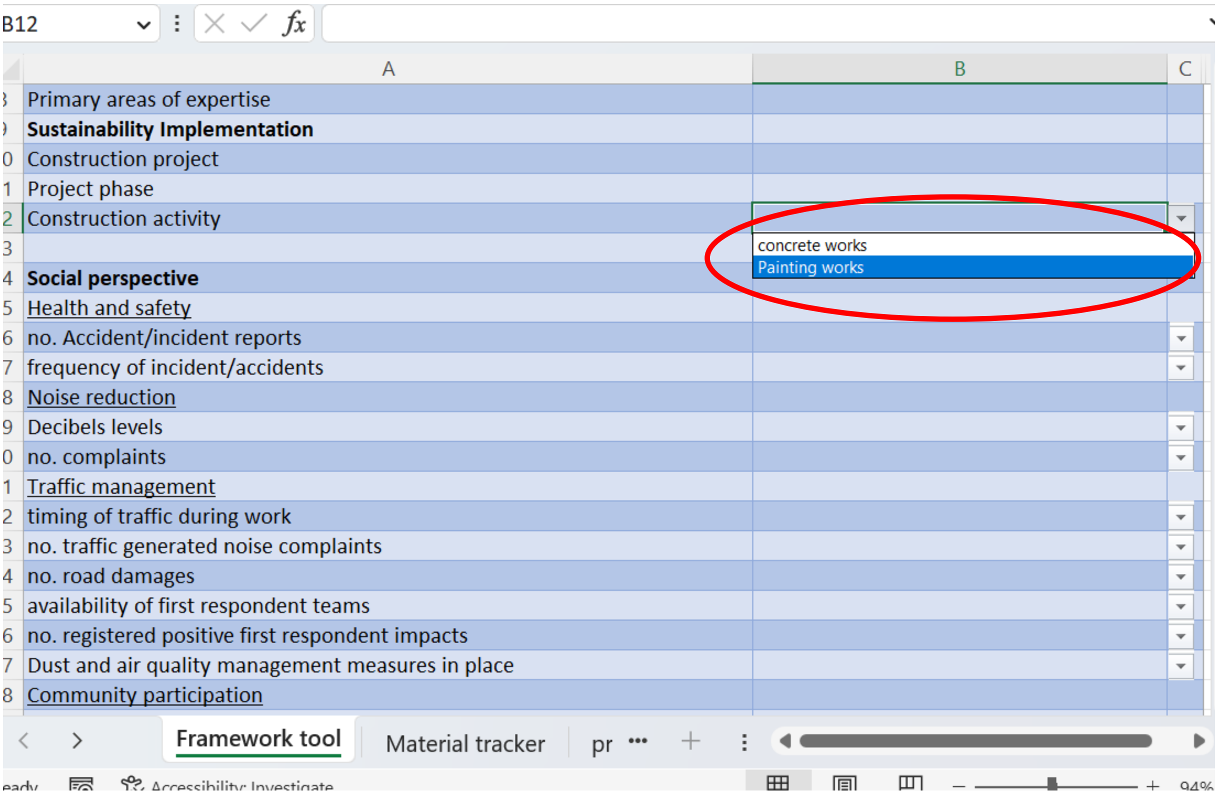


Figure 5: showing the different types of construction activities to be selected as circled in red. (By Author)

As previously explained, the framework indicators were categorized into social, and environmental perspectives. In the social perspective, the indicators were categorized under ‘health and safety reporting’, ‘noise reduction’, ‘traffic management’, and ‘community participation’.

Under the Health and Safety reporting section, the respondents were asked to define the number of accidents, near misses, and other incident reports quantified in numbers. The respondent was required to select a number from 0 to 5no. And the other aspect was the frequency or the degree at which the incidents, near misses, or accidents occurred form of weeks (from 0-5) as shown in *Figure 6* highlighted in red.

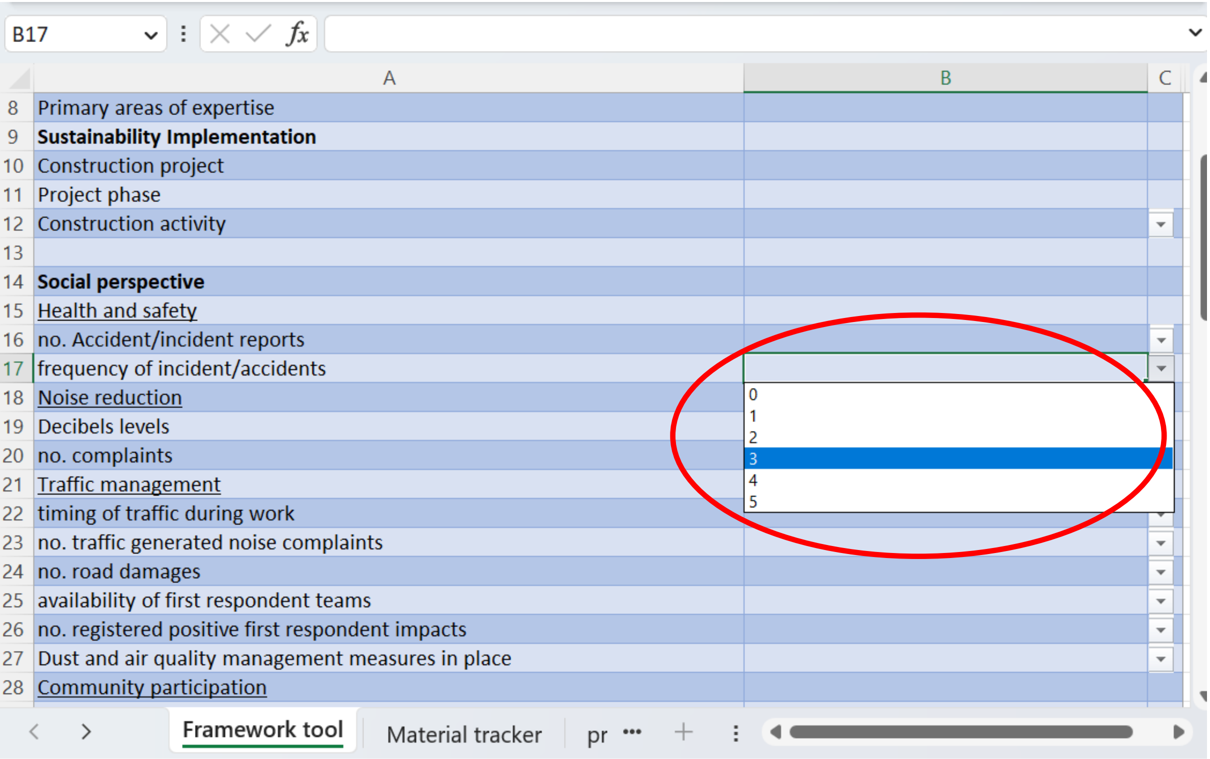


Figure 6: showing selection type 0-5. (By Author)

Under the ‘noise reduction’, two ways were established to ascertain adherence to sustainability requirements. To determine whether there was no noise pollution, this parameter was introduced to confirm this adherence through noise reduction by defining the number of decibels. These were to be extracted from the sound level meter or alternative such as smart phone applications assuming it was being used on the case study project. The respondent was required to select from the provided ranges either ‘less than 40db, ’40-55db’, or ‘above 55db’ options as shown in *Figure 7* and highlighted in red.

In addition, or as a counter measure, the ‘no. complaints’ field was introduced to define the number of complaints from project staff or neighbourhood issues raised as a result of the works. The respondent had to select a value from 0-5, the same parameter just as shown in *Figure 6*.

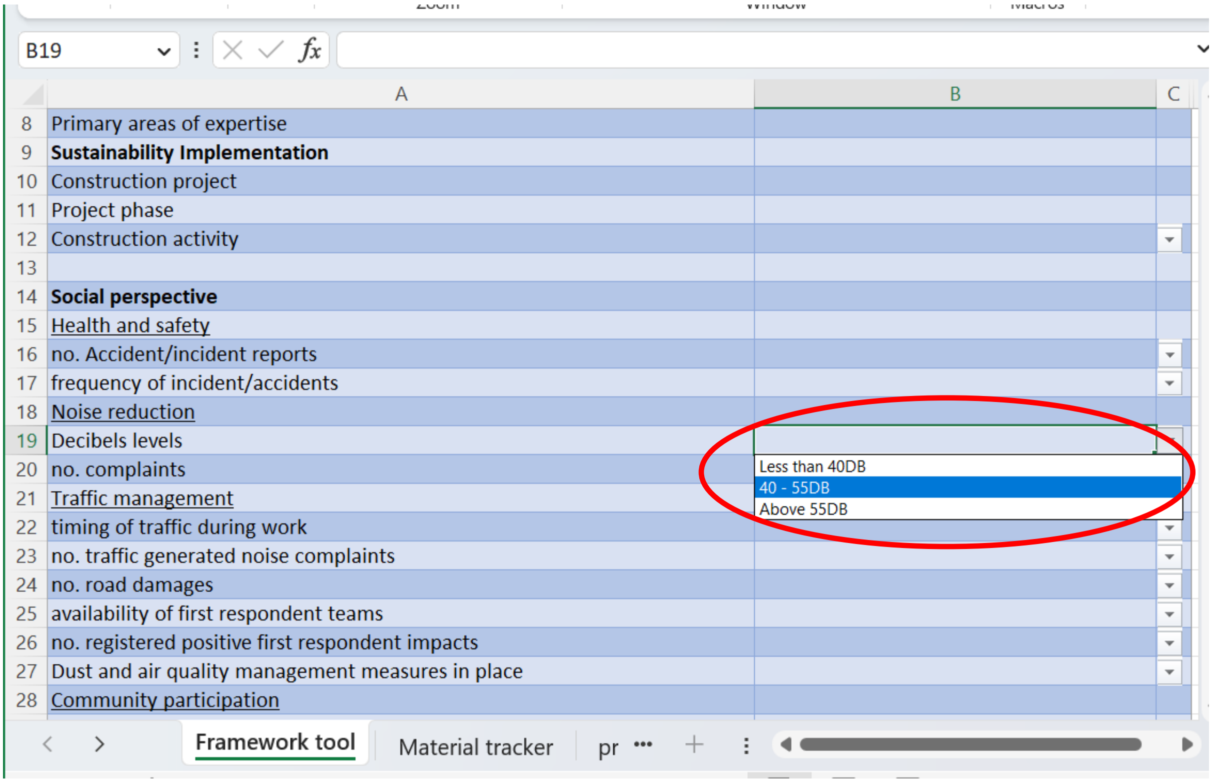


Figure 7: showing selection options for noise pollution levels. (By Author).

