# A ROADMAP FOR THE REDUCTION OF CARBON AND ECOLOGICAL FOOTPRINT OF CONSTRUCTION ACTIVITY IN GHANA

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Thesis submitted in fulfilment of the requirements for the Degree

**DOCTOR OF ENGINEERING:**

**CIVIL ENGINEERING**

in the

Department of Civil Engineering

Faculty of Engineering, Built Environment and Information Technology

at the

Central University of Technology, Free State

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August, 2023

# DECLARATION

I, MOSES KWADZO AHIABU, student number _________, do hereby declare that this research project submitted to the Central University of Technology, Free State, for the Degree of DOCTOR of ENGINEERING: CIVIL ENGINEERING, is my own, independent work; and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State; and has not been submitted before to any institution by myself or any other person in fulfilment of the requirements for the attainment of any qualification.

______________________________ _07 August 23___________

**SIGNATURE OF STUDENT** **DATE**

# DEDICATION

Firstly, I dedicated this work to my parents, Mr. Christopher Kofi Ahiabu and Mrs Rebecca Afi Akpabli-Ahiabu, for their inspiration and prayers that laid the solid foundation of my life.

Secondly, this work is dedicated to my wife, Mrs. Janmmery Asante-Ahiabu, for her support, prayers and endurance.

Lastly, this work is dedicated to my children, Jemima Ahiabu, Jessica Ahiabu, Joshua Ahiabu, and Jacinta Ahiabu for their prayers and understanding throughout this study.

## ACKNOWLEDGEMENTS

Glory be to God Almighty who makes heaven and earth and makes all things beautiful in His own time. This study would never have been achieved without the grace of God. I want to sincerely thank my principal promoter, Professor Fidelis Emuze, for his unflinching advice, unwavering guidance, mentorship, and inspiration throughout my research journey. My sincere gratitude also extends to my co-promoter, Professor Dillip Das, for his invaluable advice given to me throughout the course of my study.

I thank my colleagues, Mr. Eric Kodzo Adzivor and Mrs Patricia Asantewa-Tanor, for their advisory support and encouragement throughout my research experience. My appreciation also goes to the co-ordinator of this programme, Professor Denis Yao Dzansi for his constant admonishing and encouragement. My sincere appreciation also goes to the Vice-Chancellor of Ho Technical University, Professor Ben Quarshie Honyenuga, and his entire management team for this collaboration.

I am grateful to Dzokoto Senyo and Martin Abimo for the statistical data analyses, the Delphi panellists and the survey participants. My sincere appreciation also goes to my wife, Mrs Janmmery Asante-Ahiabu, and children, Jemima, Jessica, Joshua and Jacinta for their love, prayers, endurance, and understanding throughout the study period.

Finally, I am indebted to members of Knight of St. John International and Ladies Auxiliary (Commandery Number 855), Holy Spirit Parish, Ho and all my Priests for your prayers. I am also grateful to the workers of my company, Mojeko Comapay Limited for their prayers and encouragement, not forgetting my friends, and all those who supported me, prayed for me, and inspired me in any ways during this research. I pray that the Almighty God of all goodness abundantly bless you.

## LIST OF PUBLICATIONS

**Refereed Journal Article**

1. Ahiabu, M.K., Emuze, F.A. & Das, D.K. 2023. Perception of the benefits of sustainable construction in Ghana. *Journal of Built Environment Project and Asset Management.* 13(2), pp. 306-323. https://doi.org/10.1108/BEPAM-06-2022-0088.

**Referred Conference Papers/Book Chapters**

2. Ahiabu, M.K., Emuze, F.A. & Das, D.K. 2022. A review of sustainable construction practices in Ghana. In: Gorse, C., Scott, L., Booth C. & Dastbaz, M. (eds). *Climate Emergency – Managing, Building, and Delivering the Sustainable Development Goals*. Springer, Cham. https://doi.org/10.1007/978-3-030-79450-7_9.
3. Ahiabu, M.K., Emuze, F. & Das, D. 2021. Achieving sustainability in construction waste management in the Ghanaian Built Environment: Systemised review. In: *Proceedings of International Sustainable Ecological Engineering Design for Society (SEEDS) Conference 2021: Adapting and Changing Behaviour and Practice, Leeds Beckett University, Leeds, United Kingdom.*
4. Ahiabu, M.K., Emuze, F. & Das, D. 2020. A review of sustainable construction practices in Ghana. In: *Proceedings of International Sustainable Ecological Engineering Design for Society (SEEDS) Conference 2020: Sustainability and Practice*, *Leeds Beckett University, Leeds, United Kingdom.*
5. Ahiabu, M.K., Emuze, F. & Das, D. 2019. A framework towards the reduction of the ecological and carbon footprint of construction activity in Ghana. In: *Proceedings of 14th International Postgraduate Research Conference: Contemporary and Future Directions in the Built Environment, University of Salford, Manchester*. pp. 525-537.

## ABSTRACT

Sustainable construction is acknowledged globally to be a viable means to reduce the negative environmental effects of construction projects. Sustainable construction utilises ecological and resource-saving concepts in executing projects. The reduction of carbon and ecological footprint of construction activity contributes to the achievement of sustainable construction. The sustainable construction practices are advanced in developed countries where governments have established legislation, codes, policies, and frameworks to promote the sustainability concept to reduce carbon and ecological footprint. However, sustainable construction implementation is immature in emerging countries like Ghana, because of implementation issues and unavailability of clear roadmap or government policies and legislation to promote the uptake. This study was motivated by a gap identified in the literature to develop a sustainable construction roadmap for the Construction Industry in Ghana to reduce carbon and ecological footprint of construction activity. Accordingly, the specific objectives of the research were: to determine why sustainability is a focus area that cannot be ignored by the Ghanaian Construction Industry; to determine how design should respond to sustainability requirements in the Ghanaian Construction Industry; to determine how construction materials should respond to sustainability requirements in the Ghanaian Construction Industry; to explore the effects of energy-efficiency on the construction process in the Ghanaian Construction Industry; to evaluate the modalities employed to reduce construction site solid waste in the Ghanaian Construction Industry; and to develop a sustainable construction roadmap that would reduce the carbon and ecological footprint of activities in the Ghanaian Construction Industry. The study was grounded in the pragmatist paradigm, and both qualitative and quantitative data were gathered using a mixed method strategy. The qualitative data collected from three rounds of a Delphi study were analysed descriptively and inferentially. The strong agreement reached on the key elements of sustainable construction is supported by the comparative analysis between the 18 Delphi panel experts. In order to better understand the phenomenon of sustainable construction in Ghana, 405 valid and completed questionnaires were received and retrieved. The data were then analysed using Partial Least Square - Structural Equation Modelling (PLS-SEM). According to the research, one of the benefits of implementing sustainable construction is to raise standard of living in general. The response of construction industry in Ghana to sustainable design requirements highlights resource conservation, adaptations, whole life-cycle designs, and cost efficiency as the main areas of concern for sustainable construction.

Also, the renewable, recyclable, and re-usable materials; durable materials; and materials of minimum adverse impact on the environment are to be adopted to respond to sustainability requirements in Ghana. Some of the advantages of energy efficiency on the construction process identified include reduction in fuel usage of construction equipment, minimal energy consumption and reduction in energy cost, reduction of emission levels and protection of the environment. The just-in-time operations, careful handling of tools and equipment on site, early and prompt scheduling of deliveries, and use of more effective equipment are the primary construction waste management practices in the Ghanaian construction industry to achieve sustainability. The quantitative data provided a basis on which the roadmap evolved to serve as a guideline for carbon and ecological footprint reduction of construction activity in Ghana. Through semi-structured qualitative interviews, the developed roadmap was validated by academics and industry practitioners in Ghana, and the results indicated that the roadmap is useful and appropriate for application in the Ghanaian construction industry. Policy-makers, academics, developers, and investors who want to implement sustainable construction in the Ghanaian construction industry can use the study as a tool because it has practical, theoretical, and methodological relevance for sustainable construction. The Green Building Council in collaboration with the government should open offices in all the Assemblies to intensify the awareness creation and promotion of the roadmap to increase the adoption of the sustainable construction concept in Ghana. The government should implement financial incentives for construction companies and professinals that adopt sustainability practices to reduce carbon and ecological footprint of construction activity in Ghana. The study has contributed to sustainable construction body of knowledge since it re-affirmed the potential contributions to realising the relevant United Nations Sustainable Development Goals such as 9, 12 and 13.

**Key words:** Construction, Carbon footprint, Ecological footprint, Sustainability, Ghana.

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# LIST OF ABBREVIATIONS

AESL – Architectural and Engineering Services Limited

ARC – Architects Registration Council

B.Sc. – Bachelor of Science

BEAM – Building Environmental Assessment Method

BREEAM – Building Research Establishment Environmental Assessment Method

CASBEE – Comprehensive Assessment System for Building Environmental Efficiency

CF – Carbon Footprint

DRH – Department of Rural Housing

EC – Engineering Council

ECG – Electricity Company of Ghana

EDGE – Excellence in Design for Greater Efficiencies

EF – Ecological Footprint

EI – Executive Instrument

ENDA – Environmental and Development Action in third-world action

EPA – Environmental Protection Agency

GCI – Ghanaian Construction Industry

GDP – Gross Domestic Product

GhGBC – Ghana Green Building Council

GhIE – Ghana Institution of Engineers

GhIS – Ghana Institution of Surveyors

GIA – Ghana Institute of Architect

GRA – Ghana Revenue Authority

GREDA – Ghana Real Estate Developers Association

GSS – Ghana Statistical Service

HND – Higher National Diploma

HSD – Hydrological Services Department

IIED – International Institute for Environment and Development

LCA – Life Cycle Assessment

LEED – Leadership in Energy and Environmental Design

M.Sc. – Master of Science

Central University of Technology, Free State

MPhil - Master of Philosophy

Ph.D. - Doctor of Philosophy

PLS-SEM - Partial Least Square-Structural Equation Modelling

PNDCL – Provisional National Defence Council Law

PSHLSB – Public Servants Housing Loan Scheme Board

PWD – Public Works Department

QS - Quantity Surveyor

RCD – Rent Control Department

SC – Sustainable construction

SHC – State Housing Company

SPSS -Statistical Package for Social Scientist

TCPD – Town and Country Planning Department

TDC – Tema Development Company Limited

UN - United Nations

UN SDGs – United Nations Sustainable Development Goals

UNDP – United Nations Development Programme

UNEP – United Nations Environmental Programme

UNESCO - United Nations Educational, Scientific and Cultural Organisation

UNFPA – United Nations Forum Population Agency

US – United States

US EPA – United States Environmental Protection Agency

WGBC – World Green Building Council

# DEFINITION OF TERMS

**Carbon emission** is defined as the discharge of carbon gases and its precursors into the atmosphere over a predetermined area and duration (Zainordin & Zahra, 2020).

**Carbon footprint** is defined as the greenhouse gases released during the production of products and services intended for ultimate consumption as well as during the consumption processes themselves (Hertwich *et al*., 2019).

**Ecological footprint** describes the value of the land and water areas required to replenish the resources used and encompasses all environmental issues as a whole (Emuze *et al*., 2016).

**Energy efficiency** is the use of energy-efficient design techniques by construction to lower its energy consumption and attain low energy consumption or utilizing less energy without sacrificing a building's function (Mersal & Academy, 2017).

**Life cycle assessment** is a method of assessment whose goals are to analyse the negative environmental impacts associated with a process, product, or operation as well as to assess and pursue opportunities to affect improvements to the environment (Chau *et al*., 2015).

**Sustainable construction** is the implementation of sustainability concepts throughout the entire construction life cycle, including planning, mining for raw materials to create materials for construction, using minimal embedded energy materials, conserving energy and water, deconstructing, and controlling waste (Mustafa & Bakis, 2015).

**Sustainable development** involves the implementation of programmes that provide economic benefits now without restricting social and environmental options that people may have in the future or gives people genuine improvements in their quality of life while also preserving the variety and vitality of the planet's ecosystems (Flint, 2013).

# CHAPTER ONE: THE RESEARCH DIRECTION

## 1.1 INTRODUCTION

This chapter introduced the direction and outline of the thesis. The foundation of the research, the formulation of problem statement, the primary research question and secondary questions that were investigated are presented. The goal and objectives of the research are stated. The scope, limitations, and overview of the research; the significance and contribution of the research; the structure of the thesis; and the chapter summary are presented. It is anticipated that the reader will know the orientation of the study by the end of this chapter.

## 1.2 BACKGROUND OF THE STUDY

The global population growth has seen a noticeable increase over the years and is estimated to surpass 8.5 billion in 2030, 9.7 billion in 2050, and 11.1 billion by 2100, with Africa expected to have much higher growth rate (Sadigov, 2022: 2). The increasing population growth and urbanisation requires more construction projects to cater for the people's necessities. In an effort to fulfill the increasing demand for shelter, the construction sector has led to adverse effects on the ecosystem. Unacceptable amounts of material waste are produced by the building industry, amounting to approximately 10% of material cost (Hussein *et al*., 2013: 15). Building construction and maintenance are linked to 40% of global energy and resource use (Edeoja & Edeoja, 2015: 112), and account for 40% to 50% of the GHG produced and responsible for a quarter of the world's total carbon emissions (Huang *et al*., 2017: 1008). According to Hong *et al*., (2015) 96% of all carbon emissions in construction were caused by the gasoline used by construction machinery, and how to reduce carbon emission to prevent global warming and avoid catastrophes has become the motivation of political, environmental, economic, and international studies. According to Emuze *et al*. (2016: 156), tackling carbon emission is a local issue that will depend on an individual country's emission status and vulnerability to climate change. However, there are currently no practical steps that everybody can follow locally to ensure that buildings are constructed sustainably in Ghana (Ampratwum *et al*., 2019: 1265).

The construction sector in Australia supports approximately 1 million employments and contributes 7.5% to the country's GDP (Zuo & Zhao, 2014: 273) whilst in Ghana, the construction sector accounts for 11.8% of the country's GDP and employs around 3.1% of the labour force

(GSS, 2014). However, the construction industry in Ghana still adopts traditional methods of construction and contributes to high energy consumption, air and water pollution, and habitat loss (Djokoto *et al*., 2014: 135). In 2010, the rate of deforestation was 0.81% of the total land area, and the cost of environmental degradation is among the highest in the world at approximately 10% of GDP (UNEP, 2015: 16). The two main sources of direct and indirect emissions were the production of building materials and energy used on construction site (Hong *et a*l., 2014: 249-259). Most previous researchers have focused on carbon emissions from construction materials but there is a lack of studies related to carbon emissions in the construction process that target the actual construction site (Nasab *et al*., 2019). According to Kim and Rigdon (2016: 1), there is little research on carbon emissions generated from human activities throughout the construction project stage.

Arguably, the concept of sustainable construction (SC) has been accepted as the greatest means of protecting the environment and natural resources. However, there is no clear roadmap or legislation in Ghana to promote the adoption of SC practices. The adoption of the SC idea, which is in its infancy stage, is left up to the stakeholders in the industry. It has been confirmed in the literature that incentives and regulatory frameworks help to drive SC adoption. Therefore, the goal of this study was to develop a SC roadmap that helps to reduce the carbon and ecological footprint of construction activities in Ghana, in relation to the existing regulations to adopt SC practices in the Ghanaian Construction Industry (GCI) to achieve sustainable building.

The necessity for the building industry to embrace SC practices is becoming more widely understood to promote the achievement of sustainable development goals, which is thought to be crucially dependent on the building sector. However, little attention has been focused on minimizing the ecological and carbon footprints of construction site operations (Nasab *et al*., 2019; Carmichael *et al*., 2014: 534). Although the Government of Ghana aims to promote SC, there are no government policies and regulations for authorising the concept (Ampratwum *et al*., 2019). A non-governmental organization called the Ghana Green Building Council (GHGBC) was founded in 2009 to develop and advance SC practices in Ghana (GHGBC, 2019). In developing nations and economies in transition, like Ghana, the United Nations Environmental Programme (UNEP) has played a vital role in supporting clean production, sustainable consumption, and green sector strategies. Therefore, it is vital to employ SC techniques to lessen Ghana's ecological and carbon impact.