In the 'Traffic management section', first, as a section, there was need to know whether there was need to establish whether there was a traffic management plan. Second "timing of traffic during work' was one of the parameters identified as an indicator to ascertain the project's responsibility and concern towards the community. For example, executing works during times that would cause a traffic inconvenience that would affect the community social wellbeing. And since, such data was non quantitative in nature, the respondent had to select among the options 'Yes', 'No' and 'N/A' as shown in *Figure 8*.

Thirdly, the respondent had to define the number of damages recorded because of works being executed, the respondent had to select from 0-5. Fourthly, was 'no. registered positive first respondent impacts" which had to be defined by the respondent in percentage ranges 0-100% as shown in *Figure 9*. Fifthly, 'the availability of first respondent teams' in case there was an occurrence during work. As for the last parameter, the "dust and air quality management plan' and the respondent had to answer it also in a qualitative aspect as shown in *Figure 8*.

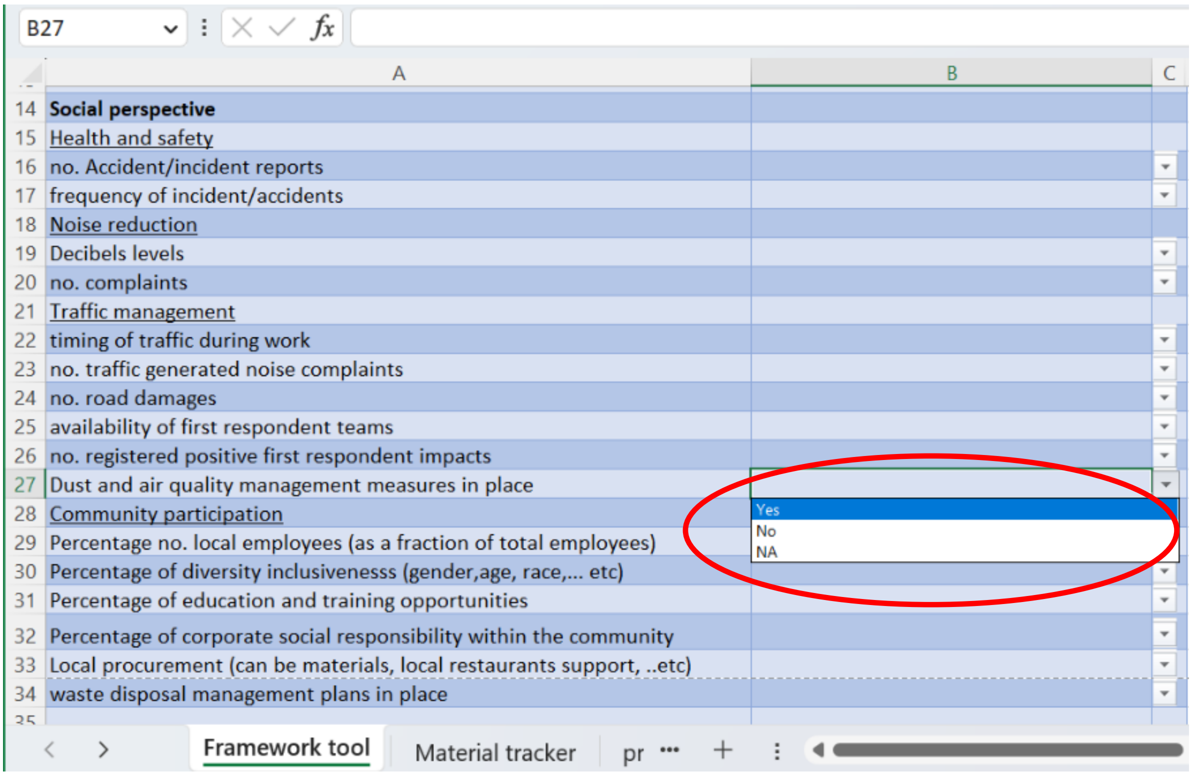


Figure 8: showing selection option 'Yes', 'No' and 'N/A' for qualitative information. (By Author).

The last section within the social perspective was the “community participation” category which involved sub indicators such as the ‘percentage number of local employees’, average age group of employees, percentage of diversity inclusiveness’, percentage of education and training opportunities provided, ‘local procurement’ and ‘waste disposal management planning’.

Under the subcategory ‘percentage of number of local employees’, the research study needed to establish how the construction project was being beneficial to the local community members and thus respondents had to confirm the percentage of local employees employed on the construction project as a fraction of the total number. The other subcategories “percentage of diversity, and age group’ were included to establish the degree of inclusiveness and diversity of project staff. These categories were all expressed in percentages and the respondents had to select from the different percentage ranges as shown in *Figure 8*.

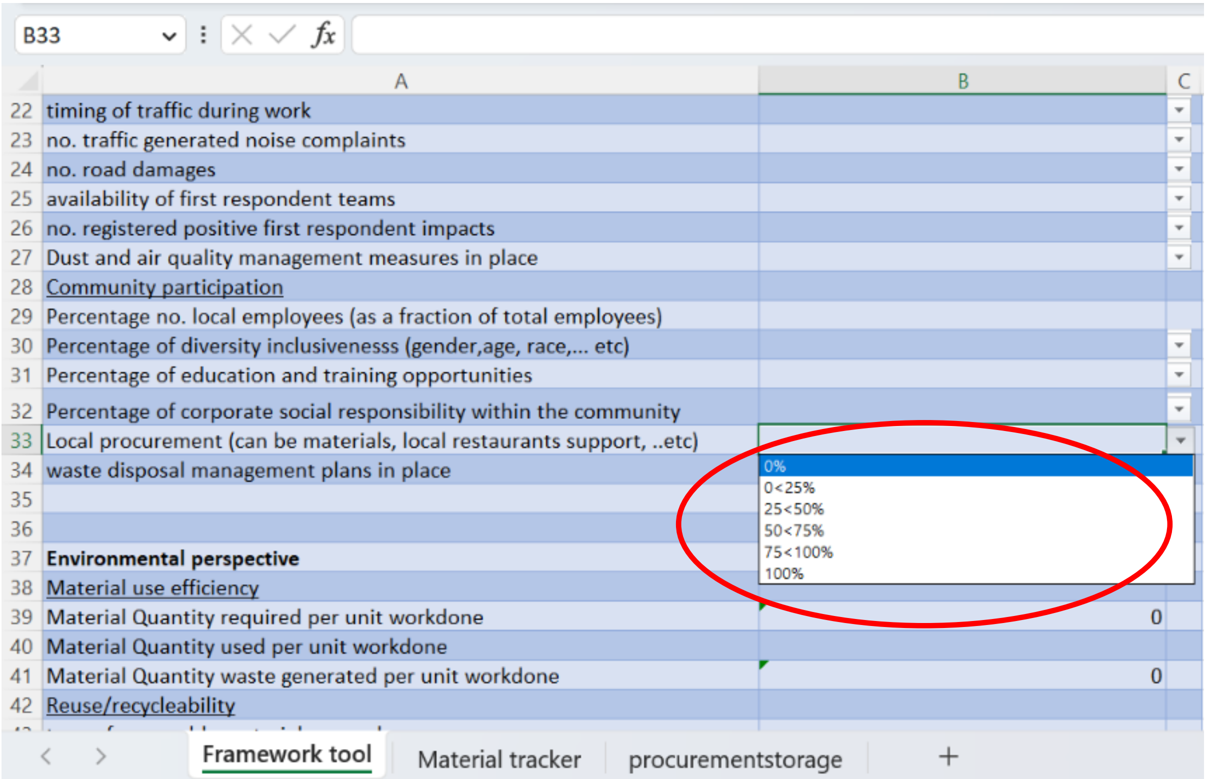


Figure 9: showing selection type in percentages 0 up to 100%. (By Author).

As for the local procurement subcategory, the study needed to find out how much involvement the project was contributing to the community economy for example, through supporting local community content such as local construction outlets, or shopping facilities, restaurants, among others. This was also expressed in the form of a percentage as shown in *Figure 9*. And finally, within the social perspective indicators, was ‘waste disposal management planning’. Since this parameter was almost difficult to quantitative, the qualitative approach was used, and the respondents had to select the availability or not of the said management plan through selection type shown in *Figure 8*.

For purposes of this study, the environmental perspective involved several indicators such as material use efficiency, reuse/recyclability, water reduction, energy efficiency, and water efficiency use. During the design concept of the framework, the material use efficiency was to be linked to the material tracking system of the case study project in order to properly track efficiency in utilization as shown in *Figure 10* and *Figure 14*. Subcategory “material quantity per unit work done required and material quantity used per unit work done were used to determine the quantity waste that was being generated per unit work done.

Under the reuse/recyclability indicator of the environmental perspective, the research study required the respondents to define the type of renewable and sustainable materials used. the study defined several recyclable materials that were commonly used and found on the market, and this included fly ash, blast furnace slag, recycled concrete aggregates, rice husk, glass powder, silica fume, among others as shown in *Figure 11* and *Figure 13*. The respondents had to select from these options and if the utilized option was not among those defined, the 'others' option would be selected. In addition, the research required the respondents to define the percentage of the recycled content being used, as well as the percentage of renewable materials used, and these had to be selected as shown in *Figure 15*.