Consequently, several nations are putting a strong emphasis on SC as a result of the worldwide campaign against climate change, which is being intensified by the damaging environmental effects of construction operations. The built environment is seen to be able to contribute to sustainable development through SC. Ghana's built environment is liable for environmental problems such as habitat loss, air and water pollution, and high energy use (Djokoto *et al*., 2014: 135). However, these negative effects may be lessened if the built environment embraces SC methods. The GCI stakeholders are aware of how destructive conventional construction methods are (Ayarkwa *et al*., 2017). Clients, sponsors, construction experts, government organizations, and other concerned regulatory entities have all expressed a growing need for sustainable construction methods (Ogungbile & Oke, 2019). Hence there is the need for built environment to adopt SC principles into both new and existing residential and commercial building structures due to the numerous advantages associated with the concept (Ahn *et al*., 2013). The building of residential and commercial offices, much of which takes place in the capital city, Accra dominated the construction industry in Ghana (Anzagira *et al*, 2019). Notwithstanding the importance of SC, unsustainable design and construction practices still exist, which undermine the efforts to realise sustainable development goals. Ghana uses 43% of its energy for maintenance and construction of new buildings, leading to economic loss of $2.1 million in production per day (ECG, 2015), high consumption of natural resources, and air and water pollution (Kumi, 2017).

Even though the Government of Ghana intends to promote SC, there are no government policies and regulations for authorising the concept (Ampratwum *et al.*, 2019). Therefore, adoption of SC practices in Ghana is minimal, with only four certified green buildings (Anzagira *et al*., 2019). Notwithstanding the advantages of SC, literature has indicated that the concept is still in its early stages in Ghana and that unsustainable design and construction practices, as well as ongoing environmental destruction for construction purposes, continue to persist (Ayarkwa *et al*., 2017). Hence, there is the need to overcome challenges of implementing SC in Ghana, including those related to lack of commitment by government, perceived initial expenses, lack of regulation, lack of technical support and lack of professional competence. Analysing the extent to which the challenges prevent the adoption of sustainable construction is of growing importance (Ayarkwa *et* *al.*, 2017). Therefore, it is important to promote the benefits of SC among stakeholders to ensure uptake of the concept to help protect the scarce resources, both for the present and future generations in Ghana and reduce the carbon and ecological footprint of construction activity in the GCI.

## 1.3 PROBLEM FORMULATION AND STATEMENT

The African continent is in danger of not being able to meet the rising demand for housing due to its rapid growth, economic development, and urbanization (De Boeck, 2013: 3). It is estimated that the global construction sector produces 40% of man-made waste materials and uses 40% of energy generated (Saleh, 2015: 177-184). This increased the carbon emissions from construction projects by 2.7% annually on average (Hong *et al*., 2014: 249-259). The effects of carbon emissions include decreasing water availability for humanity, global warming, pollution of air, water, and soil, degradation of the ozone layer, melting ice caps and increasing ocean levels, changes of the seasons, extreme weather events, desertification and reducing bio-diversity (Radu *et al*., 2013: 354). These matters are changing the planet negatively, while there is little research on the building sector in the developing countries to reduce the effects of construction projects on the environment (Huang *et al*., 2017: 1008). In 2009, the carbon emission of the global construction industry was 5.7 billion tons (Huang *et al*., 2018). Therefore, the inclusion of the concepts, criteria, and tools of SC to reduce carbon emission requires its dissemination and application by the construction industry stakeholders (Valdés *et al*., 2018).

### 1.3.1 Sustainability and sustainable construction practices

The Brutland Report, released by the United Nations' Global Commission on Environment and Development, defines the sustainability notion as "...filling the requirements and aspirations of the present without sacrificing coming generations to satisfy their own requirements and aspirations" (WCED, 1987). Concerns about striking a balance between ecological, economic and social growth are the main sustainability dimensions (Persson, 2015:43). The design and responsible management of a sound built environment focusing on ecological principles and resource-efficiency is referred to as sustainable construction (Saleh, 2015: 179).

### 1.3.2 Carbon footprint

In Ghana, most of the carbon emissions are from: fossil fuel consumption; deforestation; gas flaring because of oil exploration; and land usage. According to Huang *et al*., (2017:1007), the carbon emissions generated from production of construction material and use of energy in buildings contribute to 45% and 40% of the carbon footprint (CF) respectively. These emissions are influenced directly by burning of fossil fuel, and indirectly by consumption of electricity. Huang *et a*l. (2017:1007) anticipated that global warming will continue and have a greater detrimental effect on both natural and socio-economic systems for the next 100 years. Hence, how to reduce carbon emission to prevent global warming and avoid catastrophes is currently the subject of research in environmental, economic, international, and political fields (Emuze *et al*., 2016: 156). However, tackling carbon emission is a local issue that will depend on an individual country's emission status and vulnerability to climate change (Emuze *et al*., 2016: 157; Edeoja & Edeoja, 2015: 112).

### 1.3.3 Ecological footprint

The term "ecological footprint" (EF) refers to all environmental issues as a whole and sets sustainable development as its primary objective (Emuze *et al.*, 2016: 156). The EF shows the value of the water and land areas required to replenish the resources used which have a direct impact on the built environment. In Ghana, there is a pressing need to increase the demand for sustainable building practices to encourage construction companies to undergo a modernisation process involving more eco-friendly production and consumption to preserve the ecosystem (Djokoto *et al*., 2014: 141). The ecological modernisation integrates improvements in technical innovations together with environmental, economic, and social issues on the challenges of sustainability. The behavioural change of stakeholders including individual clients, contractors, and designers would reduce the CF and EF (Emuze, 2015, cited by Emuze *et al*., 2016: 158).

### 1.3.4 Problem statement

The high population growth and lack of basic infrastructural facilities, together with an approximately two million housing deficit in Ghana, provide opportunity for more construction projects. The question is, should Ghana continue with the traditional way of construction in a bid to bridge the gap of infrastructural facilities before tackling the issues of climate change and sustainable development? Certainly, no, but there are limited country-specific studies on the implementation of SC from emerging nations such as Ghana (Darko & Chan, 2016). It is important to close this empirical research gap in Ghana to adopt SC practices that are conducive to the environment to ensure social sustainability and economic viability.

Currently, SC implementation in Ghana is fraught with difficulties such as resistance to change, concern about greater investment costs, lack of government commitment, lack of appropriate laws, and lack of specialised knowledge (Ametepey, 2015: 116). According to Sarfo (2015: 338), legal, technical, contractual, and framework enablers should be available if SC practices are to be implemented in Ghana. There is no clear strategic plan to guide the construction activities in Ghana to reduce carbon and ecological footprints. The process and methods used to conduct and implement SC have not received much attention. Kwaku *et al*. (2014: 40) suggested that it is important to assess whether the GCI is implementing the essential procedures and practices and taking the necessary steps to become sustainable. Accordingly, the research problem statement was postulated as: the lack of a roadmap hinders the reduction of carbon and ecological footprint of construction activity in GCI.

## 1.4 RESEARCH QUESTIONS

The primary research question of the study is: How does a focus on sustainability help to reduce the carbon and ecological footprint of construction activities in Ghana?

To resolve the research problem and respond to the main research question, the subsequent supplementary questions were formulated:

1. Why is sustainability a focus area that cannot be ignored by GCI?
2. How should design respond to sustainability requirements in GCI?
3. How should construction materials respond to sustainability requirements in GCI?
4. How is the use of energy efficiency influencing the construction process in GCI?
5. What modalities are employed to reduce construction site solid waste in GCI?
6. What SC roadmap would reduce the carbon and ecological footprints of activities in GCI?

## 1.5 RESEARCH AIM AND OBJECTIVES

The aim of this study was to develop a SC roadmap that helps to reduce the carbon and ecological footprint of construction activities in Ghana. The novelty of this study is to develop a roadmap for SC practices that works for GCI. To achieve the aim of the study by providing answers to the research questions, six specific objectives were established as follows:

1. To identify why sustainability is a focus area that cannot be ignored by GCI.
2. To determine how design should respond to sustainability requirements in GCI.
3. To determine how construction materials should respond to sustainability requirements in GCI.
4. To explore the effects of energy-efficiency on the construction process in GCI.
5. To evaluate the modalities employed to reduce construction site solid waste in GCI.
6. To develop a SC roadmap that would reduce the carbon and ecological footprint of activities in GCI.

## 1.6 SCOPE OF THE STUDY

The current study is focused primarily on the development of a SC roadmap to reduce carbon and ecological footprints of construction activity to contribute to the implementation of SC in Ghana. The conceptual framework adopted is centred on environmental sustainability and was influenced by the contextual issues of pollution and emission reduction, waste reduction, efficient use of energy, and protection of resources and eco-systems. Only experts in GCI was used for the Delphi study including policy-makers, regulators, and implementers such as contractors, consultants, clients, and industry professionals in the building construction sector of Ghana. The analysis of the study results was restricted to structural equation modelling (SEM-PLS) and the Statistical Package for the Social Science (SPSS), and the findings are relevant to the GCI.

## 1.7 THE LIMITATIONS OF THE STUDY

The limitations of this study include:

1. The research was conducted on building construction projects in Ghana and did not consider other areas of the construction industry.
2. The roadmap is limited to the environmental pillars of sustainability.

3. The data for the study was collected using questionnaire survey and Delphi techniques without conducting interviews and case studies to obtain in-depth appreciation of SC practices in GCI.
4. The developed roadmap has not been tested on a live project but was evaluated by professionals in GCI.

## 1.8 OVERVIEW OF THE RESEARCH PROCESS

An overview of the methods and processes utilized to generate the primary data makes up the research process for this study. The methods used to identify the various research processes and objectives pursued are explained in Figure 1.1. This study was primarily undertaken to establish the research problem and review pertinent literature to find any knowledge gap. It was discovered that construction activities contribute to carbon and ecological footprints, knowingly or unknowingly, through the practices adopted. Lack of an empirical framework, awareness of sustainability practices in construction, and technological and technical expertise for SC hinder sustainability of construction activities in Ghana.

To address the gaps, the aim and objectives, research problem, and research questions were constructed. The main search data were gathered using Delphi studies and a survey within a sequential, exploratory, mixed method design. The outcomes of the qualitative data analysis were utilized as the foundation for collecting quantitative data. The Delphi survey used three rounds to collect data from experts in the construction sector. Closed-ended questions were formulated based on the Delphi study to collect data from construction companies. SPSS was used for statistical analysis of the data gathered to identify factors contributing to the phenomenon being investigated.

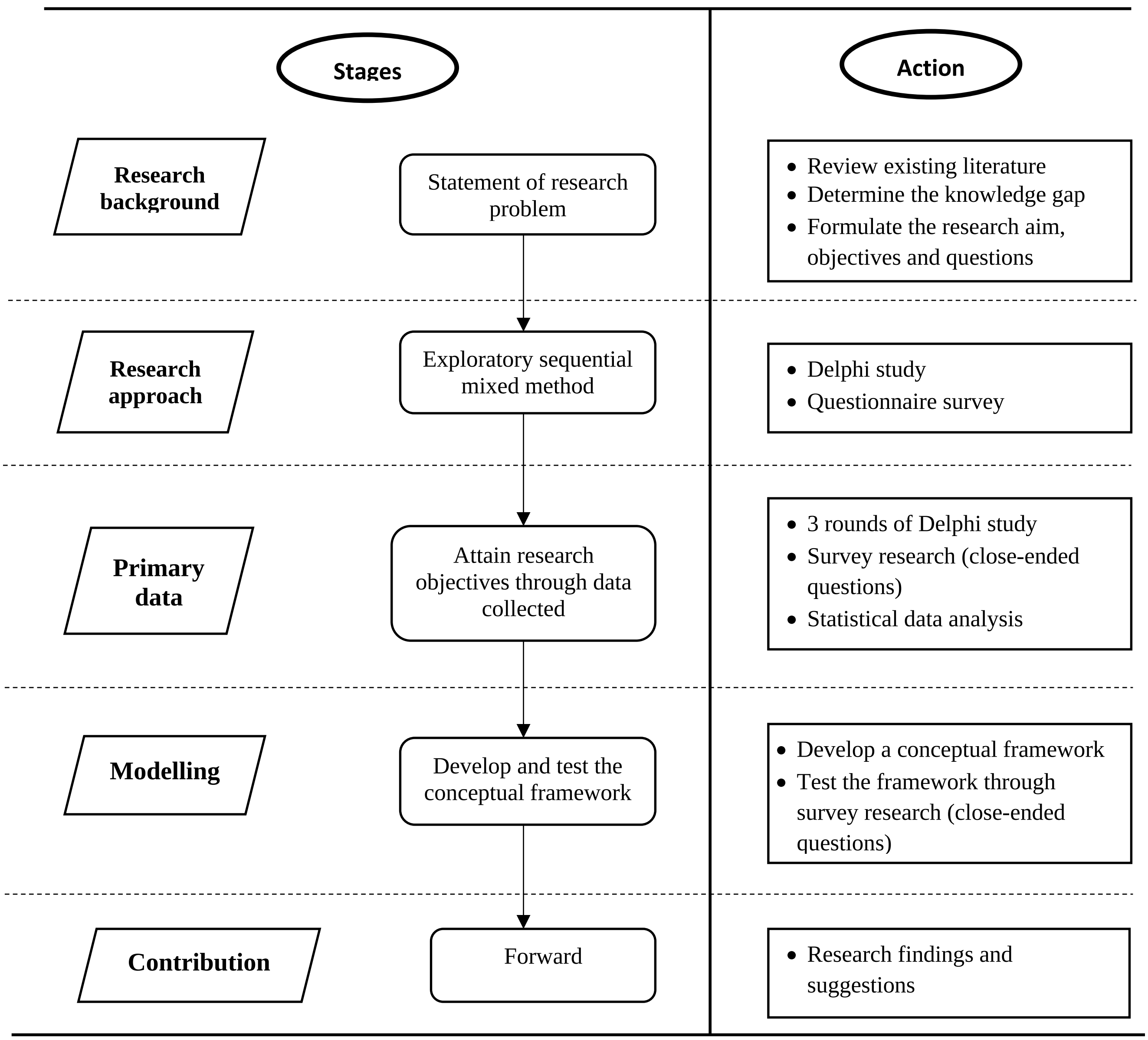


**Figure 1.1: The research process**

(Source: Researcher's construction)

### 1.8.1 Modelling and contribution from the research process

For this study, the roadmap developed was tested through a survey using closed-ended questions, administered to professionals with a background in sustainable construction and registered with GhIS, GIE, and GIA, to ascertain its validity. The results of the questionnaire were analysed statistically using SPSS and SEM-PLS. The research findings from the study were summarised and the researcher provided recommendations for future research.

## 1.9 SIGNIFICANCE AND CONTRIBUTIONS OF THE STUDY

The research contributes to the discussion of sustainability in the GCI. In order to achieve sustainability in GCI, this study developed a roadmap to lower negative environmental impact. The roadmap would stimulate the demand for SC practices in GCI. It could motivate a behavioural change by clients, designers, and contractors in favour of a lower carbon and ecological footprint of construction activities (Emuze, 2015).

This GCI study is novel and contributes to the amount of existing research on management of construction projects (Zhao *et al*., 2019; Darko, Ping, *et al*., 2018; Aktas & Ozorhon, 2015). The concept of SC has not been extensively studied in Ghana. Through investigation and analysis of previous studies, the developed roadmap for reduction of carbon and ecological footprint can be used in other emerging nations like Ghana with some modification. Ayarkwa et al. (2017) emphasised that the key factors that could initiate, stimulate and sustain SC in Ghana are framework, legislation, financial incentives and by-laws. The developed roadmap is anticipated to identify practical sustainability strategies that construction professionals should use to lessen the ecological and carbon footprints of construction activities on the environment. It gives policy makers, practitioners, and academics a forum to rethink how to approach sustainability practices in GCI and other developing countries.

## 1.10 THE STRUCTURE OF THE THESIS

The thesis is set up as follows:

**Chapter One:** The research direction

This is the introduction chapter and contains the problem statement, background to the study, the primary research question and secondary questions that were investigated. The purpose and goals are highlighted. The study's scope, and limitations are discussed.