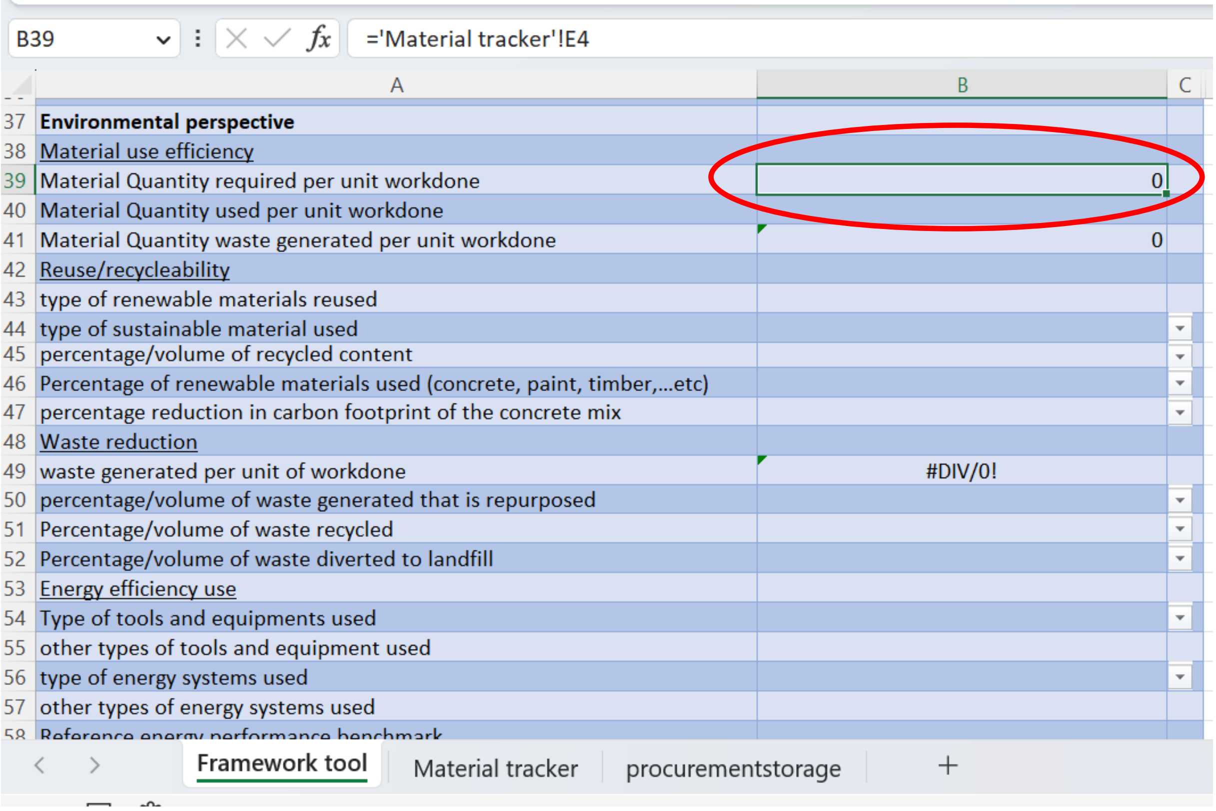


Figure 10: showing extracted figures from the material tracker. (By Author).

Based on the presented data from the material quantities required versus utilized, the volume of the waste generated was estimated. However, the research study needed to find out how much of the waste generated was being recycled and /or repurposed. and for this, the respondents were required to select a percentage range for which this waste material was repurposed and recycled as shown in *Figure 9*.

Under the ‘energy efficiency use’ indicator, the framework tool expected the respondents to define the type of construction tools and equipment being used and had to be selected from the categories that were provided as shown in *Figure 16*.

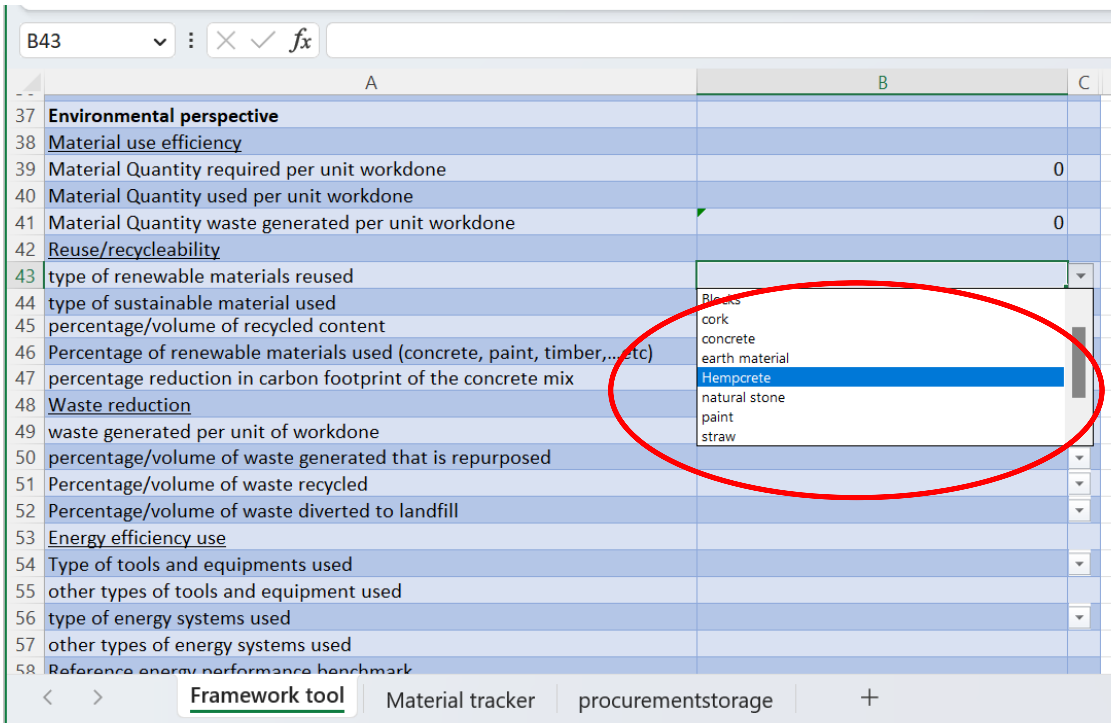


Figure 11: the different selections for the renewable materials. (By Author).

The other subcategory considered in energy efficiency use was the type of energy system the tools and equipment used such as electric powered, diesel or gasoline powered, and the respondents had to pick from the selections defined as shown in *Figure 12*.

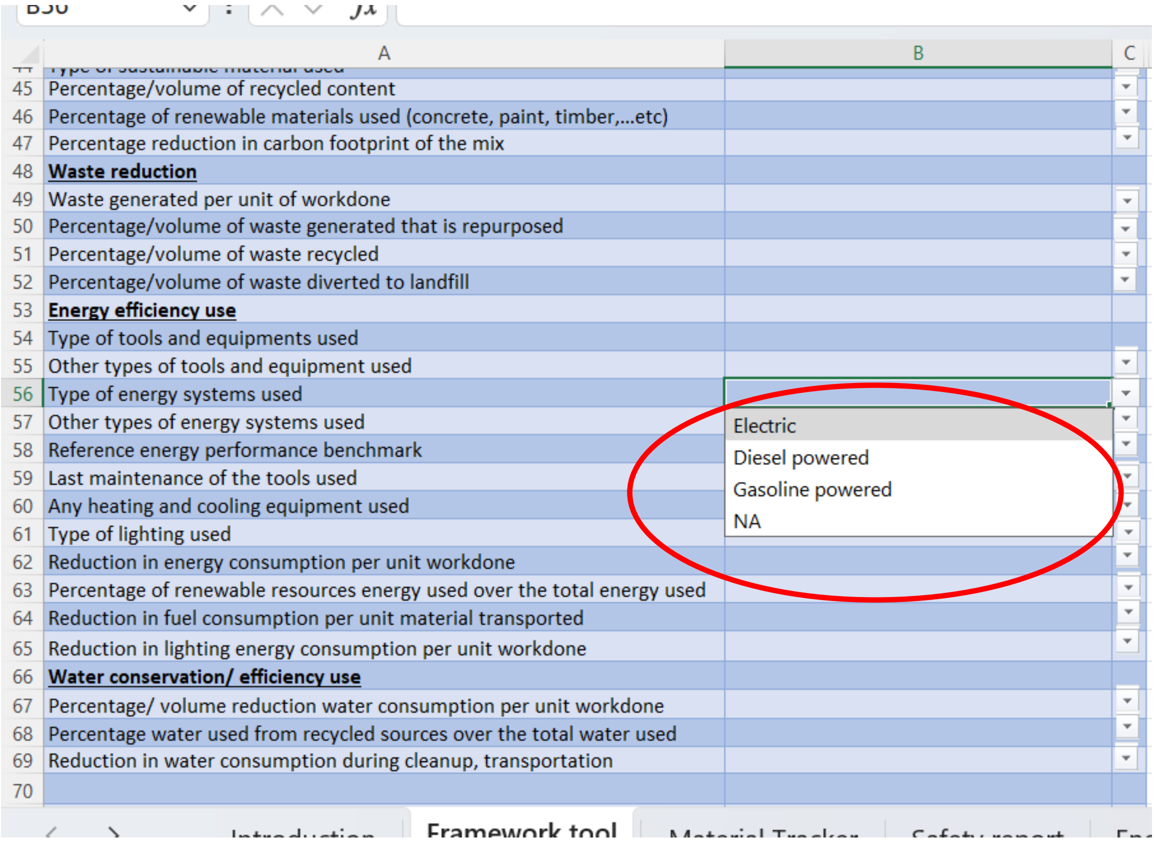


Figure 12: different energy systems. (By Author).

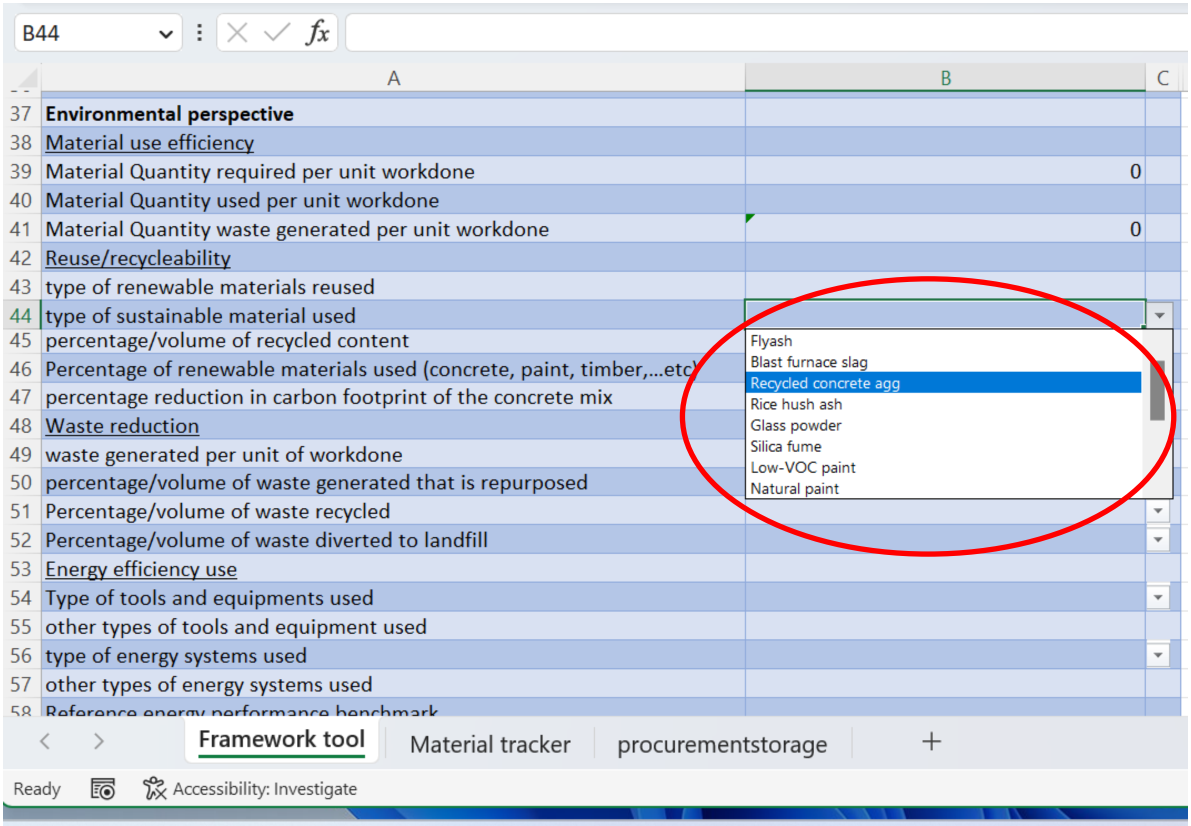
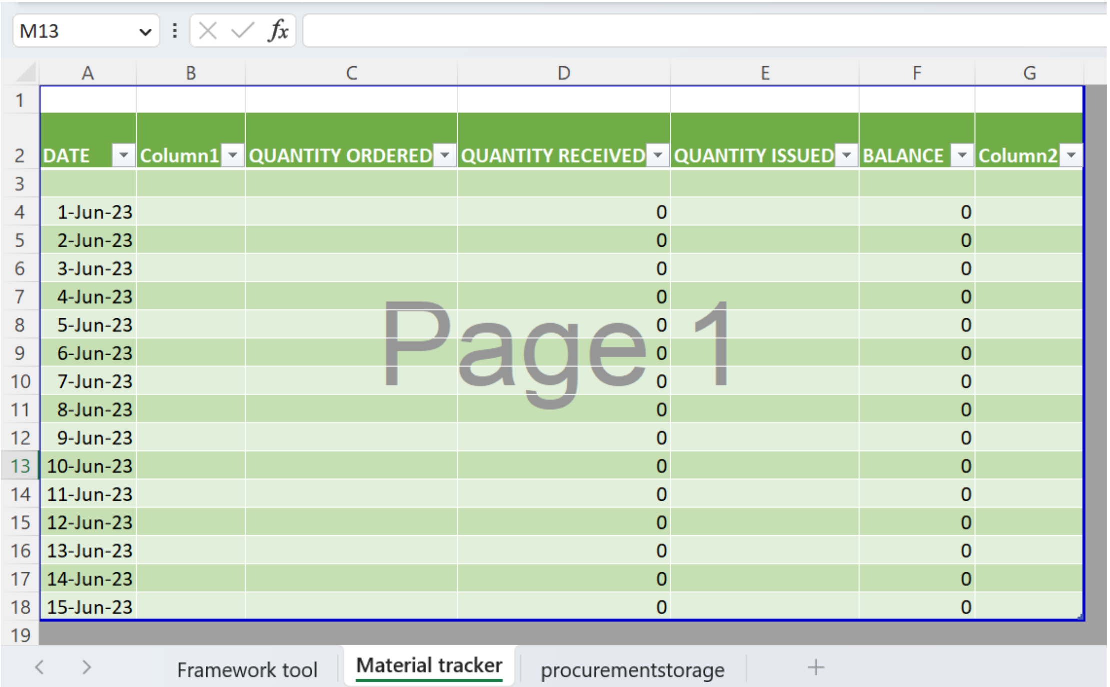


Figure 13: selections for the recyclable materials used. (By Author).

The maintenance schedules based on the last service period were also considered as a subcategory, and the value ranges for selection were from less than a month to above one year.



DATE	Column1	QUANTITY ORDERED	QUANTITY RECEIVED	QUANTITY ISSUED	BALANCE	Column2
1-Jun-23			0		0	
2-Jun-23			0		0	
3-Jun-23			0		0	
4-Jun-23			0		0	
5-Jun-23			0		0	
6-Jun-23			0		0	
7-Jun-23			0		0	
8-Jun-23			0		0	
9-Jun-23			0		0	
10-Jun-23			0		0	
11-Jun-23			0		0	
12-Jun-23			0		0	
13-Jun-23			0		0	
14-Jun-23			0		0	
15-Jun-23			0		0	

Figure 14: showing details within the material tracker. (By Author).

Fourthly, lighting systems used during works were another subcategory, and the respondents had to define whether aspects such as solar lighting, LED lights, natural lighting, motion sensitive lights had been used during the construction works as shown in *Figure 15*.

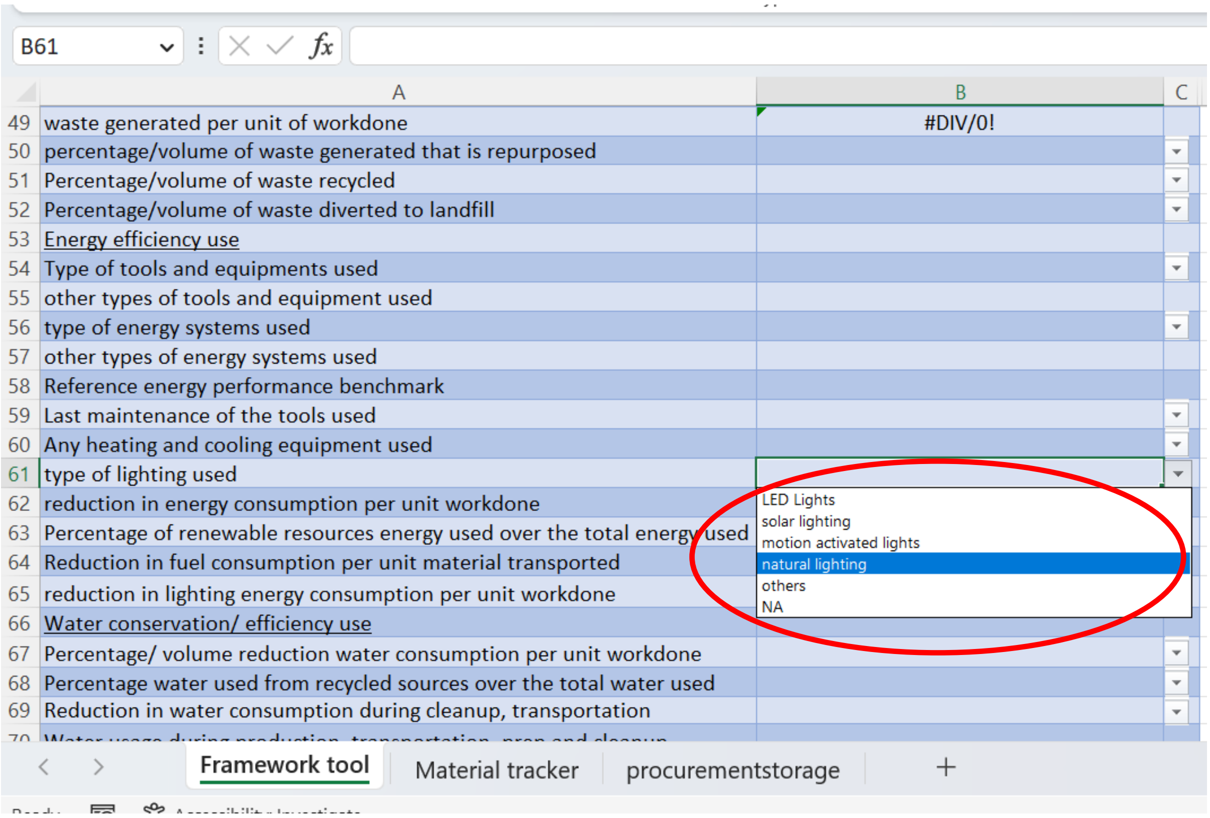


Figure 15: showing selection for lightings used. (By Author).

The other subcategories of the energy efficiency use indicator were ‘reduction percentage in energy consumption per unit work done’, ‘percentage of renewable resource energy used over the total energy used’, ‘reduction percentage in fuel consumption per unit materials transported’ and the ‘reduction percentage in lighting energy consumption per unit work done’. The respondents had to provide a percentage range from the selections as shown in *Figure 9*.