**Chapter Two**: Literature review

This includes a survey of the pertinent academic literature on the topic. The chapter's main themes include ecological and carbon footprint reduction, sustainability, and SC.

**Chapter Three**: Research methodology

An overview of the design and execution of the research is provided in this chapter. It comprises an explanation of the study design, the methods used to gather and analyse the data, the sample population, the data analysis, and the results interpretation.

**Chapter Four**: Delphi survey results and analysis

This chapter mainly emphasised on the presentation of the Delphi research results and data analysis. The chapter offers solutions to the research-related queries.

**Chapter Five**: General survey results and analysis

The results and analysis of data from the survey are reported in this chapter.

**Chapter Six**: Development of Roadmap

The developed roadmap and validation is presented in this chapter.

**Chapter Seven**: Conclusions and recommendations

The overview, findings, and suggestions pertaining to the study are included in this chapter.

## 1.11 CHAPTER SUMMARY

This chapter introduced the thesis and provided background information for the study. The research problem, the aim and objectives, the research questions, and the importance of the research were all described in this chapter. It was noted that there is a gap that exist (i.e., there is no enabling framework) in an effort to lessen ecological and carbon footprint for SC, and why the need to close the gap, were indicated. This chapter provides the basis for the literature review in which the pertinent concepts relevant to the GCI study are examined in Chapter Two.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter highlights key ideas in which major concepts are explained and their implications for SC and GCI. The discourses that were relevant to the aim of the study have been reviewed to include issues of sustainable development, SC concepts, and CF and EF of construction practices. The barriers, drivers and benefits of SC implementation are presented in this chapter.

## 2.2 SUSTAINABLE DEVELOPMENT

The universally accepted definition of sustainable development by the World Commission on Environment and Development (WCED, 1987) produced the Brundtland Report, which calls for "development that meets the needs and expectations of the present without compromising the ability of future generations to meet their own needs". According to Bridgewater (2016), the sustainable development concept is believed to have originated in 1960s with the concern regarding pollution and environmental conservation referred to as "Silent Spring" by Rachel Carson. This was followed by the Biosphere Conference in Paris which was organised by UNESCO as an agent of the United Nations. The conference brought together an inter-governmental panel of experts to promote the idea of the utilisation and conservation of environmental resources for Sustainable Development. The experts debated the scientific justification for the wise use and preservation of the biosphere's resources. The first Earth Day in 1970 and the establishment of organisations, such as Greenpeace, Environmental and Development Action in third-world action (ENDA) and International Institute for Environment and Development (IIED), propelled the growth of Environmental Movement around the world. The UN conference on Human Environment in 1972 proclaimed that humanity has "reached a point in time when we must mold our conduct throughout the globe with a more responsible care for the environmental implications" (Pandey & Swaroop, 2021). At the conference, which was focused on economic development in conjunction with improvement and protection of the human environment, sustainable development was defined as:

> To protect and improve the human environment for both the present and the future generation to live in harmony with the long-standing and fundamental aims of peace and global economic and social growth.

The established principles by UNEP laid the foundation of the three main pillars of sustainability: environment, society, and economy.

### 2.2.1 Dimensions of sustainability

The construction industry has been engaging in poor sustainability performance and the sector is offered the opportunity to undertake sustainability initiatives (Svajlenka & Kozlovska, 2020; Lee *et al*., 2019). Sustainable development applies to the various methods and routes taken to attain sustainability, which is frequently viewed as a long-term objective to create a more sustainable world. (Afzal *et al.*, 2017). A flourishing society depends on a healthy environment to give its residents access to resources, food, clean water, and air. Sustainable development's three major pillars

The three main pillars of sustainable development – **environment, society, and economy** – which are intertwined, not separate, are shown in Figure 2.1. Sustainability is a way of looking at the world's future in which sociological, economic, and environmental concerns are all balanced in the quest for a higher standard of living.

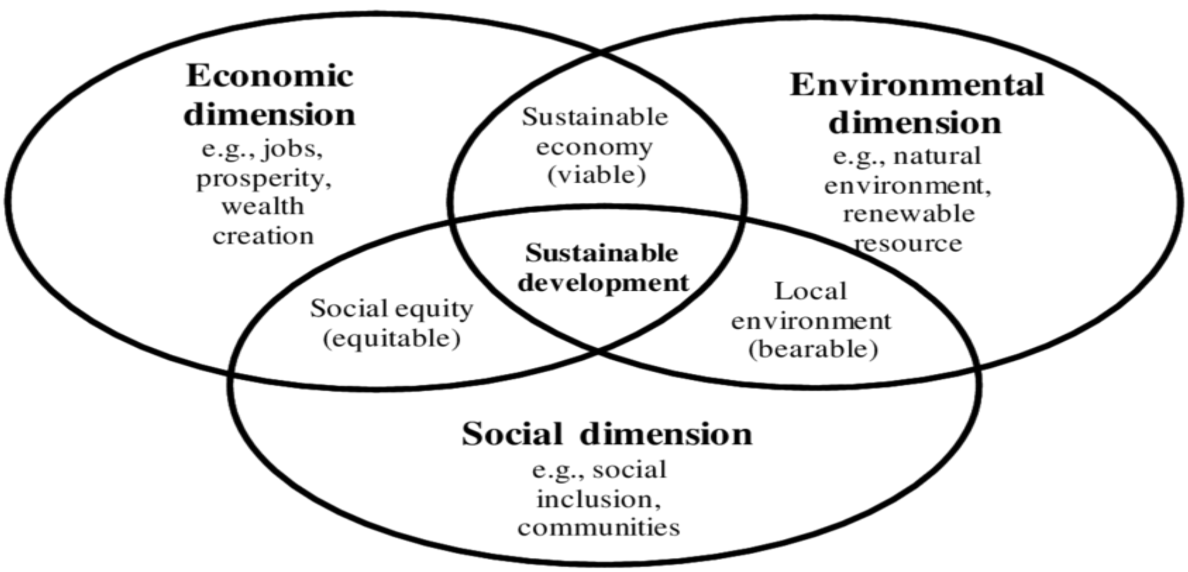


**Figure 2.1: Sustainability dimension**

(Source: Leat *et al*., 2011)

#### *2.2.1.1 Economic sustainability dimension*

Sustainability practices must be economically viable in the long term and serve as the catalyst to process productivity. To adopt any strategy towards sustainability, cost/benefit analysis is a major criterion because the ultimate goal of the industry is long-term financial performance. Darko *et al*. (2017) argued that the potential benefits of implementing sustainability are the reduction of cost from inception to demolition and the cost of taking corrective actions when ecological problems occur. The sustainability practices help the industry to meet the needs of the operating communities to increase customer and community goodwill, strengthen the survival of the organisation to reduce cost, increase productivity, and contribute to profitability of the organisation and sustainable development (Gyamfi *et al*., 2017).

#### *2.2.1.2 Social sustainability dimension*

The social sustainability dimension is concerned mainly with the well-being of individuals and the community in which the industry operates. The Sociological well-being involves satisfaction, emotions, comfort, safety, and security (Rajabi *et al*., 2022). The social responsibility of an organisation reflects concern for its employees' social needs, extension of resources to uplift the community and improve quality of life, maximise health and comfort, improve social civilisation and be just and fair, and obey the laws of the country (Windapo, 2014). Corfe (2013) explained that, in considering sustainability, attention should be paid to the significant elements that can influence the processes. Social sustainability goes beyond the process and mandate of the industry to provide infrastructure to provide social corporate responsibility to develop human capital, talent attraction and retention, and utilise locally-sourced material and skills in a professional manner to create jobs. The construction industry should understand the dimensions of sustainability concepts holistically and adopt them to attain more sustainable results.

#### *2.2.1.3 Environmental sustainability dimension*

During the past two decades there is an increasing awareness of the need to adopt SC to minimise the environmental impact of construction practices has been experienced around the globe (Ahmed & El-Sayegh, 2022). Mining of raw materials for construction projects contribute to the negative effects on environment.

The construction projects contribute to severely adverse impacts on the environment as a result of the extraction of natural resources. Yao (2013: 4) suggested that there is a need to take a second look at how we develop as a group to mitigate the effects of global climate change, extreme weather events, effects of a rise in sea levels on the ecosystem, and urban pollution and environmental degradation which affect the economy, safety and well-being of individuals. The essential functions of the natural environment for the welfare and survival of the human species on the earth, such as carbon cycle, hydrological cycle, and ozone layer cannot be compromised (Darko *et al*., 2017). Corfe (2013) insisted that preserving the natural resources that provide essential functions for the well-being of society are the driver of sustainable growth. The industry should focus on the natural environment, the renewable resources, effort to minimise waste, using alternative energy sources, creating low carbon pollution, and develop new and environmentally-friendly technology to protect our irreplaceable and non-substitutable natural capital.

## 2.3 CONCEPT OF SUSTAINABLE CONSTRUCTION

The original purpose of the SC idea was to outline the role of the construction sector in achieving sustainability (Yu *et al*., 2018). Goel *et al*. (2019b), highlighted the past and current situation of the construction sector and argued for the implementation of SC. The creation and responsible administration of a healthy building sector based on ecological principles and resource-efficient was the initial definition of SC proposed by Kibert in Tampa in 1994 (Kibert, 2016; Yu *et al*., 2018). SC constitutes a novel field that calls for additional research to be developed further and focused on sustainability issues (Goel *et al*. 2019a). SC seeks to reduce energy use and emissions that are hazardous to human health and the environment. Mustafa and Bakis (2015) concluded that SC is the implementation of sustainability concepts to the construction process from planning, mining natural materials to make construction materials, constructing, employing low embodied energy materials, saving energy and water, to deconstruction and controlling waste. SC is a building process that reduces the damaging effects that construction projects have on human health and the environment. SC was described by Saleh (2015: 179) as the construction and ethical maintenance of a healthy built environment based on ecological and resource-efficient principles. SC is a comprehensive process that aims to construct settlements that uphold economic equality and human dignity by restoring and sustaining harmony between the built and natural ecosystems. In its simplest form, SC is the implementation of sustainability concepts to the entire construction process, from inception to deconstruction and cotrolling waste (Mustafa & Bakis, 2015). True sustainability is supported by achieving a balance between the three fundamental pillars of the SC idea, namely: social well-being, environmental preservation, and economic prosperity. Consequently, in order to create balance and constant synergy among the three elements of sustainability, businesses should pursue a comprehensive approach to projects delivery.

### 2.3.1 Sustainable construction practices

Many nations have turned their attention to SC practices as part of the worldwide movement against global warming as a result of the detrimental effects that building operations have on the planet. The built environment is expected to contribute to equitable growth through the use of SC practices (Ogunbiyi *et al*., 2013). The three bottom-line concerns regarding social equality, environmental quality, and a healthy economy are addressed by SC practices, which are also focused on delivering infrastructure that adds value for the consumer and improves societal well-being. In addition to maximizing the effective use of limited resources, it offers and supports the desired natural and social environment. The GCI adopts unsustainable design and construction practices which are focused mainly on cost, time and quality, and contributes largely to high energy usage, constant degradation, air and water pollution, and loss of habitats (Djokoto *et al*., 2014: 135; Ahiabu, *et al.*, 2023:307). However, SC practices help to minimise the depletion of resources, minimisation of environmental degradation, and the creation of healthy built environments to support the ecology. According to Ayarkwa *et al.* (2017), the GCI's stakeholders are aware of how destructive traditional construction methods are in comparison to advantages of SC. The relevant stakeholders, such as clients, construction professionals, government agencies, sponsors, and other relevant regulatory authorities, have shown an increasing interest in SC practices (Ogungbile and Oke, 2019). The building sector is gradually integrating sustainability in the construction activities of new projects and the maintenance of existing structures constructed due to the many advantages associated with SC, such as decreased health and safety effects on idividuals and communities, lower legal cost associated with eliminating waste, and reduced delays in construction (Ahn *et al*., 2013). Therefore, the adoption of suitable SC principles enables the achievement of SC as indicated in Figure 2.2. To achieve SC, all stakeholders must be committed and change their behaviour, adopt new product ideas and practices, integrate environmental systems with normal work process, and involve all project participants.

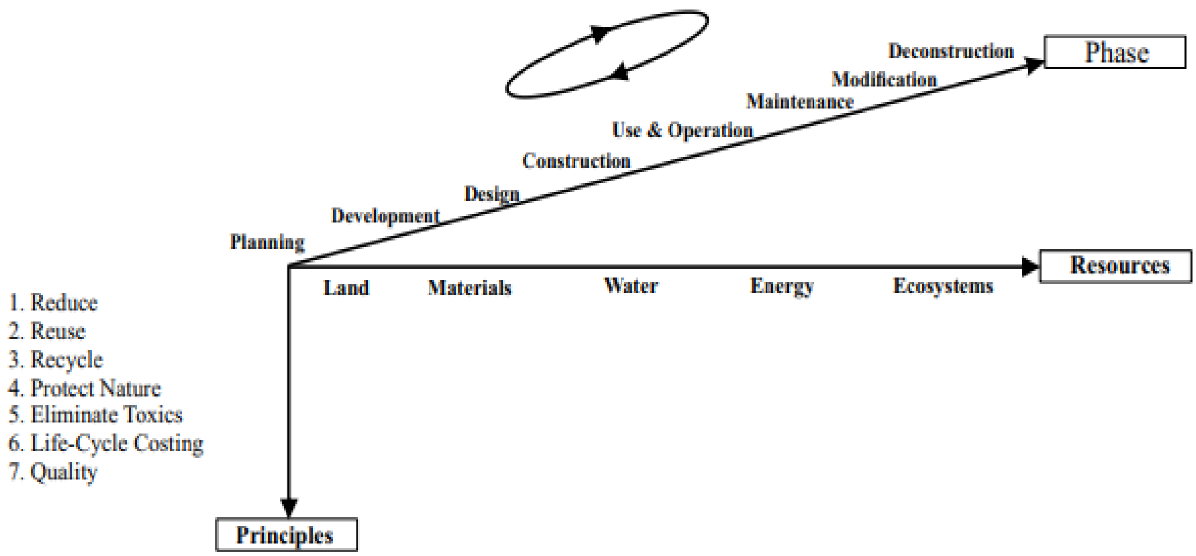


**Figure 2.2: Sustainable construction principles**

(Source: Kibert, 2005, as cited by Moradibistouni et al., 2018)

## 2.4 DRIVERS OF SUSTAINABLE CONSTRUCTION

Drivers of SC are different factors that promote, maintain, and increase the adoption and use of necessary sustainability tools (Ayarkwa *et al*., 2017). The successful SC implementation would depend on a thriving local building industry and its capacity to innovate in a manner that would meet the needs of sustainable growth (Bash & Häkkinen 2015). According to Adjarko *et al*. (2016), SC is driven by minimising resource consumption, improving the quality of air, avoiding health challenges, using re-cycled resources, maximising re-use and reducing wastage in the GCI. Ayarkwa *et al*. (2017) emphasised that the important drivers to increase the implementation of SC in Ghana are legislation, building codes and by-laws.

In contrast to barriers, drivers of SC (Table 2.1) according to Ayarkwa *et al*. (2017) are a variety of factors that initiate, maintain, and increase the adoption and use of necessary practices for sustainability. Some drivers advocate for the adoption of SC principles as pull forces, which include economic gains, ability to retain quality employees and a favourable company image, whereas push elements include financial incentives and responses to regulatory requirements (Darko *et al*., 2017; Shabrin & Kashem, 2017). Ayarkwa *et al*. (2017) posited that moderators that could initiate, promote, and sustain SC include changes to laws, bylaws, and construction codes. Ayarkwa et al. (2017) claim that the availability of integrated technology, and policies like tax breaks or subsidies for eco-friendly goods can promote and improve SC in GCI.

**Table 2.1: Drivers of sustainable construction**

| Drivers | Research Approach | Sample | Reference |
|---|---|---|---|
| • Influence of stakeholders.<br>• Demand and requirements of client.<br>• Cost effectiveness.<br>• Laws and regulations.<br>• Awareness and expertise of senior management.<br>• Competitive edge.<br>• Winning additional contracts to stay in business.<br>• Clear and consistent guidelines for measuring sustainability.<br>• Brand image and reputation of a company to recruit and keep qualified people.<br>• Financial motivation/incentives<br>• Accessibility of life-cycle cost analysis.<br>• Investment.<br>• A moral commitment to safeguard the environment. | Quantitative | Architects in Ghana | Ayarkwa *et al*. (2017) |
| • Risks, costs and market value.<br>• Policies.<br>• Demand and the responsibility of clients.<br>• Procurement and Tendering procedures.<br>• Networking and co-operation.<br>• Production stages and job scheduling.<br>• Available integrated methods.<br>• Innovation.<br>• Awareness and common terminology. | Quantitative | Construction professionals in Finland | Bash & Häkkinen (2015) |
| • Financial gains.<br>• Stakeholders interest<br>• Sustainability of the environmental.<br>• Requisite corporate/social responsibility. | Qualitative | South African construction professionals | Windapo (2014) |

| **Drivers** | **Research Approach** | **Sample** | **Reference** |
|---|---|---|---|
| • Building bye laws.<br>• Financial gains.<br>• Client knowledge.<br>• Client request.<br>• Planning policy.<br>• Levies /Taxes.<br>• Measurement/labelling.<br>• Investment. | | Construction professionals in the UK | Pitt *et al*., (2013) |
| • The application of more stringent rules.<br>• Knowledge of the effects on society, the environment, and the economy.<br>• The development of a long-term supplier-customer relationship.<br>• Adopting a system for environmental management.<br>• Implementation of 14,000 ISO types of certification.<br>• Leadership from the top. | Quantitative | Construction professionals in India | Arif *et al*., (2013) |

(Source: Ahiabu *et al.*, 2022)

### 2.5 BARRIERS TO SUSTAINABLE CONSTRUCTION

Barriers (Table 2.2) are defined as characteristics and situations that can restrict progress towards implementing SC principles or prevent certain actions from being undertaken (Ayarkwa *et al.*, 2017). Consequently, barriers hurt chances of achieving SC. Ayarkwa *et al.* (2017), posited that awareness, knowledge, and attitude are considered internal constraints whereas technological accessibility, green technology, and financial resources are considered external barriers. The biggest obstacle to SC implementation in Ghana is said to be lack of financial motivations.

**Table 2.2: Barriers to sustainable construction**

| Barriers | Research Approach | Sample | Reference |
|---|---|---|---|
| • Absent of building bye laws and regulations.<br>• Unavailability of financial motivations.<br>• Inadequate investment.<br>• Exorbitant initial cost<br>• Lack of client demand.<br>• Exorbitant prices for environmental technologies and services.<br>• Insufficient research.<br>• Limited public awareness.<br>• Competitive pressure.<br>• Unavailability of database and information.<br>• Deficit of green products.<br>• Shortage of professional experience and knowledge.<br>• Unavailability of green technology.<br>• Tendering and contract requirements.<br>• High level of perceived risks. | Quantitative | Architects in Ghana | Ayarkwa *et al*. (2017) |
| • Financial concerns and repercursions.<br>• Limited understanding about sustainability techniques.<br>• Attitude of professionals.<br>• Absence of a sustainability rating tool.<br>• Complete control of the design by the client.<br>• The price tag of for renewable energy sources. | Quantitative | Finland | Bash & Häkkinen (2015) |
| • Absence of construction laws and codes.<br>• Insufficient incentives.<br>• High cost of investment.<br>• The hazards of investment.<br>• Higher total price.<br>• Low public awareness.<br>• Dearth of demand.<br>• Insufficient promotion strategy.<br>• Unavailability of experts.<br>• Failure to cooperate.<br>• Absent of databases.<br>• Aversion to change.<br>• Lack of experience and training.<br>• Absence of technology.<br>• Unavailability of governmental assistance.<br>• Absence of tools for measuring. | Quantitative | Construction professionals in Ghana | Djokoto *et al*. (2014) |

| Barriers | Research Approach | Sample | Reference |
|---|---|---|---|
| • Absence of construction laws and codes.<br>• Insufficient incentives.<br>• Greater cost of investment.<br>• The hazards of investing.<br>• Unavailability of construction and design team.<br>• Higher total price.<br>• Lack of experience and training.<br>• Absence of technology.<br>• Failure to cooperate. | Mixed method | Contractors and consultants in the UK | Opoku & Ahmed (2014) |
| • More stringent contract creiteria for capital costs.<br>• Substantial and varied business operations.<br>• The idea that sustainability is more expensive.<br>• Managing conflicting and incompactible goals with other corporate objectives.<br>• Low sustainability priorities. | Quantitative | Architects in Ghana | Bangdome -Dery & Kootin-Sanwu (2013) |

(Source: Ahiabu *et al*., 2022)

## 2.6 BENEFITS OF SUSTAINABLE CONSTRUCTION

Sustainability in the built environment is rapidly gaining worldwide attention, although many emerging economies like Ghana are yet to accomplish much progress in this area (Kongela, 2021). The significance of the building sector for progress in every economy around the globe cannot be over-estimated. However, the increasing demand for infrastructure results in high demand for water, energy and natural resources, which over-burdens the ecosystem and causes pollution of air and water bodies (Darko *et al*., 2018). It has become clear that SC leads to more significant benefits and profitable rewards than conventional construction methods (Oguntona *et al*., 2019). The benefits of SC are enormous and consist of the three main aspects of sustainability – environmental, economic and social benefits (Ibrahim *et al*., 2018) as indicated in Table 2.3. The potential benefits to be accrued include protection of resources and ecosystem, enhancing standard of living for each person, and alleviating poverty (Oluwunmi *et al*., 2019).

**Table 2.3: Benefits of SC identified from the literature**

| Code | Factors | References |
|---|---|---|
| **Environmental benefits** | | |
| BSC1 | Safeguard land, water, air, and ecosystems | Oluwunmi *et al.*, 2019; Hill and Bowen, 1997; Lai *et al.*, 2017 |
| BSC2 | Protect natural resources | Darko *et al.*, 2013; Ojo-Fafore *et al.*, 2018; Adjarko *et al.*, 2016; Simpeh and Smallwood, 2018 |
| BSC3 | Preserve genetic diversity and animal species | Darko *et al.*, 2013; Hussin *et al*. 2013 |
| BSC4 | Conserve the biosphere | Oluwunmi *et al.*, 2019; Hussin *et al*. 2013 |
| BSC5 | Utilise renewable natural materials | Adjarko *et al.*, 2016; Darko *et al.*, 2013 |
| BSC6 | Reduce waste generation and disposal | Oguntona *et al* 2019, Darko *et al.*, 2013 |
| BSC7 | Decrease $CO_2$ emission and pollution | Oguntona *et al.*, 2019 |
| BSC8 | Sustain life support system and ecological processes | Opoku *et al.*, 2019 |
| BSC9 | Adopt vigorous re-cycling | Hussin *et al.*, 2013; Simpeh and Smallwood, 2018 |
| BSC10 | Conserve the natural environment | Opoku, *et al.*, 2019; Adjarko *et al.*, 2016 |
| BSC11 | Avoid global warming | Darko *et al.*, 2017; |
| **Social benefits** | | |
| BSC12 | Enhance quality of life for all | Oluwunmi *et al.*, 2019, Ojo-Fafore *et al.*, 2018 |
| BSC13 | Alleviate poverty | Oguntona *et al.*, 2019 |
| BSC14 | Satisfy the needs of human | Darko *et al.*, 2017 |
| BSC15 | Consider local information when developing | Oluwunmi *et al.*, 2019; Lai *et al.*, 2017 |
| BSC16 | Optimise social benefits | Darko *et al.*, 2017; Mensah *et al.*, 2015; Adjarko *et al.*, 2016; Simpeh and Smallwood, 2018 |
| BSC17 | Improve health, comfort and well-being | Ojo-Fafore *et al.*, 2018; Hussin *et al.*, 2013, Darko *et al.*, 2017; Simpeh and Smallwood, 2018 |
| BSC18 | Have concern for inter-generational equity | Ahn *et al.*, 2013 |
| BSC19 | Minimise cultural disruption | Whang and Kim, 2015 |
| BSC20 | Provide educational services | Du Plessis, 2007 |
| BSC21 | Promote unism among, society, humanity and nature | Lai *et al.*, 2017 |
| BSC22 | Understand the importance of cultural and social capital | Ahn *et al.*, 2013 |
| BSC23 | Understand multi-disciplinary societies | Ahn *et al.*, 2013 |
| **Economic benefits** | | |
| BSC24 | Improve economic development | Whang & Kim, 2015; Ahn *et al.*, 2013 |
| BSC25 | Reduce the cost of energy consumption | Darko *et al.*, 2017; Ayarkwa *et al.*, 2017 |

| | | |
|---|---|---|
| BSC26 | Raise real revenue | Whang and Kim, 2015 |
| BSC27 | Improve productivity | Oluwunmi *et al.*, 2019 |
| BSC28 | Reduce cost of infrastructure | Ojo-Fafore *et al*., 2018; Ahn *et al.*, 2013 |
| BSC29 | Reduce cost of environmental impact | Ojo-Fafore *et al*., 2018; Adjarko *et al.*, 2016 |
| BSC30 | Reduce cost of water consumption | Oguntona *et al.*, 2019, Ojo-Fafore *et al*., 2018 |
| BSC31 | Lower health costs | Oguntona *et al.*,2019, Kats, 2013 |
| BSC32 | Prevent absenteeism in organisations | Oguntona *et al.*, 2019 |
| BSC33 | Improve return on investments (ROI) | Shabrim and Kashem, 2017; Darko *et al*., 2017; Oguntona *et al.*, 2019; Kats, 2013 |

(Source: Ahiabu *et al*., 2023)

### 2.6.1 Environmental benefits

The benefits to be derived from using a technology will engender its adoption. The importance of SC and the environmental benefits it can provide for mankind cannot be over-emphasised and have been well discussed in the literature (Oguntona *et al*., 2019; Ojo-Fafore, 2018). The adoption of sustainability in construction practices has been confirmed in previous studies to have direct benefits related to the environment (Shabrin & Kashem, 2017; Darko *et al*., 2013; Nurick & Cattell, 2013). The environmental advantages of SC, include the preservation and conservation of natural resources as well as the protection of ecosystems and biodiversity (Darko *et al*., 2013). The adoption of SC helps to improve energy efficiency and minimise $CO_2$ emissions. Also, SC enhances and protects ecosystems, improves quality of water and air, decreases material waste, preserves sustainable resources and is one of the surest ways by which Sustainable Development Goals (SDGs) relevant to the environment can be achieved by 2030 (Oluwumni *et al*., 2019). A new direction for the global community is represented by the 2030 Agenda for Sustainable Development. Opoku (2016) argued that the building sector has a responsibility to ensure the realisation of global effort towards achieving sustainability. When the construction industry integrates sustainability with environmental protection, economic growth, and social progress, it may significantly contribute to a sustainable future (Tupenaite *et al.*, 2017). Arora and Mishra (2019) claim that there has been little progress achieved in meeting the environmental-related SDGs 6, 7, 12, 13, 14, and 15. To help accomplish the pertinent SDGs, it is important for stakeholders to pursue SC practices aggressively. Therefore, it is crucial to consider the advantages of implementing the sustainability techniques used in GCI.

### 2.6.2 Economic benefits

Similar to environmental benefits, economic benefits are important for the adoption of SC practices. There are financial benefits derived from the reduced consumption of energy and water, and improved health and productivity (Oluwunmi *et al.*, 2019; Ojo-Fafore *et al*., 2018; Whang & Kim, 2015). Shabrin and Kashem (2017) reported that the economic benefits for adopting SC practices include: a better payback period; an increase in revenue; and a quick return on investment (Oguntona *et al*., 2019; Ojo – Fafore *et al*., 2018). Darko *et al*. (2013) argued that the economic advantages of SC include: enhanced productivity; reduced cost of operation; and optimised economic performance over a building's lifetime.

### 2.6.3 Social benefits

The desire to demonstrate commitment to social responsibility can drive the uptake of SC practices. According to Darko *et al*., (2013), SC practices enhance health and comfort for occupants, and aesthetically pleasing. Shabrin and Kashem (2017) indicated that SC is a new venture that provides the local populace with additional opportunity for employment creation and offers many job opportunities. Consequently, SC practices will benefit mankind by improving quality of life and alleviating poverty (Ahiabu *et al.*, 2023). This means that the benefits of SC practices include various savings and financial gains during construction phases to create opportunities resulting from social benefits (Khoshbakht *et al*. 2017). The House of Lords (2016) affirmed that construction contribute to prosperity, quality of life, well-being and happiness of communities depending on how the construction project is carried out. Even though construction practices can have negative effect on the environment, they have the potential to drive the realisation of the SDGs when SC practices are adopted.

### 2.6.4 Gap in sustainable construction literature

The literature review on SC survey reveals that there is a wealth of information on the advanced countries, but Ghana and other emerging nations have few information. (Darko *et al*. 2017). This results in the SC benefits for education in Ghana being limited. The professionals in Accra, Ghana's capital city, are the only ones included in the study by Darko *et al*. (2017). Ghana's construction industry is quite active, with a wide range of profesionals spread across the entire country, especially in the major cities. Therefore, it is inadequate to limit SC opinions to only those of Accra-based professionals. The purpose of this study was to close this knowledge gap by identifying the crucial advantages of adopting SC in addition to their effects on SC from a wide range of professionals in the GCI.

Understanding personal perceptions, total devotion to the principles, a thirst for study, and thorough involvement are all necessary for developing an awareness of SC practices. SC awareness in developed countries is relatively high with the availability of relevant regulations. For example, the Environmental Protection Agency (EPA) is one of several organizations working to apply the concepts of sustainable development in the USA. This organization makes sure that rules and regulations are followed and properly applied. The agency successfully monitors the problems with air pollution, waste, and dangerous substances in the building industry. (Issa & Al Jabbar, 2015, cited by Asuman, 2017).

The concept of sustainability is still in its infancy stage in developing nations. Many nations are still attempting to understand the idea and its possible advantages for the sector. For instance, the sustainability of the building industry is lacking in Nigeria. Similar results have also been found in recent research conducted in other African nations (Dania *et al.*, 2013). Sichali and Banda (2017) assert that Zambia has a relatively low degree of awareness and demand for information and interests. Similar evaluations were also carried out in the built environment of Ghana by Darko *et al*. (2018). As a result, many developing nations still have a limited understanding of SC, which calls for increased sensitisation and a clear roadmap to achieve the goals for environmental sustainability.

## 2.7 CONCEPTUAL PERSPECTIVE OF THE STUDY

The consensus guided by the literature, indicate the need for a roadmap to be developed scientifically and verified empirically for SC to take root in Ghana as a developing country. Therefore, this study aimed to offer decisive support for the reduction of CF and EF of construction projects, which led to a conceptual framework depicting the research problem of the study, as indicated in Figure 2.3.