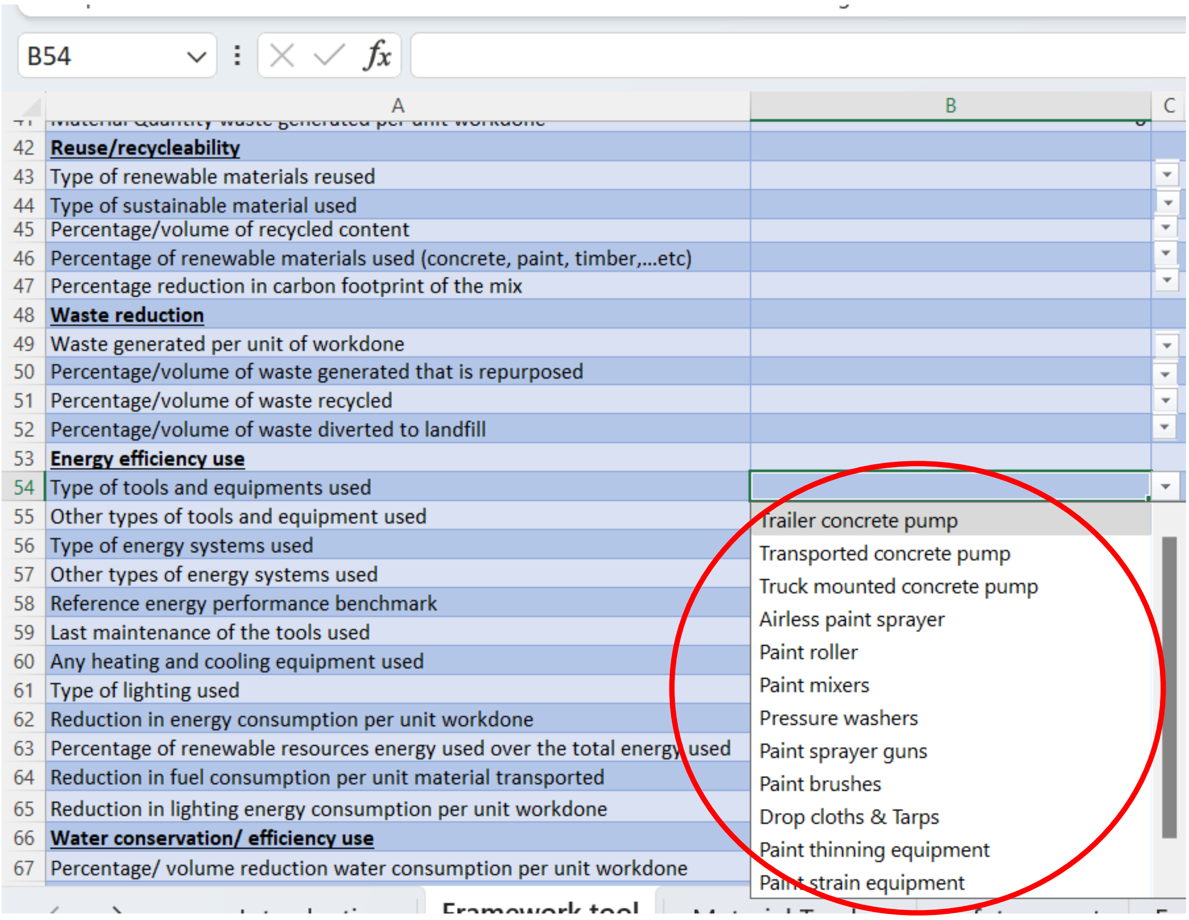


Figure 16: showing tools and equipment being used. (By Author).

The final indicator in the environmental perspective was the water efficiency use and the subcategory assessment indicators were the percentage of water consumption reduction per unit of the work done, the percentage of water used from the recycled sources over the total volume used, the percentage reduction in water consumed during production, cleaning up, preparation and production. The respondents had to define how much of these percentages they had covered as per *Figure 9*.

6. Results and Analysis

This part involves assessment of the sustainability assessment framework developed and the execution of case study data and information to test the theory from the literature review and examined the applicability of the proposed tool. However, for the scope of this research and due to time limitations, the investigation of the applicability of the proposed tool was examined based on sustainability reports and the observations from the case studies were used to propose further improvements to the framework tool.

6.1. Current Sustainable Practices Implemented based on the Case Study Project.

Upon completion of the development of the proposed framework tool, as part of the study, an assessment of the current sustainable practices being implemented during the construction phase/ execution phase of the construction project was carried out to answer the first research question. This section presents and discusses the results of the findings. The study was carried out on case study companies, namely SKANSKA and HCC (Skanska , 2022) (HCC, 2022). The companies were selected based on their performance and geographical representation.

From the companies' perspectives, the following were sustainable practices being used on their several construction projects in their respective locations, and they all followed the environmental, economic, and social sustainability aspects.

6.1.1. Energy Efficiency Utilization

According to SKANSKA, energy emissions were one of the sustainability impact areas being implemented under the umbrella of Climate change impact. In a bid to reduce carbon emissions, decisions and actions were taken from the design and planning phase to construction depending on the type of project since they differed in objectives and scope. For instance, Skanska, on one of their projects in Norway, carried out a pilot test using a digital tool called Ditio to cut back on fuel usage on-site to ensure fuel optimization of construction machines. This digital tool helped reduce the usage of fuels by 10%. Other actions involved using innovative design, digital carbon-calculation tools, efficient transport systems, renewable energy, electric vehicles, and machinery.

In addition, through these actions employed in the SKANSKA projects operations, a reduction in energy intensity (energy use/SEK M revenue) of 36% between 2015 and 2022 was registered with 6.33 MWh/SEK M in 2022 as compared to 9.94 MWh/SEK M energy intensity in 2015.

Furthermore, through an innovation project between SKANSKA and Volvo, the quarries in Sweden started to use more electricity in operations, with 30% of the quarry sites in Sweden have replaced diesel with electricity for the production line improving overall energy efficiency in raw materials acquisition. Also, in Norway and Sweden, heavy electric vehicles were being used at fossil fuel-free building sites courtesy of clients' initiatives and implementation. For instance, in SKANSKA Norway, 17 electric excavators were used among other electric machinery.

As for the other case study company, HCC (Hindustan Construction Company Ltd.), just like SKANSKA, also considered energy efficiency optimization as one of the current practices towards sustainability implementation. With HCC, energy-saving measures included the usage of Load Sharing System in D.G. plants, which would provide various ratings in synchronized arrangements with D.G. sets of interrupted loads even when switched off and on to ensure better productivity,

Secondly, automatic power factor controller panels would be installed at site electrical installations at strategic locations to improve the power factor, and additional capacitor banks would also be installed at high inductive load ends together with motor load (i.e., inductive load) that acted as power factor correcting devices that reduced reactive current, hence low electricity consumption.

Another energy-saving option was the flux compensated magnetic amplifier, starter for main crusher motors. In a conventional system, the transformer D.G. set and switch gear, a configuration that required a high rating to start a crusher motor. These main crusher motors had a high rating because of their starting torque requirements, and hence the use of flux compensated magnetic amplifier starters lowered the need for a transformer, D.G. set and switch gear ratings as compared to the conventional systems, which indirectly reduced electricity consumption.

fourthly, variable frequency drive starting system for ventilation fans & gantry cranes and the use of energy efficient motors in gantry cranes that were used in reducing the fan speed/air flow of ventilation systems in machines like excavators which reduced power consumption.

Other energy-saving measures included using of LED lights and tubes at all the construction projects, procurement of new cranes energy efficient motors and reducing overall dependency on fossil fuel by using more grid electricity supply at various projects that were not in remote locations since most of their projects depended on the use of diesel generators.

6.1.2. Material Efficiency Use and Carbon Footprint Reduction

Given that concrete was among the materials with the highest levels of embodied carbon used in the construction industry, Skanska projects were using different low-carbon concretes worldwide, made internally or from the company's business partners. For example, Skanska Betong, the Swedish concrete company, introduced various low-carbon concrete mixes in 2019 that replaced a portion of cement with either slag, a waste product from steel mills, or fly ash, produced by power plants. Furthermore, five different types of concrete were developed and implemented for different use cases in Skanska Sweden construction sites, reducing climate impact by approximately 50% compared to traditional material without compromising on strength, durability, and workability. Of the 15% low-carbon concrete produced by Skanska Betong in 2022, 41% was used internally by Skanska projects in Sweden, compared to 17% in 2021. In addition, more efforts were being made by Skanska Betong to increase supply.

Furthermore, one of the Skanska projects in downtown Houston, USA, an Embodied Carbon in Construction Calculator planning tool to calculate emissions for the primary construction materials used on their project, which enabled the project team to develop a strategic procurement process that enabled the selection and use of low embodied carbon in the foundations, basement, superstructure, and the garage. Using fly ash in the concrete mix reduced climate emissions by approximately 34%.

6.1.3. Social Community Engagement and Participation

Community engagement was another sustainability aspect practice implemented by SKANSKA projects through giving back to the community through social benefits. For example, through collaboration with the Swedish Sports Confederation, Skanska Sweden provided 200,000 tonnes of excavated material for reuse in the riding facilities and other sports arenas in 2022. the Skanska Costain, in partnership with STRABAG, designed and constructed Phase One of the UK's new high-speed railway, High-Speed Two, which provided various initiatives like provision of a wide range of training and employment schemes, apprenticeships, and work experience.

With HCC, an initiation that supported the purchase of raw materials like aggregates, and sand, among others, locally from the closest project location was implemented to help support community businesses and the economy. Furthermore, initiatives were made by setting up worker camps and sites to ensure support for general stores. This registered a 75% procurement rate of primary raw materials from the local markets.

In addition, through projects, the company voluntarily donated Fifty traditional musical instruments worth ₹5 lake to community participants of Uttarakhand Lok Sanskriti near the Tehri Pump Storage Project. Also built a cemetery in Phalong village and constructed a water supply line for Kangchup Chiru village near the Imphal-Kangchup-Tamenglong Road project in Manipur.