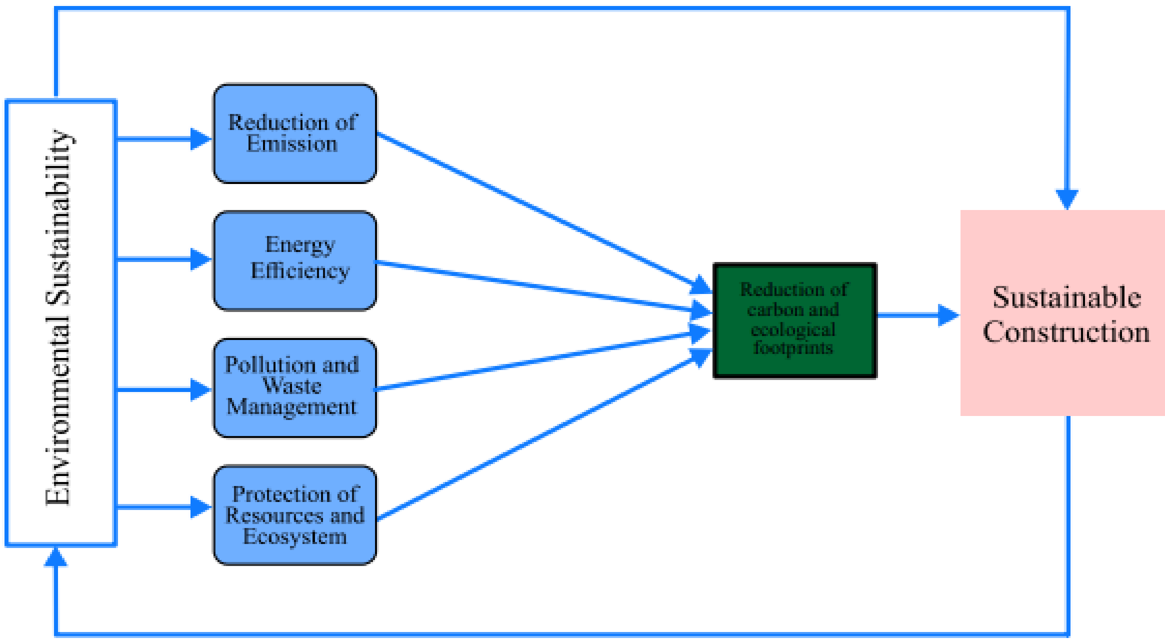


**Figure 2.3: Conceptual framework for the study**

(Source: Researcher's construction)

### 2.7.1 Environmental sustainability of construction activities

Although, there are numerous benefits of environmental sustainability, the activities of most construction companies do not reflect its principles. The activities of construction works are stretching the earth's carrying capacity to the limit and threatening the possibility of regenerating the carrying capacity. It can be argued that one of the most resource-intensive industries is the building sector. According to Sandanayake (2022), construction of buildings affects the environment and accounts for one-quarter of the wood harvest, one-sixth of the world's fresh water consumption, and two-fifths of the energy and material usage. It is important for construction activities to achieve sustainability. The principles of environmental sustainability are defined as measures that are designed to meet the resilience, resources, and interdependence of human society to meet its needs without compromising biological diversity or going beyond the capacity of the ecosystem that supports the continue regeneration of the services required to meet those needs. (Adjarko, *et al.*, 2016). According to Adjarko *et al.* (2016), the identified environmental SC practices in Ghana include pollution prevention, minimisation of resources consumption, re-use of materials to reduce and maximise resources.

### 2.7.2 Reduction of emissions

Construction and operations in the built environment contribute to carbon emission (Adabre & Chan, 2020). According to Hong *et al.* (2015: 249-259), 88% to 96% of all carbon emissions were caused by GHG emissions from the production of materials and the fuel utilized in building machinery. 315 million tons of direct CO2 emissions are produced by the global construction industry, which accounts for 5.5% of all CO2 emissions (Huang *et al*., 2018). The built environment in Ghana is facing many challenges, including increasing environmental pollution from solid waste disposal (Darko *et al*., 2017). Ayarkwa *et al*., (2017) posited that most of the construction waste generated in Ghana has resulted in illegal dumping at landfill sites leading to environmental pollution which has caused many risks to human health and the environment. Huang *et al*. (2018) identified that carbon emissions from the construction industry can be reduced by using energy-efficient construction equipment, renewable energy, and low embodied-carbon building materials. Reducing greenhouse gas (GHG) emission, pollution and carbon monoxide level in construction activities will contribute to the achievement of SC if the construction companies embrace a new approach to construction methods, new business strategies, and technologies.

### 2.7.3 Energy efficiency

Construction that uses energy-efficient design techniques to reduce its energy consumption in order to attain low energy consumption is referred to as energy-efficient construction (Asman *et al*., 2019). According to Wang *et al*. (2020), energy performance is defined as the quality of a structure with regard to energy consumption, and energy efficiency is defined as "using less energy without compromising the performance of the building". Mersal (2017) opined that energy efficient building design and construction use passive design principles to minimise the need for energy.

Building construction and maintenance account for about 40% of worldwide energy use (Edeoja & Edeoja, 2015:112; Rahim, *et al.*, 2014: 84), 40% to 50% of the GHG produced, and a quarter of the world's total carbon emissions (Huang *et al*., 2017: 1008; Kim & Rigdon, 2016:1). Ghana's residential sector's energy usage has been rising substantially in recent years, by 140% from 2000 to 2020 (Energy Commission, 2021). According to the survey, the industrial and residential sectors consumed 33.3% and 47% of the total amount of electricity in 2020, respectively.

Once more, residential buildings in Ghana utilize 54% of the country's electricity (Asumadu-Sarkodie & Owusu, 2016). The global construction industry's carbon dioxide emissions in 2009 were 5.7 billion tons (Huang *et al*., 2018). This is as a result of the growth of new communities and residential compounds, in addition to the use of household appliances like air conditioners during warm weather (Asumadu-Sarkodie & Owusu, 2016). The approach to construction delivery needs to evolve in order to achieve sustainability, while still respecting economic considerations and taking into account how the rising population and construction projects are negatively affecting the energy demand. The adoption of energy efficient construction will reduce operation cost and prevent global warming. The effective implementation of energy efficiency design and construction would help government, real estate companies and other stakeholders to achieve economic, social and environmental sustainability in construction projects.

#### *2.7.3.1 Energy-efficient equipment utilisation*

The call for energy efficiency is increasingly assuming a global dimension due to high energy demand, GHG emission, and global warming. However, there are limited studies about energy utilisation on construction sites, as most studies have been focused on energy in building design and operations (Asumadu-Sarkodie & Owusu, 2016; Edeoja & Edeoja, 2015; Jaini *et al*., 2013). Consequently, significant amount of energy is used for transportation, levelling, concrete mixing and compacting (Bastos, Batterman *et al*., 2014). The most common types of energy use for construction equipment are diesel, petrol, gas, and electricity. Globally, construction equipment alone consumes 688 million gallons of gasoline and 5,968 million gallons of diesel as diesel is considered to be safe and efficient and offers greater power density for construction equipment, but it has a high $CO_2$ emission level (Huang *et al*., 2018). The huge amount of energy consumed during construction is as a result of transportation, demolition, excavation, and hoisting. The use of natural gas in construction burns more cleanly, has lower sulphur, nitrogen and carbon emissions and leaves no ash particles. Bansal Sigh *et al*. (2014) indicated that $15 billion worth of energy is consumed annually in the construction industry, where building construction, operation and maintenance accounted for approximately 30%-40%. The efficient use of construction equipment will lead to reduced usage of fuel, reduction in energy cost, reduced emission level and protection of the environment, minimised energy consumption, improved productivity and increased value (Huang *et al*., 2018; Bastos, Batterman *et al*., 2014). Energy can be used efficiently on construction sites when construction method statements are well known, sites have an efficient layout, the right equipment is used for the right job, training of personnel to be conscious of energy conservation, and effective maintenance of the equipment.

### 2.7.4 Pollution

Numerous negative environmental effects of the construction industry include pollution (air, noise, and water), carbon emissions, and waste generation (Fatima Afzal *et al*., 2017). Construction-related pollution has a significant impact on global warming. Construction-related dust is a substantial source of air pollution, which harms the physical health of construction workers and results in serious environmental contamination (Zuo et al., 2017). The Institute for Health Metrics and Evaluation in its 2016 Global Burden of Disease Study research revealed that air pollution causes more deaths than water-related contamination and chemical exposure (HPAP Ghana, 2019). SC is a sure way to improve and safeguard the ecosystems, increase the quality of water and air, reduce waste streams to the air and land, and maintain the natural resources.

### 2.7.5 Waste management

In an attempt to meet the increasing demand for shelter, the construction industry has contributed to the creation of larger amounts of waste than the environment can absorb (Atombo *et al*., 2015). Up to 65% of the waste products disposed into landfills are produced by the industry (AlSanad, 2015). Construction waste affects productivity, loss of material and completion time of projects, leading to 30%-35% loss of production amount (Ahiabu *et al.*, 2021). Consequently, the surge in production of construction waste, most of which ends up in landfills, contributes to the global waste production and climate change, as well as public health challenges. Dzokoto *et al*. (2014) confirmed that construction using unsustainable methods and processes is a sizeable contributor to environmental degradation.

The concept of managing construction waste encompasses: removing waste where possible; re-using materials which might otherwise become waste; and reducing waste where feasible, to achieve sustainability. Osmani and Villoria-Sáez (2019), indicated that waste management is the procedure for treating waste once it has been generated and includes site design, transportation, material handling, segregation, storage, on-site operation, re-use and recycling, and final disposal.

Responsible management of construction waste would promote the attainment of sustainability in GCI.

Atombo *et al*. (2015) suggested that enforcement of a waste management plan, with a binding clause within the tender document of a construction project, is key in achieving sustainable waste management in Ghana. Construction waste directly affect material loss, productivity, and completion time of a project, causing loss of a huge amount of money (Mohammed *et al*, 2020). Construction waste can be hazardous and, therefore, requires an effective and well-defined policy and technology to manage. According to Hamid *et al*. (2016), the hierarchy of waste management is recognised as the finest option in construction waste management as it benefits the economy of the country and produces less impact on the ecosystem. The highest priority is prevention and minimisations of waste followed by the 3Rs (re-use, recycle and recovery).

According to Mohammed *et al*. (2020) re-use, recycle and recovery of waste are important strategies to manage construction waste. Mohammed *et al*. (2020) posited that re-using waste means using it in its entirety again for the same purpose to reduce costs in purchasing less material and maximising space, to reduce accidents on site through use of correct materials and to use less storage. Re-cycling is the act of separating, gathering, processing, marketing, and finally utilizing a material that would have otherwise been discarded. Recovery means removal of material or components from the waste stream that preserve its original re-usable nature in the same way it was created. The least priority in the waste hierarchy is disposal to landfill sites and incineration. Waste disposal is the last choice and the lowest criterion in approaches to the hierarchy of sustainable waste management. Re-use or recycling of a building component should be encouraged to limit the threat of waste disposal on the environment (Yeheyis *et al*., 2013). Most developing countries, such as Ghana, have already had problems with a lack of landfill space (Ahiabu *et al*., 2021). Effective management of demolition and construction waste is important to protect the environment, conserve natural resources and promote good health for persons and communities (Mohammed *et al*., 2020). The waste management hierarchy based on priority action is shown in Figure 2.4. The integrated and comprehensive waste reduction mechanisms, frameworks, and technologies are broadly recognised in the sustainable management of construction waste (Yeheyis *et al*., 2013). Construction projects generated various kinds and amounts of waste during the construction process. SC waste management can be achieved through a life-cycle-based, integrated framework. The integrated, life-cycle-based management of construction, refurbishment, and demolition waste uses the 3Rs (re-use, reduce, and recycle) in the various phases of the construction life-cycle to achieve sustainability. The recycling and re-use approaches preserve the ecology, save energy, reduce pollution, divert waste from landfills and prevent environmental impacts (Yeheyis et al., 2013).

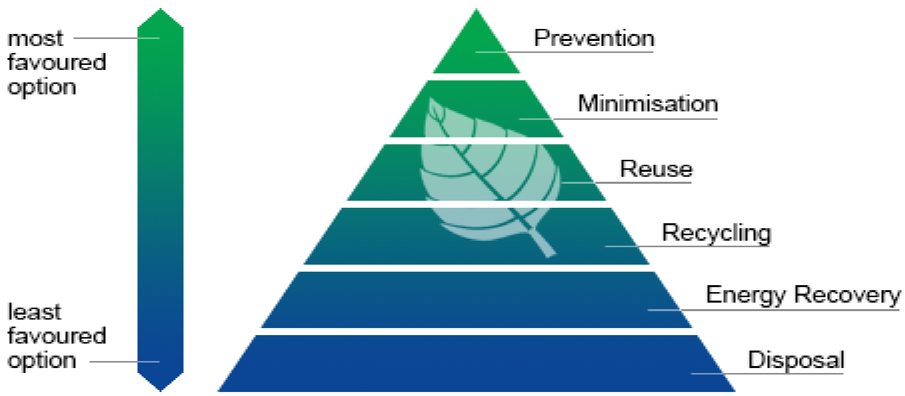


**Figure 2.4: Sustainable waste management hierarchy**

(Source: Mohammed et al., 2020)

### 2.7.6 Protection of resources and ecosystem

The construction process involves extensive construction activities, which result in climate change. The increased construction activities and urbanisation destroys wild-life habitat, natural resources and will affect more than 70% of ecosystem by 2032 (UNEP, 2002). The built environment in Ghana is facing many challenges, including decreasing natural resources. Sources of natural material are fast diminishing because of increased demand and fewer available alternatives. The sustainability approach can help to conserve natural resources and the ecology (Yeheyis *et al*., 2013). The following are technologies for conservation of resources.

#### *2.7.6.1 Material efficiency*

Effective usage of natural materials and underground space development is recommended by Roufechaei *et al*. (2014, cited by Darko *et al*., 2018) for sustainable construction. When applied, this technology reduces the usage of scarce resources and materials. It was emphasized that using these techniques is primarily intended to save money and minimise land wastage (Huo *et al.,* 2017). The temperature of the building envelope has the biggest impact on the thermal environment inside a building. In light of this, Chen *et al*. (2015) proposed that materials with thermal insulative qualities, reflective surfaces, and a capacity for heat storage be used in order to improve passive thermal performance of buildings, which will eventually improve interior climate. Additionally, Bernados *et al*. (2014) pointed out the cost savings achieved in underground building systems, especially for the use of dug material for filling, and less than 40% energy demand.

#### *2.7.6.2 Water efficiency*

According to Darko *et al*. (2018), water-efficient techniques in bildings are still vital. This lowers the building's operational utility rate. A few of the techniques investigated are permeable pavement systems, low-flow sanitary ware and faucets, harvesting of rainwater, irrigation, and water-efficient devices (Ahmad *et al.*, 2016; Sheth, 2017). In addition, Das *et al.* (2015) advocated systems for recycling and reusing grey water and harvesting of rainwater. According to Vitalis *et al*. (2013), this is the first step towards attaining efficiency of water. The most crucial system recommended for green-rating of buildings in terms of water efficiency is regarded to be rainwater harvesting techniques (Sheth, 2017). The system is made to use roof run-offs that are collected in tanks for later usage (GhaffarianHoseini *et al*., 2015). This system of water storage is excellent for flushing, irrigation, and mechanical cooling and heating.

According to Darko *et al*. (2018) the technology for grey-water, which is waste-water produced from activities like bathing and washing, has been recommended and studied by many researchers (Ahmad *et al*., 2016). The grey-water usage has the ability to reduce the need for potable water, minimise energy demand, and decrease the associated CF. El-Hassan and Kianmehr (2016), explained that the idea behind this system is to tap into pavement run-offs. This will lead to water retention, improve drift resistance, decrease the demand for storm-water collection systems, and refill the water table and aquifers continually (Sheth, 2017).

### 2.7.7 Carbon and ecological footprints

The time has come for the construction sector to embrace the decline of CF and EF in construction activity to remediate climate change. The bio-capacity, carbon footprint (CF) and ecological footprint (EF) determine how sustainable or unsustainable a development is in preventing resource-intensive and resource-dependent infrastructure where CF makes up 60% of EF (Global Footprint Network, 2019). It is important to protect the biological regenerative productive area that can provide goods and services for persons and communities, space for construction of roads and buildings, and absorb carbon dioxide.

#### *2.7.7.1 Carbon footprint*

According to Huang *et al.* (2017:1007), the carbon emissions from the manufacture of building materials and the energy used in buildings account for 45% and 40% of the building CF, respectively. These emissions are directly impacted by the burning of fossil fuels and indirectly by the usage of electricity. The greenhouse gases are those released both before and after the consumption of commodities and services intended for ultimate consumption. According to Huang *et al*. (2017: 1007), within the next 100 years, global warming is predicted to continue, if not worsen, and to have a greater negative impact on both socio-economic and natural systems. In Ghana, most of the carbon emissions are from fossil fuel consumption; deforestation; gas flaring as a result of oil exploration; and land usage. Hence, the focus of current research to reduce carbon emission to prevent global warming and avoid catastrophes (Emuze *et al.*, 2016: 156).