6.1.4. Health and Safety Management

According to Skanska, the company, through projects, implemented action plans on lifting, loading and logistic operations, which were recognised as their most significant safety risks. Some of these actions included monitoring safety performance for noise, working in traffic, vibrations, hazardous materials and lifting operations through tracking lost time accident rate (LTAR); high potential incidents that could have resulted in fatal accidents (serious near misses); Executive Safety Site Visits, total case accidents, severity rate of accidents, and training and auditing. For example, Skanska UK banned truck-mounted cranes from their projects to ensure safe and healthy workplaces. It convinced three significant manufacturers to modify their equipment to avoid people being hit by the stabiliser arm. This was because of the previous fatal accident on one of our projects in October 2021 with the operation of certain types of stabilisers after. The move eliminated the risk of crashing when operating certain types of stabilisers.

In addition, an annual employee survey was also carried out to monitor and get feedback from employees about safety efforts and management's commitment to addressing health and safety issues. For example, in 2022, the employee survey showed that 86% of employees recognised and appreciated the efforts in monitoring and improving safety at the workplace, which was better than the industry rating of 82%. In the case of all severe accidents, Identification and mitigation of risks were done to manage, learn and prevent potential future outcomes from happening.

On the overall spectrum, Skanska implemented the following action points on their projects to ensure social sustainability in the health and safety spectrum such Building a safety culture where the focus was on raising leadership awareness and a proactive safety culture that ensured greater engagement and safety on construction sites; developed a hierarchy of Control which focused on eliminating or reducing exposure to risk in the workplace, and allowed even more proactive measures in addressing safety risks at an early stage;

Analysis of safety data that focused on identifying and addressing critical risks and measuring the impact of our safety activities; finally ensured subcontractors followed Skanska standards and created the right conditions for improved safety.

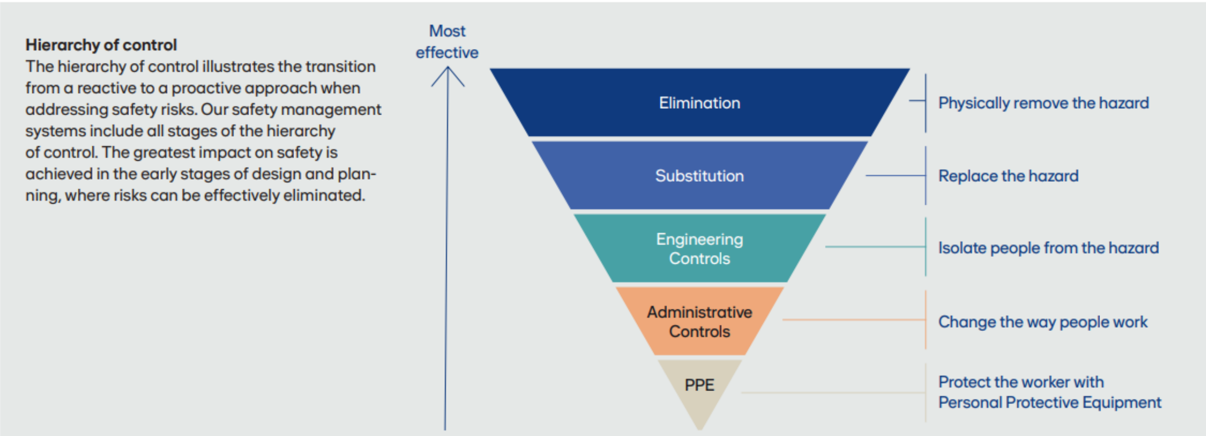


Figure 17: Skanska hierarchy of control adapted (By Author).

As for HCC, several initiatives were undertaken on sites to improve safety performance, including mandatory induction, and training programs, holding toolbox talks, ensuring full-time use of personal protective equipment, etc., and adopting a zero-tolerance policy.

In addition, there were several programs implemented on HCC construction sites, such as Proactive Safety Observation Program (PSOP) that involved a cross-functional team and project managers walking around through the project site every week to identify unsafe acts, unsafe conditions, and unsafe practices that existed at the site. Later, the Project HSE uploaded the observations on the PSOP portal and provided detailed action plans required to be addressed. Then the responsibility was assigned to department supervisors to take corrective and preventive actions and then closeout. The observations of severity rating 5 were sent to the responsible person, and auto-generated reminder escalation updates for the closeout of the observation were sent to management.

The online portal was initiated for daily safety reporting. Project-wise safety performance disclosures such as the number of corrections of unsafe conditions, number of corrections of unsafe acts, near misses, first aid cases, toolbox talks, training, and penalty enforced, among others, were recorded. Senior management teams could access this information through an automatically generated mail. Furthermore, this helped make site personnel responsible and more involved in health and safety management.

Another aspect of sustainability practice by HCC projects was the Hazard Identification and Risk Assessment program, whose sole purpose was to understand the occupational hazards that would arise during routine/ non-routine activities and ensure that the risks that arose from those hazards were evaluated, ranked, and controlled to an acceptable level. The team led by the project manager classified the main activities and allocated them into sub-activities for routine and non-routine activities. By understanding the activity's workforce, plan and methodology, the team identified the hazards, provided the register and sent it to the HSE team for review. Afterwards, following the risk assessments and assessments based on severity and probability (as per the matrix), the level of risk was determined to be high, medium and low. Subsequently, the control measures of the risks were identified. These details were furnished in the register and were periodically reviewed.

Site Audits A construction audit reviewed various aspects of a project to ensure they performed appropriately and kept within the contract. Since construction projects typically involve several entities performing several concurrent tasks, a construction audit was a crucial tool used to keep construction activities on track and under budget by Internal and external auditors.

Emergency Response planning through conducting mock drills was made on construction projects as part of HCC management objectives to prepare site teams better, especially when emergencies from Construction operations such as occupational injury/illness or Indirect conditions such as adverse weather conditions were prone to happen anytime.

Finally, Safety-related training for site workers to enhance their capability was held; HCC conducted training sessions with the help of experts in the field on several aspects such as basic construction safety, environmental protection at the site, workplace ergonomics, housekeeping, defensive driving, which improved skills overall productivity of the workers.

Sr. No.	List of on-site training	Sr. No.	List of on-site training
1	Behaviour-based safety	9	Importance of PPE
2	Defensive Driving	10	Material Handling
3	Electrical Safety	11	Reinforcement Work
4	Emergency Response	12	Scaffolding Safety
5	Ergonomics	13	Shuttering and De-shuttering of framework
6	Fire Safety	14	Tunnel Safety
7	Handling of power tools & electrical safety	15	Vehicle Safety
8	Housekeeping & its importance	16	Working at height

Figure 18: HCC site training programs adapted (By Author).

6.1.5. Waste Management and Circularity

According to SKANSKA, Skanska projects focused on increasing resource efficiency by reusing and recycling materials and products where possible. Waste reduction and efficiency improvements were made through more innovative design, planning, procurement, logistics, and tracking of self-generated waste to landfills. For example, in 2022, 4.3% of generated waste went to landfill, close to the target of less than 5%. In addition, there was the use of a more granular measurement of self-generated waste management reporting, which was initiated in 2021, and as a result, a reporting in 2022 of 72% of total waste recycled, 8% prepared for reuse and 13% other waste treatments were registered. It was also able to identify concrete, demolition waste, mixed construction waste and wood as the four most significant waste types on construction projects.

As for the HCC, some resource optimization initiatives implemented on construction projects included: Cut-to-length plates & structural steel instead of using the readily available standard-size plates and standard-length Structural Steel. For example, at the Anji Khad project, steel with customized sizes was procured to avoid wastages, whereas, at Rajasthan Atomic Project, and Mumbai Metro Projects, among others, reinforcement couplers were used, which helped these projects to achieve a considerable reduction in consumption of approximately 17.5 metric tonnes of reinforcement steel wastage and cost reduction by extension.

6.1.6. Sustainable Water Management

Skanska promoted more sustainable water usage by integrating innovative water-efficiency solutions, such as replacing potable water with alternative quality grades where possible. Examples include grey-water systems, where domestic wastewater except that from toilets is reused for non-potable uses. Advantages of these systems included lower use of potable water, high efficiency and reduced operating costs. For example, the lower use of potable water concept was used on the housing project Botanica K in the Czech Republic has been saving drinking water for its residents this way. It was the first apartment building in the Czech Republic to start recycling drinking water, and it has received the highest BREEAM sustainability rating on the Czech market. After four years of operation, it had recycled more than 10 million Liters (264,000 gallons) of drinking water, worth more than SEK 1 M.

HCC, as the first Indian company to endorse the United Nations Global Compact's 'The CEO Water Mandate' and an industry partner of the World Economic Forum (WEF), adopted the 4 R (reduce, reuse, recycle, replenish) water management approach at its project sites.

On the construction sites, the trained team of water champions deployed across all project sites was responsible for accounting for water withdrawal, implementing the 4Rs, and water sensitization among all employees. At each project, water source labelling and utility mapping were initially carried out. Water withdrawal from all sources was then monitored. Batching plants at every project were equipped with sedimentation tanks. The supernatant water was reused for dust suppression. This helped eliminate the use of freshwater for the said purpose. at coastal road project, wastewater treatment system was installed to treat sewage and kitchen water, which was recycled for gardening and dust suppression. Furthermore, rooftop water was harvested whenever possible at site offices and camp buildings.

6.1.7. Embracing Diversity and Inclusion

For both HCC and Skanska, the diversity disparity was mainly recognised with gender. For example, as of 2022, Skanska reported that 20% of employees as female. The percentage of women in senior positions was 25%, and three out of eight of our Management elected board members are women. In addition, gender ratios varied between professional groups, business streams and construction projects. Craft worker employees accounted for the most significant gender gap, with 96%men and 4% as women. Other aspects of diversity, such as ethnicity, disability, or age, were tracked by individual projects due to differing legal requirements between countries. Whereas for HCC, the number of females was 60, and no percentage was reported to be part of the artisans' team.

6.2. Current Assessment Methods for Current Sustainable Practices Based on Case Studies.

6.2.1. Sustainability Reporting Principles

Skanska and HCC were reporting following the GRI Standards for sustainability reporting and aiming to ensure that all information and data was relevant, transparent, consistent, accurate and complete and provided an objective picture of the Group's operations. The reporting period was for the financial year from 2021 to 2022. Sustainability disclosures included in the reports were extracted from the business units quarterly or monthly using our sustainability reporting system unless otherwise indicated.

6.2.2. Greenhouse Gases and Energy

Skanska calculated and reported greenhouse gas emissions following the GHG Protocol Corporate Standard. Scope 2 emissions were calculated following GHG Protocol Scope 2 Guidance applying the market-based and location-based methods. Scope 3 emissions were calculated following the GHG Protocol Corporate Value Chain (scope 3) Accounting and Reporting Standard. Activity data was based on invoiced data, real-time meters, models, assumptions, estimates or data reported by suppliers.

Energy conversions used publicly available conversion factors, and emission factors were sourced from databases such as the IEA (2022), BEIS (2022), ICE 3.0 and the AIB's European Residual Mixes 2021. Greenhouse gases included in the reported carbon inventory were carbon dioxide, methane and nitrous oxide. Biogenic emissions of Carbon dioxide from the combustion of biofuel and biomass were reported separately from the gross direct (scope 1) GHG emissions as Outside of scope.

The GWPs used in the calculation of carbon dioxide emissions were based on the IPCC Fourth Assessment Report 4 over 100 years, except for scope two calculations applying emission factors from the IEA, which are based on Assessment Report 5. Skanska applies the financial control approach. Emissions data was subject to inherent uncertainties due to incomplete scientific knowledge. The base year was 2015 for scope 1 and 2 emissions and 2020 for scope three emissions.

6.2.3. Construction Waste

The indicator for waste to landfill was defined as the amount of self-generated waste to landfill. Self-generated by Skanska meant materials brought into the project that were not used in the project's production but were instead treated as waste. Excavated materials were not included in the definition. The waste disposal method was based on the corporate defaults of the waste disposal contractor. The waste indicator is measured as the weight sent to the landfill divided by the total weight of self-generated waste. Data was based on invoiced data, qualified estimates or data reported by the supplier and was subject to inherent uncertainties.

6.2.4. Health and Safety

The lost time accident rate (LTAR) represents the number of accidents resulting in an injury that restricts the individual from being able to perform their customarily assigned duties for a period of one or more working days, multiplied by 1,000,000 hours and divided by total labour hours. Total case accidents included all accidents requiring medical treatment; lost time accidents were a subset of reportable accidents and were therefore included in this number. The number of fatal accidents refers to the year when the accident occurred. The reported data included Skanska employees and subcontractor employees working on Skanska job sites. The data was based on reports from the projects. The LTAR was influenced by national regulations, norms and regional definitions and hence was subject to inherent uncertainty.

6.2.5. Human Resources

The HR statistics were reported manually by the individual projects' human resource departments which were then uploaded to the Skanska Common Analytics data entry portal. Uploaded information was according to gender and was reported quarterly. The headcount reflected the number of people directly employed by Skanska at the end of the quarter and the final average calculated based on the four quarters.

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6.3. Performance Assessment of the Proposed Framework

Upon establishing the current sustainability practices used on construction projects and how the assessment of their performance through the sustainability reports of the construction projects, the data and values were input in the research project's proposed framework tool for assessing sustainability performance. This was the functionality of the proposed framework tool.

SUSTAINABILITY ASSESSMENT FRAMEWORK TOOL		
Personal information		
Name	Sustainability report 2022	
Position	various	
Professional experience (years)	136 years (since 1887)	
Previous construction projects	various	
Previous project locations	International	
Primary areas of expertise	all	
Sustainability Implementation		
Construction project	SKANSKA	
Project phase	Construction phase	
Construction activity		
Social perspective		
Health and safety		
no. Accident/incident reports	1	
frequency of incident/accidents	1	
Noise reduction		
Decibels levels		
no. complaints		
Traffic management		
timing of traffic during work	NA	
no. traffic generated noise complaints		
no. road damages	NA	
availability of first respondent teams	NA	
no. registered positive first respondent impacts		
Dust and air quality management measures in place	Yes	
Community participation		
Percentage no. local employees (as a fraction of total employees)		
Percentage of diversity inclusivenesss (gender,age, race,... etc)	75<100%	
Percentage of education and training opportunities	75<100%	
Percentage of corporate social responsibility within the community		
Local procurement (can be materials, local restaurants support, ..etc)		

Figure 19: Skanska performance evaluation part 1. (By Author).

The data extracted from Skanska and HCC annual sustainability reports of 2022 was input in the second column with each in a separate form as shown in the *Figure 19*, *Figure 20*, *Figure 21*, *Figure 22*, *Figure 23*, and *Figure 24*. Key to note was that not all the information was available to make a proper assessment. Irrespective of that, the proposed tool was able to provide sustainability performance feedback as shown in *Figure 21* and *Figure 24*. From Skanska, it showed that the sustainability performance was GOLD which according to the matrix of the tool meant that the sustainability performance was above 65% whereas the sustainability performance from HCC was SILVER which meant that the value was below 65%.

waste disposal management plans in place	Yes	
Environmental perspective		
Material use efficiency		
Material Quantity required per unit workdone		
Material Quantity used per unit workdone		
Material Quantity waste generated per unit workdone		
Reuse/recycleability		
type of renewable materials reused	concrete	
type of sustainable material used	Flyash	
percentage/volume of recycled content	50<75%	
Percentage of renewable materials used (concrete, paint, timber,...etc)	50<75%	
percentage reduction in carbon footprint of the mix	50<75%	
Waste reduction		
waste generated per unit of workdone		
percentage/volume of waste generated that is repurposed	0<25%	
Percentage/volume of waste recycled	50<75%	
Percentage/volume of waste diverted to landfill	0<25%	
Energy efficiency use		
Type of tools and equipments used		
other types of tools and equipment used		
type of energy systems used	Electric	
other types of energy systems used	fuel based systems	
Reference energy performance benchmark	2015 base year	
Last maintenance of the tools used		
Any heating and cooling equipment used	Yes	
type of lighting used		
reduction in energy consumption per unit workdone	0<25%	
Percentage of renewable resources energy used over the total energy used	25<50%	
Reduction in fuel consumption per unit material transported	25<50%	
reduction in lighting energy consumption per unit workdone		
Water conservation/ efficiency use		
Percentage/ volume reduction water consumption per unit workdone		

Figure 20: Skanska performance evaluation continued. (By Author).

Percentage water used from recycled sources over the total water used		
Reduction in water consumption during cleanup, transportation		
Sustainability performance	Gold	

Figure 21: Skanska performance evaluation continued. (By author).

As previously expressed, the framework tool was categorized into social perspective and environmental perspective. The economic perspective was not directly categorized separately because of its indirect influence on all if not most of the indicators within the other perspectives. As a recap, in the social perspective, we looked at the health and safety, noise reduction, traffic management, and community participation indicators for assessment.

SUSTAINABILITY ASSESSMENT FRAMEWORK TOOL		
Personal information		
Name	Sustainability report 2022	
Position	various	
Professional experience (years)	97years (since 1926)	
Previous construction projects	various	
Previous project locations	India	
Primary areas of expertise	all	
Sustainability Implementation		
Construction project	HCC	
Project phase	Construction phase	
Construction activity		
Social perspective		
Health and safety		
no. Accident/incident reports	1	
frequency of incident/accidents	1	
Noise reduction		
Decibels levels		
no. complaints		
Traffic management	Yes	
timing of traffic during work	Yes	
no. traffic generated noise complaints		
no. road damages	NA	
availability of first respondent teams		
no. registered positive first respondent impacts		
Dust and air quality management measures in place	Yes	
Community participation		
Percentage no. local employees (as a fraction of total employees)		
Percentage of diversity inclusivenesss (gender,age, race,... etc)	0<25%	
Percentage of education and training opportunities	0<25%	
Percentage of corporate social responsibility within the community	Yes	
Local procurement (can be materials, local restaurants support, ..etc)	Yes	

Figure 22: HCC Performance evaluation part 1. (By Author).

waste disposal management plans in place	Yes	
Environmental perspective		
Material use efficiency		
Material Quantity required per unit workdone		
Material Quantity used per unit workdone		
Material Quantity waste generated per unit workdone		
Reuse/recycleability		
type of renewable materials reused	natural stone	
type of sustainable material used	Flyash	
percentage/volume of recycled content		
Percentage of renewable materials used (concrete, paint, timber,...etc)		
percentage reduction in carbon footprint of the mix		
Waste reduction		
waste generated per unit of workdone		
percentage/volume of waste generated that is repurposed		
Percentage/volume of waste recycled		
Percentage/volume of waste diverted to landfill		
Energy efficiency use		
Type of tools and equipments used	NA	
other types of tools and equipment used		
type of energy systems used	Diesel powered	
other types of energy systems used	electric	
Reference energy performance benchmark	N/A	
Last maintenance of the tools used		
Any heating and cooling equipment used	NA	
type of lighting used	LED Lights	
reduction in energy consumption per unit workdone		
Percentage of renewable resources energy used over the total energy used		
Reduction in fuel consumption per unit material transported		
reduction in lighting energy consumption per unit workdone		
Water conservation/ efficiency use		
Percentage/ volume reduction water consumption per unit workdone	0<25%	

Figure 23: HCC Performance evaluation continued. (By Author).

Percentage water used from recycled sources over the total water used	0<25%	
Reduction in water consumption during cleanup, transportation	0<25%	
Sustainability performance	silver	

Figure 24: HCC Performance evaluation score. (By Author).

6.3.1. Social Perspective

To begin with the health and safety social perspective, from Skanska, the data collected showed 1159 total accidents that happened during or that were in connection with work, however, with a total of 149 Skanska ongoing projects (Skanska, 2023) within the financial year 2021/22, by extension the average number of incidents/accidents input in the system equated to 08no. persons per year and divided by the

12months in a year, it equated to an overall of 01no. person, a value that was included in the system. Whereas from the HCC, the number of injuries and fatalities extracted was 07no. and 02no. persons respectively in the financial year 2021/22. Divided by the 12months in a year, an average equivalency of 01number person was input in the performance tool.