By 2030, according to the IEA's estimation from 2020, carbon emissions from buildings would need to drop by 50%, while emissions from the indirect building industry would need to drop by 60%.

The IEA (2020) estimated that carbon emissions from buildings should drop by 50% and emissions from the indirect building industry should decline through a reduction of 60% in generation of emissions by 2030 to ensure that net-zero building carbon emission is achieved by 2050. Tackling carbon emission is a local issue that will depend on an individual country’s emission status and vulnerability to climate change (Emuze *et al.*, 2016: 157*;* Edeoja & Edeoja, 2015: 112). Therefore, Ghana, as a developing country, must strive to decrease CF and EF of its construction activity.

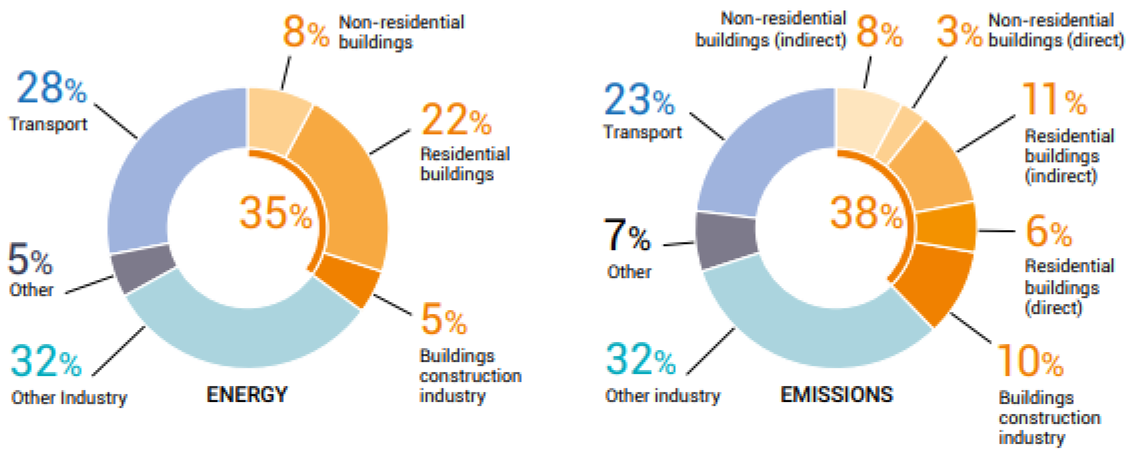


**Figure 2.5: Global share of building construction energy and emission**

(Source: IEA, 2020)

### *2.7.7.2 Ecological footprint*

Sustainability is a major concern when a new building construction project is to be undertaken, as it affects its surrounding environment. The impact of a new construction project on the environment is determined by the EF (Solis-Guzman & Marrero, 2015). The EF incorporates all issues of the environment and targets sustainability objectives (Emuze *et al*., 2016: 156). The EF indicates the value of the water and land areas that are available to replenish the materials used for construction. It is important to encourage the professionals to adopt sustainable construction practices in the GCI (Djokoto *et al.*, 2014: 141) to inspire construction companies to undergo a modernisation process involving more eco-friendly production and consumption to preserve the ecosystem. The behavioural change of professionals, clients, contractors, and designers would rescue the CF and EF (Emuze, 2015, cited by Emuze *et al.*, 2016: 158).

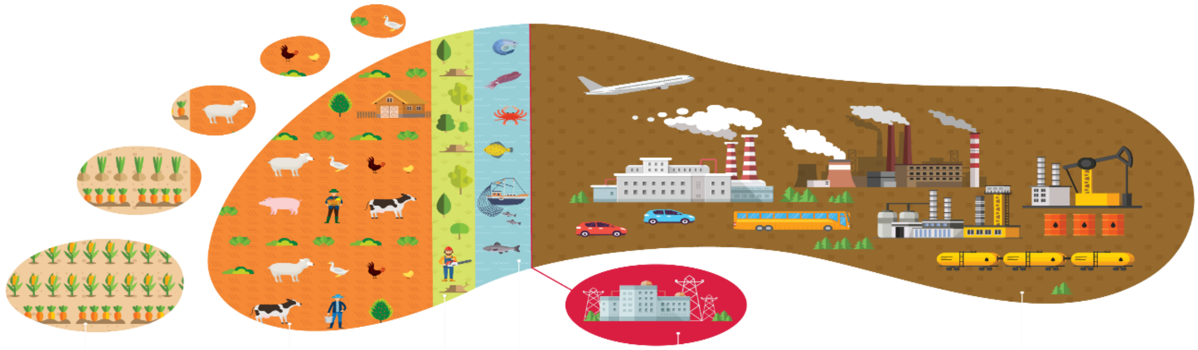


**Figure 2.6: Ecological footprint**

(Source: Bahr, 2022)

### *2.7.7.3 Carbon and ecological footprints in construction activity*

The result of population growth and rapid urbanisation contributes to the consumption of many natural resources that leads to climate change (Ayarkwa *et al.*, 2022). The world is experiencing depletion of resources, global warming, energy scarcity, and ecological toxicity, among other unfriendly challenges to the environment, which are partly attributed to construction activities. Huang *et al.* (2017: 1007) concluded that carbon emisions contribute to global warming which is expected to continue and add significantly to CF.

The production and transportation of building materials, use of energy by construction equipment, energy consumption for resource processing, and treatment of construction waste are the four main emission sources on construction (Hong *et al*., 2015: 249-259). The construction sector is generating high levels of material waste, amounting to approximately 10% of material cost (Hussin *et al*., 2013: 15). About 40% of the world's resources and energy are used in the construction of new buildings and maintenance of existing structures, which accounted for 40% to 50% of the global carbon emisions (Edeoja & Edeoja, 2015: 112; Rahim *et al*., 2014: 84; Huang *et al*., 2017: 1008; Kim & Rigdon, 2016:1). According to Hong *et al.* (2015: 249-259), 88% to 96% of all greenhouse gas emissions come from the fuel used in building machinery and production of materials. Yao (2013: 20) concluded that "... seeking to create healthy urban environments remains mandatory if humanity is to survive and prosper on Earth while we approach a period of uncertainty with depletion of resources and energy security issues."

This suggests that in order to achieve SC, firms must be proactive and adopt new method of construction practices by using resources more effectively to safeguard materials, water, energy, and manage construction waste. The construction industry can provide the required boost for economic growth in Ghana (Osei, 2013: 56) if given the right legislation, rules and regulations for sustainability practices (Mustafa & Bakis, 2015: 2257). The successful adoption of SC will help the worldwide campaign to combat the effects of climate change by lowering carbon and ecological footprints to ensure sustainability. The result of these studies demonstrates the importance of preventing additional environmental harm and offers the chance for ongoing development and the achievement of ecosystem balance for sustainable development. Therefore, construction companies in Ghana should evaluate the modalities and sustainability practices employed to lessen the CF and EF on the environment.

**Table 2.4: Carbon footprint vs ecological footprint**

| S/N | Carbon footprint | Ecological footprint |
|---|---|---|
| 1 | Measurement of $CO_2$ produced by activities | Measurement of the used renewable and non-renewable resources |
| 2 | Includes only carbon emission numbers | Includes both carbon emission and environmental impact |
| 3 | Can be used for carbon credit marketplace | Used to gauge global consumption |
| 4 | Directly impacts climate change | Directly impacts continuing life on earth |

(Source: Adapted and modified from Mello, 2022)

## 2.8 OVERVIEW OF LITERATURE AND THE GAP IN KNOWLEDGE

The backdrop of SC adoption, including its drivers, challenges, and promotion methods, is outlined in the approach established by Darko *et al*. (2018). Three steps are suggested in the approach to overcome the obstacles and encourage adoption as follows: 1) Identify significant drivers, 2) Ascertain main barriers to adoption, and 3) Implement the major promotion techniques. However, the initiatives do not account for stakeholders' levels of awareness and expertise or provide a roadmap for a strategy to lessen the ecological and carbon impact for SC. Therefore, the study was to close this gap and create a roadmap for lowering the environmental and carbon footprints of the building industry.

The proposed paradigm according to Ampratwum *et al.* (2019) was built on Rogers (2003) five-stage process of innovation-decision. There are six steps in the framework: Exposure, knowledge, persuasion, decision, implementation, evaluation, and assessment, placed a strong emphasis on professional bodies to adopt sustainability. However, the GCI is a multi-stakeholder organization made up of professional groups that include consultants, contractors, clients and developers. As such, the study of Ampratwum *et al*. (2019) does not include a roadmap for SC to guide all stakeholders regarding the implementation of SC but is focused mainly on organisational units of professional bodies. Also, in a study to investigate the implementation of SC process, Aktas and Ozorhon (2015) highlighted drivers, barriers, enablers, benefits and resources of construction, as related to adopting the SC process.

The framework by Ampratwum *et al*. (2019), Aktas & Ozorhon (2015), and Darko *et al*. (2018) led to deeper investigation to understand the main issues affecting the implementation of SC in Ghana. In these studies, it was concluded that the implementation of SC is multi-dimensional and involves complex issues. A review of these studies indicated that there is no strategic plan that stakeholders in the GCI can follow to implement SC. Therefore, a SC roadmap was developed in this study to lessen the impact of building activity in GCI.

## 2.9 CHAPTER SUMMARY

This chapter thoroughly explored literature, established the conceptual understanding of SC, and identified the historical roots of sustainable development throughout the world. The chapter further demonstrated that SC offers the construction sector a number of advantages. It also evaluated earlier efforts on drivers, advantages, and understanding as well as knowledge generation of SC. The SC technologies, which must be thoroughly understood by all parties in order for the policies to be adopted are also discussed this chapter. Additionally, it identified the gaps in the construction body of knowledge for each of the parts that this study aims to fill. Finally, the chapter reviewed the study's conceptual framework.

# CHAPTER THREE: RESEARCH METHODOLOGY

## 3.1 INTRODUCTION

The chapter discussed the steps undertaken to realise the goals of the study. The qualitative and quantitative paradigm, the methodology, and research design adopted are presented. The focus of the chapter is on the selection of methodological framework and participants, to achieve the research aim. A mixed method study design to gather both quantitative and qualitative data was used. The mixed method approach comprised a Delphi study and questionnaire survey based on both practical and philosophical reasons. How data were collected, analysed and interpreted is also explained.

## 3.2 THE STUDY CONTEXT: GHANAIAN CONSTRUCTION INDUSTRY

posited that

The CI in Ghana is modelled on the built environment in the UK and contributes to socio-economic development (Ahiabu *et al.*, 2022). The sector is in charge of infrastructural development projects, which cover crucial phases of feasibility, design, building, operation, decommissioning, demolition, and disposal. The construction projects in the industry are supervised by ministries of Roads and Highways, and Water Resources Works and Housing, which are Central Management Agencies of the Government of Ghana accountable for construction sector of the economy.

The Public Works Department (PWD), the Engineering Council (EC), the Hydrological Services Department (HSD), the Architects and Engineering Services Limited (AESL), the Department of Rural Housing (DRH), the Rent Control Department (RCD), the Public Servants Housing Loan Scheme Board (PSHLSB), the State Housing Company (SHC), the Architect Registration Council (ARC), and Tema Development Company Limited (TDC) are the organizations and departments in charge of the built environment. This study was conducted with stakeholders in the GCI which were categorised by Akinradewo *et al*. (2019) as: consumers and users, regulators, supply-side operators, and demand-side operators. There is very little collaboration between the stakeholders in the GCI (Ofori-Kurangu *et al*. 2016). The dissemination and application of SC concepts, criteria, and tools by all the stakeholders of the sector are important to realise sustainability (Valdés *et al*., 2018).

### 3.2.1 Clients in GCI

This study was conducted with clients who are the fananciers and originators of the building projects. Clients are major stakeholders that can influence construction practices in Ghana (Akinradewo *et al*., 2019). Four main types of clients identified in Ghana are government, real estate developers, investors and owner occupiers, which can also be broadly categorised into two – public- and private-sector clients, with other intermediaries. The public-sector clients are interested mostly in the social desirability of a project and not the cost or profit of the construction. The private client, being the second major type of clients, includes both national and multi-national companies, corporate entities, local property developers and owner occupiers. The local property developers who operate under the umbrella of the Ghana Real Estate Developers Association (GREDA) are investor clients who engage in speculative construction of buildings for lease or sale. Businesses and financial organizations opt to expand into new markets by reinvesting their excess cash and profit into structures for their own use, sale, rental, or lease. Owner occupiers in the private sector, who want to construct their own houses for habitation, make up the majority of clients in this category. Therefore, clients can contribute actively to the adoption of SC in Ghana.

### 3.2.2 Consultants in GCI

Similar to clients, consulting services provided by the GCI can be divided into private and public firms. The majority of public sector road and construction projects are handled by organizations directly under the MRH and MWRWH, including the Department of Highways, Department of Feeder Roads, Department of Urban Roads, and Public Works Department. There are governmental organizations that provide architectural advice and supervision across all disciplines to the public and commercial sectors. Examples include Architectural and Engineering Services Limited (AESL), and the Building and Road Research Institute (BRRI). In addition to these, there are a number of private consultancy firms that are run by individuals or groups of experts in the fields of engineering, architecture, or quantity surveying. Within the GCI, it is rare to come across a single certified firm that provides all the services delivered by established procedures. Therefore, it is a regular occurrence for specialists from several firms to band together and submit a bid for a project that calls for a variety of experience. The professional organizations for every field within the industry, namely, GIA, GhIS, and GhIE respectively, control the professions within the sector. Interestingly, the GCI is still rife with unethical practices including planning challenges, cost overruns, lack of sustainability standards, and project management issues (Asamoah & Decardi-Nelson, 2014).

### 3.2.3 Contractors in GCI

The local businesses, make up the majority of the contractors in the GCI, which rule the industry, while foreign businesses handle the bigger projects. Several Chinese companies as well as Sonitra, Michelletti, Consar Ltd., Barbissoti, and Skanska are among the multinational construction groups that work within the GCI. The local contractors in Ghana are often run and organized by families, with the director typically being the owner and occasionally collaborating with his immediate or nuclear family.

Contractors are divided into eight categories according to the work they execute: Roads, airports, and related structures are listed under A; culverts, bridges, and other structures are listed under B; labor-based roadwork, maintenance, and rehabilitation of construction projects, are listed under C; general building construction work is listed under D; general civil engineering work is listed under K; and steel bridges and structures are listed under S. Based on the highest financial threshold of tasks that a contractor can perform, each category is further divided into four financial classes (1-4). Contractors with Class 4 classification can execute work up to $75,000, Class 3 up to $200,000, Class 2 up to $500,000, and Class 1 up to any amount.

However, this research focus on contractors within categories D and K. In terms of staff, resources, and finances, contractors in the D1K1 category and a small number in the D2K2 category are more organized. They also have offices that are well-established and can hire experienced experts, including engineers and quantity surveyors, to manage their projects. On the other hand, Class 3 and Class 4 contractors, often known as small-scale building contractors (SSBC), account for around 90% of all registered contractors in Ghana (Asamoah & Decardi-Nelson, 2014). Therefore, contractors in Ghana are major stakeholders considered for this study to ensure the implementation of SC practices in GCI.

### 3.2.4 State of SC in GCI

The adoption of SC practices still remains in its infancy and using SC techniques is uncommon in GCI. Ghana has not yet reaped the benefits of SC (Ayarkwa *et al.*, 2017). Lack of demand, unavailability of framework, lack of financial incentives, lack of legislation, lack of government commitment, and lack of rules and regulations to encourage SC are the key obstacles to the implementation of the concept (Djokoto *et al.*, 2014). The construction sector is a significant contributor to global climate change and other environmental threats. The GCI still adopts the tradition method of construction and contributes to pollution, which is detrimental to the environment and human health. The construction sector accounts for about 40%–50% of the world's greenhouse gas emissions (GHG), which are expected to rise by more than 50% by the year 2050 in developing nations like Ghana (Huang *et al.*, 2017). Despite the challenges faced by the industry to implement sustainability, the stakeholders are aware of the benefits of sustainable construction (Darko *et al.*, 2017). The client demand and requirements for SC can drive sustainability in GCI. If appropriate methods are not created to address SC, global warming might continue to be a worldwide problem for years to come. To lessen the effects of these dangers, the building industry must take appropriate measures. The research on the CF and EF in the construction activity is especially important for combating climate change.