As for the frequency rate of accidents/incidents, HCC reported 0.36, however, for Skanska, the frequency rate was not reported. With reference to (ec.europa.eu, 2023), the fatal and non-fatal accidents per 100,000persons were 1466 and 1.5 respectively. Based on the above information, the frequency rate of incidents/reports input for both Skanska and HCC was 01.

In comparison with the incident reports for the previous years, Skanska reported 1234 accidents in 2021, however, no information was available to compare with for the years 2020 perhaps due to the COVID 19 pandemic. So, the records relating to the “lost Time Accidents Report” reflected a decline in number of lost time accidents 712, 566, 504, 452, and 430 for 2018, 2019, 2020, 2021, and 2022 respectively.

And for HCC, the number of accidents were 4, 11, 12, 9, and 7 for 2017/18, 2018/19, 2019/20, 2020/21, and 2021/22 respectively. The frequency rates for the same years respectively were 0.24, 0.19, 0.24, 0.36. and 0.22. On the one hand, using this information reflected a positive outcome on reduced number of accidents which meant that the projects were addressing the health and safety social aspect. however, on the other hand, it reflected a potential unstable tracking and monitoring of information concerning these issues.

The other social aspect that was reported was the community participation. In this category, the information required had to do with how the projects were supporting and engaging the community. For the availability and percentage of local community people, HCC reported 13817 employees and 989 senior management whereas Skanska reported 28189 employees with 100 senior management for the financial year 2021/22. In both case studies, the percentages relating to the local communities were not reported and as such, the parameter was not recorded in either case study performance.

On the other hand, both cases showed strong motivation towards diversity and inclusiveness indicators. The aspect of diversity and inclusiveness in both case studies was reported in terms of gender and for Skanska, 20% were women and 80% as men of the total employees. In addition, indications of concern towards the LGBTQ community were highlighted in the report however representatives in figures were not reported. whereas for HCC, the number of females employed were 31no. irrespective of the position. In addition, it was reported that due to the remoteness of the construction projects, there were no females employed on construction sites.

Furthermore, both case studies showed strong initiatives towards apprenticeships, education, and training opportunities both to the employees as well as trainees. For example, HCC reported an average of 0.65manhours per employee which converted to a percentage between 0 and 25%. Whereas for Skanska 96% was reported as the percentage of employees that have undergone training. However, little was known as to how much time training was taken, and the category of training.

The relevance for local employment, diversity figures and training opportunity records would help in answering the Sustainable Development Goal 8 (SDG 8); Decent Work and Economic Growth that aims to promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. It recognizes the importance of creating opportunities for decent work and entrepreneurship, as well as supporting policies and measures that stimulate job creation and foster an enabling environment for businesses to thrive. Having reports concerning the local employment during the construction phase and emphasizes would highlight the positive impact of the projects on economic development, reduced unemployment rates, skills enhanced and defined contributions to the well-being of the local community.

Regardless of the above parameters, when the potential for corporate social responsibility within the community and the ability for construction projects to procure and support local community was assessed, both case studies showed a positive response towards the parameters. For example, HCC reported that 75% of the raw materials ws procured locally and on top of that, community support through corporate responsibility was done as explained before. This was then reported in the performance framework as a “YES” since it was a non-quantifiable parameter. This was because a benchmark value could not be defined unless by the company itself. Even though the potential of assessing the performance quantifiably through the percentage set aside through tax compensation targets, the projects would have needed to rely on the companies’ discretion. These parameters in a way contributed to the understanding of the projects influence and engagement to the local communities.

6.3.2. Environmental Perspective

When it came to the environmental perspective, the research focused on material efficiency, reuse/recyclability, waste reduction, energy efficiency use, and water conservation/efficiency use.

The concept of material efficiency use was supposed to be assessed based on quantities requested and used per unit work done so as to determine the waste generated per unit work done. This was to be done based on a direct link to the storage database for the project. However, due to research constraints, and limited access, there was no data collected for performance assessment of the tool. These parameters and others highlighted in orange as shown in *Figure 19*, *Figure 20*, *Figure 22*, and *Figure 23* had difficulty in acquiring the necessary data for the tool.

Regardless, according to HCC, the material quantity required or in this case, that was procured for the construction projects was 285730.21 tons for the financial year 2021/22, semi manufactured as 1,596,330.59 tons and 10334.15 tons for associated materials. As for the waste disposed from the HCC, 3,774no solid hazardous waste in the form of empty drums; 22.2 kilolitres of liquid hazardous waste in the form of oil; 3,599.6tons of non-hazardous steel scrap waste were sent to the recycler and 397,430bags of non-hazardous waste in the form of cement bags were sent disposed of. No data or information was reported concerning potential excess material wasted, something that the performance tool would have been able to capture.

With regards to Skanska report, Quantities of materials procured were defined in terms of carbon dioxide emissions as 864,000 tons, and the waste generated from operations as 3,000tons and of this, 6.8% was sent to the landfill.

Comparing the two case study reports, data collected and reported concerning material use was divergent and based on different aspects. Furthermore, it did not highlight in detail how much percentage was related to construction material use and wastage even though to some extent bits and pieces were highlighted by Skanska as included in the performance tool.

The next aspect in the environmental perspective was the “reuse/Recyclability” assessment. This aspect considered type of renewable materials used, and percentages of recycled content. According to HCC, most of the recycled materials were aggregates and the sustainable material used mostly was fly ash which was added in the concrete mix to offset the cement impact in terms of embodied carbon content ratios. Whereas for Skanska, the most sustainable material being implemented was fly ash concrete. 41% of the low carbon concrete courtesy of fly ash mix was used on construction projects. In addition, 72% of the total waste was recycled, 8% reused and 13% taken to other waste treatment systems.

Material efficiency use was important to be analysed because according to it affected most of the sustainable development goals especially SDG 12: Responsible Consumption and Production which emphasizes sustainable consumption and production patterns. Material efficiency aligned with this objective by promoting efficient use of resources, reducing waste, and minimizing the environmental impact of construction projects. plus, it encouraged a shift towards even more sustainable and responsible practices within the construction industry especially since it directly infringed on the environment's natural resources hence the meticulous analysis design in the framework tool.

As far as the energy efficiency use was concerned, the aspect looked at type of tools and equipment used, energy systems used, maintenance schedules, reference energy performance benchmarking, type of lighting systems used, percentages of renewable energy used over the total energy used, percentage reduction in fuel consumption as well as lighting consumption.

From Skanska report, the biggest percentage of energy systems used on the construction projects was from the electric systems. Other energy systems used were fuel based – diesel. Since not all construction projects based on location may or may not require heating and cooling systems, the performance required to establish whether the construction projects were used because Heating and cooling systems on construction sites consumed significant amount of energy. By assessing their use during the construction phase, it was possible to affect assessment parameters for works and required identifying opportunities for further energy efficiency improvements for example optimizing system design, using more energy-efficient equipment, implementing control strategies, and minimizing energy waste. And in this case, the Skanska projects registered a “Yes” for heating and cooling systems.

On the other hand, Skanska reported the percentages of resource energies used over the total energy used as 87% and 16% in renewable fuel used as partial replacement for non-renewable fuel consumption used. This showed a positive impact and influence towards implementation of sustainable construction practices and reporting.

For the HCC, the energy systems used mostly were diesel powered due to the remoteness of the projects. However, electric powered systems were also used to a less extent. In addition, concerning the type of lighting systems used, all had been changed to LED lights. No energy performance benchmark was reported and equally so were the percentage of renewable resource energies used, fuel consumption and lighting energy used.

And finally, within the environmental perspective, was the water efficiency use aspect that considered percentage of clean water consumed and from the recycled sources. According to HCC, amount of freshwater withdraw was 431ML, of which 20% was used a raw material, and 4% was wasted, 11% of the freshwater reused after recycling. Whereas for Skanska, no data was reported concerning water utilisation, consumption, recycle or reuse.

6.4. Discussion on the Implications and Limitations of the Study

Ultimately, the data and information collected from the case study reports were sufficient to carry out the performance assessment; however, it needed to be more comprehensive. As observed from the content above, sustainable practices were being implemented on construction projects; the only difference was in the detailing that required improving efficiency in all aspects of sustainability principles.

Based on the above, the proposed framework tool could provide a real-time sustainability performance based on the data availability and input whilst considering the minutest of details to improve efficiency to better. It also provides the stakeholders and management with monitoring and control through direct information. The great feature of the proposed tool was that it would be linked to all departments for direct accountability with no uncertainties and without having to lose data during reporting. Furthermore, the real time data availability would provide options for fast readjustment of course of direction whenever sustainability practices would be getting off track.

The research study was affected by time constraints to completely build the application. Secondly, due to inability to access sensitive site data to make a comprehensive assessment of the tool, other avenues would have to use it for further study of the proposed tool.

7. Conclusion and Recommendations.

The construction industry accounts for 40% of carbon emissions coupled with excessive resource utilization, both of which are facts. Several studies have been done in establishing ways of alleviating these issues. In practice, several innovations have been done in controlling excessive carbon emissions and ensuring effective utilization by ensuring optimal designs during the design phase and implementing innovative and sustainable material use. In addition, other efforts have been made in establishing sustainable practices during the construction phase of the project, among other aspects. However, little has been made towards assessing the performance of the sustainable practices done during the construction phase to ensure accountability, well-being, and responsible consumption as per the UN sustainable development goals.

Economic, social, and environmental perspectives of sustainability were studied, and several indicators were identified and analysed. On the one hand, economic indicators seemed to cut across to social and environmental indicators and on the other hand, gaining access to such financial information became a challenge, hence eliminating the direct approach.

Case study reports from Skanska and HCC were used to assess the functionality and practicality of the performance assessment tool which presented a positive outcome functionally. However, more in-depth assessment based on practical real-life projects will be provide more affirmative feedback in determining how sustainable the construction phase of a project would be. In addition, attempting alternative weighting systems based on potential project preference scenarios and extraction of economic indicators where confidentiality is in check will be a great advantage to the overall functionality of the proposed tool.

Declaration of Authorship

I hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, 07th July 2023

Location, Date

Signature of the student

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