## 3.3 APPLICATION OF RESEARCH ONION FRAMEWORK

According to Gray (2014), a problem can be explored in an organized manner through research to find the best answer. The approach to this study dictated which research method and tools were appropriate to adopt. The research paradigm philosophy is a basic belief system or framework that the researcher adopts to determine the research structure of the project under investigation. The framework defines the philosophical orientation of the researcher and provides beliefs and principles, which guide the study. The philosophy of the research paradigm is distinguished by four types of research elements: ontology, epistemology, axiology, and methodology.

Epistemology derived its aetiology in Greek, where the word *episteme* means knowledge (Kivunja & Kuyini, 2017) and is described as the understanding of knowledge (Tracy, 2013: 61). Theories of knowledge are adopted for a study that proffer answers to questions relating to the nature of knowledge, its acquisition and limitation. The researcher draws from four sources of knowledge to proffer answers to research questions, namely: authoritative knowledge, intuitive knowledge, logical knowledge, and empirical knowledge.

The philosophical understading of the existence or reality of nature, of becoming or being, and whatever the researcher believes, affects what he/she knows is ontology (Kivunja & Kuyini, 2017).

The Ontology concern the understanding of what stands, whilst epistemology involves understanding what it means to know (Gray, 2014: 19). General assumptions are made in a study to understand the real nature of society (Žukauskas *et al*., 2018: 124)

The methodology is a process framework available to solve the study problem and takes into consideration the general principle that guides the entire research process (Gray, 2014). The researcher selected the research methodology that best fit the research context and demonstrated a justifiable reason for choosing a particular philosophy, strategy and approach within the research context to realise the goals. This study was carried out in the built environment. The activities in the built environment interact between natural and social sciences that required a holistic approach to the study together with a rigorous process to obtain elements for achieving environmental sustainability in the construction process. This made the Delphi research method an appropriate selection for this study.

The axiology is concerned with the choice that the researcher makes and to what extent the researcher wishes his/her view to influence positively the values and beliefs of the research (Saunders *et al*., 2019: 133). The research process and values, such as aesthetics and ethics, guided the researcher to recognise and understand the roles that his values and opinions played in the gathering of research information.

The researcher relied solely on the "research onion" diagram, espoused by Saunders *et al*. (2019: 130), as a paradigm of research philosophy which is distinguished by three types of assumptions that resemble the layers of an onion, as shown in Figure 3.1. The types of study philosophy include interpretivism, positivism, post-modernism, critical realism, and pragmatism. Three approaches indicated for the development of theory are deduction, abduction, and induction. The choice of methodology includes mono-method qualitative, mono-method quantitative, multi-method quantitative, multi-method qualitative, mixed method simple, and mixed method complex. The research strategies include survey, archival research, case study, ethnography, action research, grounded theory, and narrative inquiry. The time horizon involves cross-sectional or longitudinal. The techniques and procedures adopted for research include data collection and data analysis. Table 3.1 shows how the research onion, depicted in Figure 3.1, was applied in this study.

**Table 3.1: The structure of research layers**

| No. | Research layer | Application |
|---|---|---|
| 1. | Research philosophy | Pragmatism |
| 2. | Approach to theory development | Inductive and deductive |
| 3. | Methodological choice | Mixed methods |
| 4. | Research strategy | Survey |
| 5. | Research time horizon | Cross-sectional |
| 6. | Research techniques and procedures | Delphi survey (qualitative approach) and general survey (quantitative approach) |

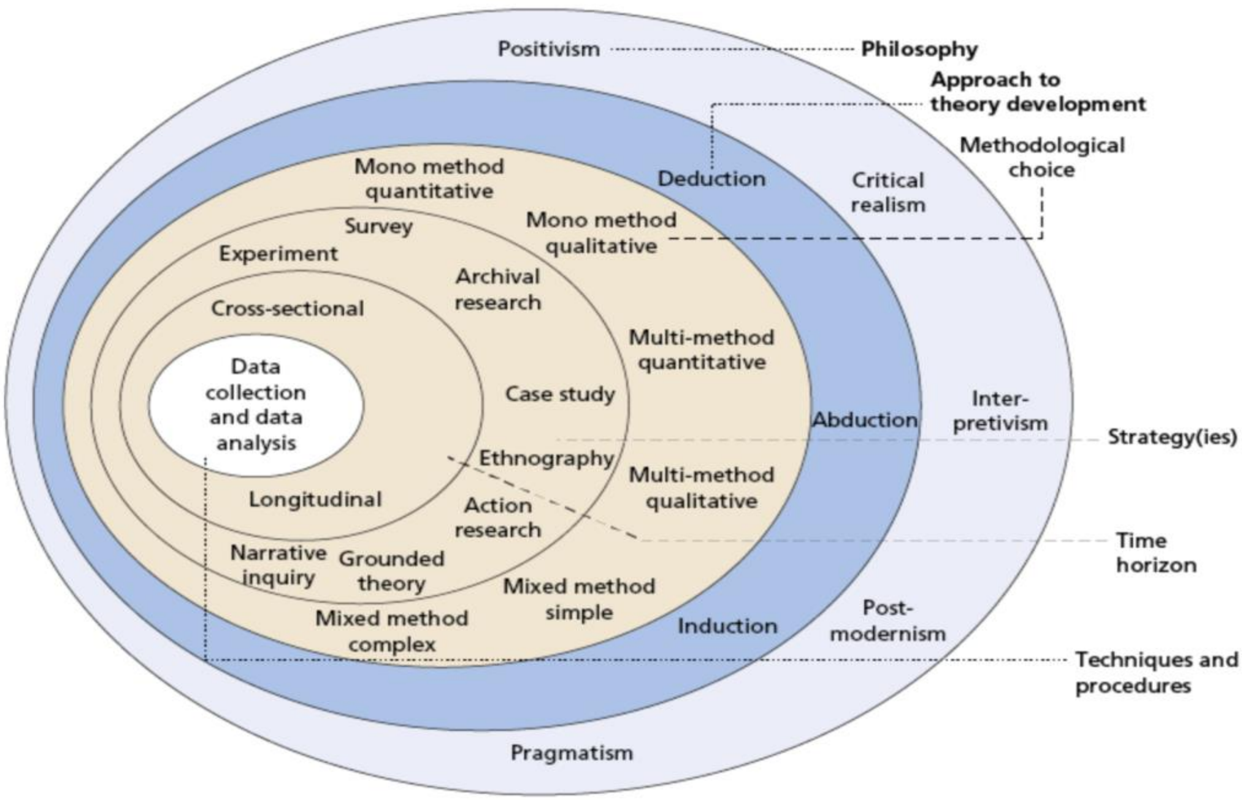


**Figure 3.1: The research onion**

(Source: Adapted from Saunders *et al*., 2019, 130)

## 3.4 RESEARCH PHILOSOPHY

According to Saunders *et al*., (2019: 30), research philosophy is defined as a system of beliefs and assumptions about the development of knowledge. It refers to the development and nature of knowledge, and exactly what the researcher is doing when engaged in research. This knowledge base guides the researcher's values, assumptions, and techniques in navigating worldviews for quality output. The goal of the study was to advance a SC roadmap that helps to lessen the CF and EF of construction practices in GCI.

This researcher adopted a pragmatic paradigm of research philosophy to achieve the research aim. According to Žukauskas *et al*., (2018: 121), the pragmatic research philosophy is defined as a broad structure that encompasses beliefs, perceptions, and understanding of different practices and theories used to undertake scientific research. Morgan (2014: 1) posited that pragmatism is a philosophy that can be adopted for social research, regardless of whether that research uses qualitative, quantitative, or mixed method. "Pragmatism argues that the main determinant of the ontology, epistemology, and axiology adopt is the research question – one may be more appropriate than the other for answering particular questions" (Saunders *et al.*, 2019). The focus of pragmatists is mainly on "how" and "what" of a study problem by adopting a research method as a result of the criteria that the researcher believes will lead to the best answers to the research questions (Creswell, 2013: 77). The pragmatic research philosophy was adopted for this study based on the study problem statement that the perception of a lack of a roadmap hinders the decrease of the carbon and ecological footprints of construction activity in GCI. This led to the postulation of the research questions that were formulated to help the researcher to fulfil the research aim and objectives. The four main elements of the research philosophy according to Žukauskas *et al*. (2018: 130), selected for this research include: the goal, the theoretical perspective, research design and research questions, as indicated in Figure 3.2.

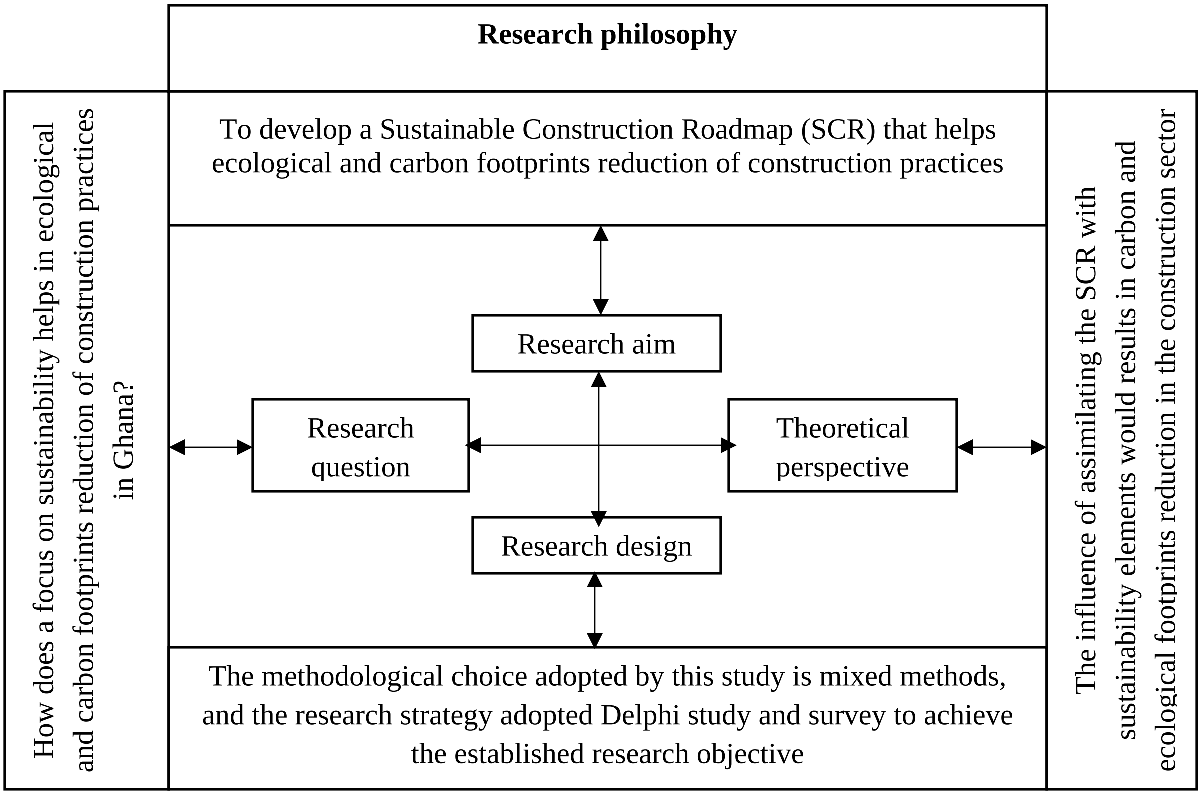


**Figure 3.2: Research philosophy**

(Source: Adapted from Žukauskas et al., 2018: 130)

## 3.5 APPROACH TO THEORY DEVELOPMENT

The theory influences the approach of research to be selected by the researcher. The research approach selected was an inductive to help formulate the study questionnaire and collect data which helped to develop the theories. The main research question formulated for this study was: How does sustainability help in reduction the carbon and ecological footprint of GCI? The research objectives were formulated with the intention to answer the research questions. The inductive research approach used in this study was to make the researcher to appreciate the research problem and explain the results to achieve the research aim and objectives. The inductive research approach also helped the researcher to decide on the research design.

## 3.6 METHODOLOGICAL CHOICE

This study required a thoughtful methodological approach and, therefore, a simple mixed method was adopted to combine both the qualitative and quantitative data collected (Creswell & Clark, 2018: 3). The research strategy adopted involved a Delphi study and questionnaire survey. The mixed method approach was determined to be the best method to address the shortcomings of both qualitative and quantitative methods by harmonising the weakness of one method with the strengths of the other method in conducting both methods separately (Creswell, 2014) using sequential exploratory design, which begins with exploring the qualitative data, analysing the results and then the findings are adopted in the second stage to collect quantitative data (Creswell, 2014: 226). The researcher collected the qualitative data from three rounds of a Delphi process and the results were analysed to achieve consensus. The identified factors were used to formulate the research survey questions to collect quantitative data.

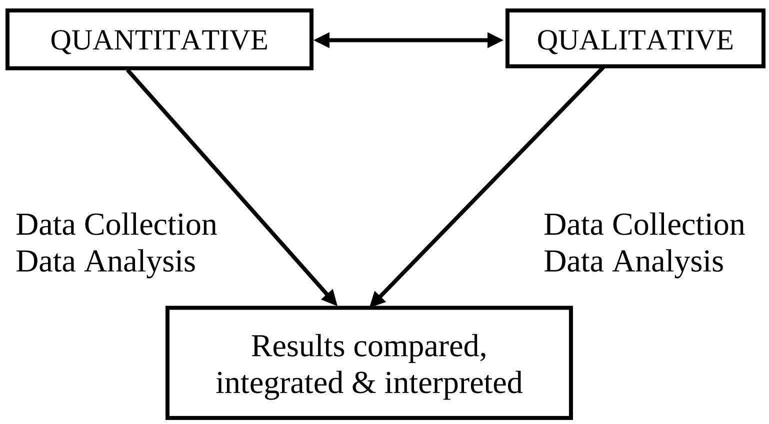


**Figure 3.3: Visual diagram of mixed method design**

(Source: Atif, *et al*., 2013)

## 3.7 RESEARCH STRATEGY

Research strategy is defined as the approach to be used by the researcher to provide responses to the study questions (Saunders *et al*., 2019). According to Robson and McCartan (2016), research strategy is the general, broad orientation adopted to seek responses to the study questions formulated. A foundation for comprehending the research is provided by the research plan. A survey was used to collect the quantitative data and a Delphi study to collect qualitative data. The research process was carried out in three stages. Stage One involved identifying the research problem and generating the research questions and goals. The main elements or indicators of sustainable construction and their measuring scales were identified in the literature review, and a conceptual framework was proposed.

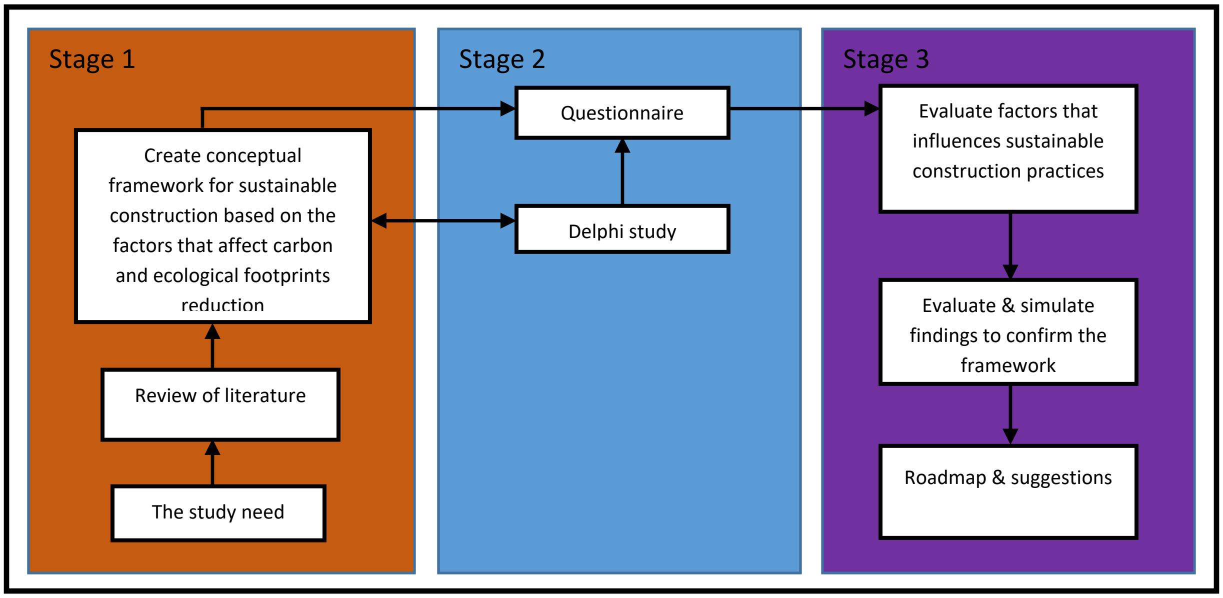


**Figure 3.4: The research stages**

(Source: Musonda, 2012: 91)

In Stage Two of the research process, three rounds of a Delphi method were adopted to validate the impact and importance of the elements in achieving sustainability in the construction practices of contractors, using a survey with open-ended questions to confirm the constituent parts of the conceptual framework. Stage Three involved a questionnaire survey that was piloted before the main survey was given to the construction industry professionals to test the conceptual framework in Stage Two, to achieve the ultimate purpose of the study to advance a roadmap that best fitted the construction industry to achieve sustainability.

### 3.7.1 Delphi study

A modified Delphi method (MDM) was adopted in the research to develop a sustainable construction roadmap for GCI. The MDM is a well-known and respected method for collecting information from participants without physically meeting, to look into policy, forecast future occurrences, or undertake in-depth analyses of certain concerns in order to achieve a defined objective (Niederberger & Spranger, 2020). MDM has been applied successfully in previous studies to forcast future occurrences and achieve consensus (Niederberger & Spranger, 2020; McBride, 2015). Using Delphi technique, researchers can gather information from qualified experts that is extremely dependable. To ascertain whether a suggested framework created by a faculty member for an undergraduate program in dairy manufacturing was in line with actual industry needs, Joyner and Smith (2015) conducted a modified Delphi study. An MDM was adopted for this study because it provides rich data which leads to more creative outcomes, and obtains high-quality responses and opinions. The study involved different organisations and professions in the GCI and, therefore, required the more private approach the Delphi method offered. The experts in Delphi survey were geographically dispersed and did not meet physically. The experts were briefed on their roles, rules of conduct and description of the process. The selected elements were presented to the experts to consider their responses, and consensus was reached after three iterative rounds using the Delphi questionnaires. The opinions of the participants were anonymous, and all experts shared the goal of synthesizing their conclusions while a state of uncertainty was present. Avella (2016) outlined the approach of a modified Delphi as follows:

i. The researcher compiles a preliminary list of responses based on an analysis of the pertinent literature, distributes it to the expert panel, and requests that they rank the list in accordance with predetermined standards. The researcher cannot limit or regulate the choices since the panel members may contribute to this first selection based on their personal experiences.

ii. The researcher interviews a number of people, either from the study panel or outside of it, summarizes the findings, and then presents the panel with the initial list that was created and distributed. Members would be invited to contribute to the original list based on their personal experiences if the interviews were performed with people other than the panel.

iii. The researcher offers the result of a study conducted among a group outside of the panel and encourage them to contribute to the initial list of potential solutions in light of their own knowledge.

McBride (2015) compiled the initial list of the study using interview to determine the most efficient leadership style. The panel members responded by scoring each item on a 5-point Likert scale, which was presented to the panel in Round 1 and was used to make changes to the curriculum. Through a series of iterative rounds using surveys, the experts' group came to an agreement. Consensus among experts can be explored using the consensus approach, which is a structured facilitation tool (Avella, 2016). The opinions of the participants are anonymous and when there is doubt, all the experts share the same goal of synthesising their opinions.

The early applications of the Delphi method were in the fields of corporate planning and technological forecasting but in recent times established a wide-spread usage in academia, administration, banking, agriculture, automotive and criminal justice, from 1975 to 1994, but has not been widely used in construction research (Niederberger & Spranger, 2020). "Delphi" is derived from *Delphoi,* a Greek word which means "womb" or "hollow", interpreted as Gaia, which is perceived to be Goddess of primordial Earth in the religion of Ancient Greek, who was believed to predict the future accurately. The aim of choosing a Delphi study is to gather as many high-quality comments and viewpoints from a given panel of experts as possible to reach consensus and improve decision-making. Delphi experts in this research are geographically dispersed and do not meet physically. The capacity to provide respondents with anonymity, a controlled feedback loop, and the suitability of a number of statistical analytic approaches to evaluate the data are important aspects inherent in adopting the Delphi technique (Avella, 2016).

**Table 3.2: Classical Delphi vs Modified Delphi**

| Type of Delphi | Objective | Members | Management | Preferred rounds | 1st round | Strength and weakness |
|---|---|---|---|---|---|---|
| **Conventional Delphi** | Solicit opinions for consensus | Selection of experts is based on the research objective | Normal postage | Not less than three rounds | Panellists provide responses to open qualitative questions in the 1st round | ▪ More time is spent to collect responses<br>▪ Expensive<br>▪ Multiple repeatition of the survey<br>▪ The recovery rate of the survey is low |
| **Modified Delphi** | Varied objectives to achieve consensus, design project, and predict future events | Selection of experts is based on the research objective | Any form including, online, postal, etc. | Less than 3 rounds may be used | A pre-selected responses are provided for the panellists to choose | ▪ Saves time<br>▪ Lower cost<br>▪ Less number of surveys<br>▪ Experts can fully express their opinions, ensuring the completeness and consistency of the group opinion |

(Source: Modified from Hasson & Keeney, 2011)

#### *3.7.1.1 The Delphi Process*

The Delphi process started with the identification of the element/leading indicator metrics from the literature to develop the Delphi questionnaire. The initial questionnaire was sent to the research supervisor and the statistician to ensure validity of the questionnaire before the Delphi procedure commenced. The supervisor suggested modification of the questions for easy understanding and responding, and content. The statistician considered the readability and scale to be used for rating. The survey was then piloted with 21 experts outside the main panel to ensure the robustness of the questions prior to the start of the main Delphi study. The final questionnaire was presented electronically to the 18 Delphi experts who accepted to participate in the study by email.

A three-round continuous iteration Delphi process was adopted for the study until consensus was deemed to have been reached. The Round 1 Delphi study used both a structured and open-ended questions. The questions gave the expert panel an opportunity to identify and elaborate on important issues to increase the richness of the data collected, as a modified Delphi process was adopted. According to Avella (2016), if the needed information exist, open-ended questions are used in a Delphi study. In Round one, all 18 experts who were sent the questionnaire responded, representing a 100% response rate. The panellists ranked the elements/indicator metrics with their expertise and experience in sustainable construction. The experts were urged to add any additional element/indicator metrics that would improve sustainable construction, which some experts did. Some of the experts also raised concerns that some questions were not clear to them, which were addressed. The group median was calculated by the statistician using Excel and the questionnaire was refined and administered to the expert panel to compare their results for Round 2.

The Round 2 Delphi questionnaire was sent to the 18 experts by email and 17 experts responded, representing a 94% response rate. The expert that did not answer the qustions provided no explanation for failing to participate in Round 2. The experts were encouraged to review their rating relative to the group median and provide written reasons for their rating that was 2 units above or below the group median of each element/indicator metric, as attached in Appendix B2. A slight increase in consensus was achieved compare with Round 1.

In Round 3, the final Delphi round, no element/indicator metric was dropped. This was to provide equal opportunity to rate each element/indicator metric in all three rounds because of attrition of the experts. All 17 experts from Round 2 responded to the Round-3 Delphi survey, representing a 100% response rate. The experts were urged to review their rating relative to the group median and give written reasons if their response was one unit below or above the median of each element/indicator metric.

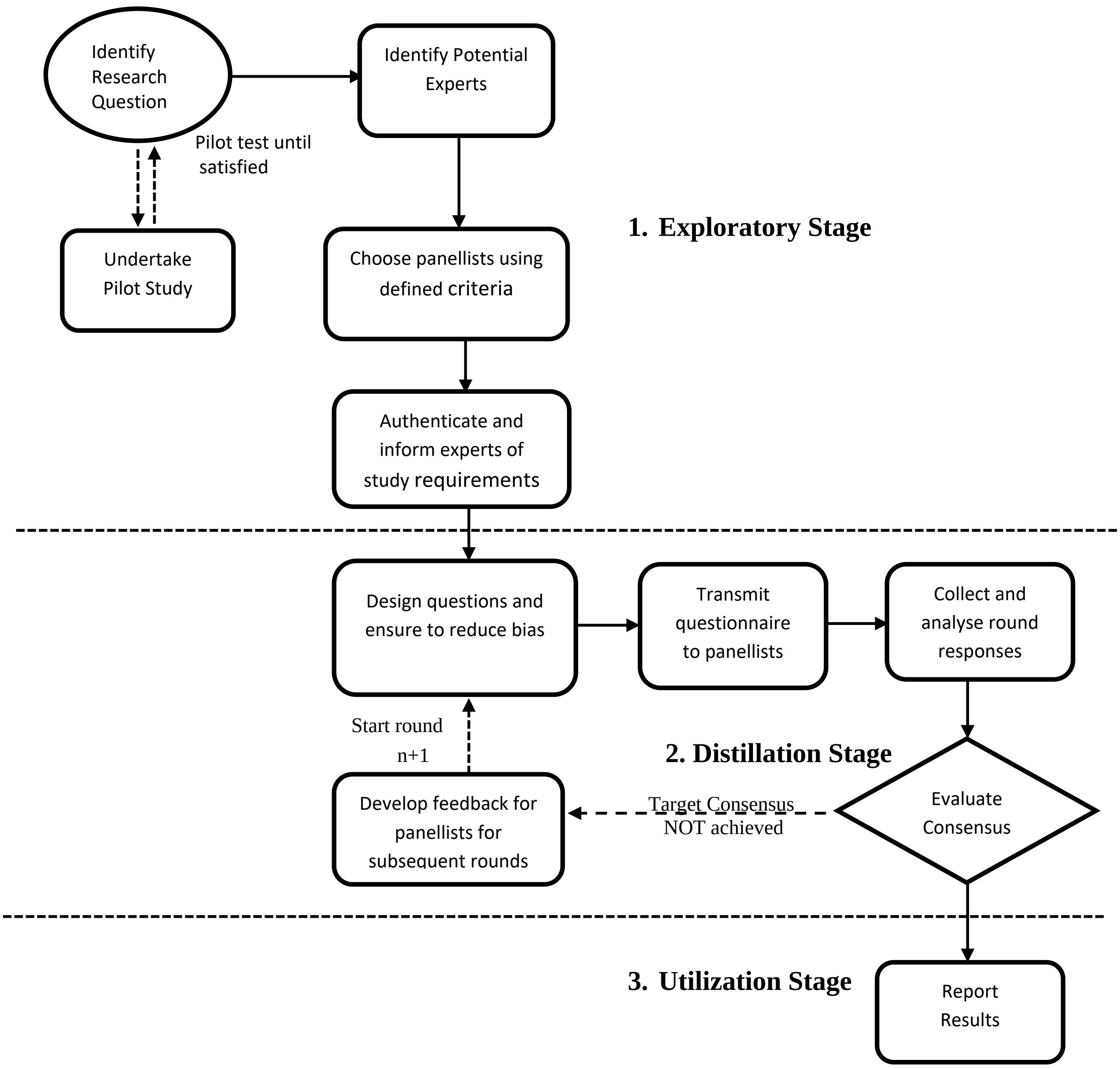


**Figure 3.5: Delphi process**

(Adapted from Hallowell & Gambatese, 2010)

### *3.7.1.2 Criteria for attaining consensus*

The criteria adopted in this study to reach consensus on the factors to be retained were that the responses should attract a final median importance score of 9.00 and 10.00 with 70% or more of the respondents rating the factors between 90% and 100% on the impact scale. Also group stability of the respondents was achieved where more than 50% of the respondents reached a stable answer. Therefore, to ensure high stability, elements that had at least 70% agreement or more of respondents rating the factors 9.00 and 10.00 on the importance scale were deemed to have reached consensus. The cut-off value of the median score was set high to ensure that extremely important factors were established to improve the SC practices in GCI. The criteria adopted in this study to reach consensus on the elements/leading indicator metrics to be retained and tested for the conceptual framework were median 9 to 10 and 70% or more of respondents rating the elements/indicator metrics between 9 and 10 on the importance scale, as indicated in Table 3.3 below. It can be confirmed that when establishing sets of indicators for a project, the Delphi technique is an appropriate and acceptable mechanism to reach consensus.

**Table 3.3: Requirements to reach consensus**

| **Requirements** | **% Response Importance scale** | **Importance Median** |
|---|---|---|
| **Consensus** | 70% response and above | 9.00 – 10.00 median value |

### 3.7.2 General perception survey

The final survey questionnaire was administered from 16 December 2021 to March 2022 to the construction companies in Ghana. The questionnaire was developed from a rigorous process including a literature review, Delphi consensus process and a pilot survey in six stages. The description of the study and what the respondents were expected to do were indicated in the cover letter. Section A contained the demographic information including qualification, experience, classification of the company and SC activities of the company. Section B contained the SC practices, whilst Section C contained sustainable building design. Sections D and E referred to low impact building materials and reduction of carbon emission/pollution & energy efficiency, respectively. Section F, on the other hand, referred to solid waste management. The questions were based on the degree of agreement and disagreement, using a rating scale of 5-point Likert type.

The construction companies were selected using non-probability sampling, including a convenience sampling method as a result of the poor response rate and the long period it took to complete the pilot study. The convenience sampling technique is a process of selecting respondents available to the researcher in the most convenient way to collect a large amount of responses swiftly and cost effectively (Faryadi, 2019). The sampling process began with contacting the Building Contractors Association, Building Contractors Register, and the website of the Works and Housing Ministry of Ghana to identify potential respondents. The researcher confirmed the suitability and readiness of the participant to participate to take part in the survey by email and telephone calls. Respondents with the rank of foreman or site supervisor and above were selected to respond to the questionnaire. The researcher assumed that the respondents of these ranks were well aware of the activities of the company.

500 questionnaires were distributed by email and 300 using a drop-and-collect arrangement, totalling 800 questionnaires. There was constant follow-up of the respondents, using phone calls, short messages and email messages, to remind the participants to fill up and submit the surveys. A total of 405 valid responses were received.

### 3.8 RESEARCH TIME HORIZONS

The research time horizon refers to how a researcher studies a particular phenomenon within a time constraint (Kim *et al*., 2017: 621). A cross-sectional time horizon was used for this research. The qualitative data were collected using three rounds of a Delphi study from June 2020 to July 2021. This was followed by collection of quantitative data using a survey questions to develop a roadmap from 16 December 2021 to March 2022. The qualitative data to evaluate and test the roadmap were collected in July 2022.

### 3.9 DATA COLLECTION PROCESS

The process of data gathering involves methods used to collect information about a situation, person, phenomenon, or problem. Data constitute a limited set of fact that must be organised, processed, sorted, and presented in a recognised study style (Silverman, 2015). An objective, representative, generalisable, qualitative and quantitative process was required for this research. For this study, both primary and secondary information sources were used. The primary information was collected using both quantitative and qualitative data techniques. A questionnaire survey, structured interviews, intensive interviews, a Delphi survey or expert panel, and introspective reflection were thought to be the best techniques for this study. However, as a result of resource constraints, qualitative data were collected using three rounds of a Delphi study. A structured, self-administered questionnaire was adopted as the most appropriate method to collect quantitative, primary, research data from individuals in GCI.

The secondary data were collected from existing literature in books, reports, databases, conference papers and journal publications. Considering the type of research problem being addressed, it was required to exclude research methodologies that were not suitable for this research as practical as possible (Silverman, 2015). Therefore, the information based on the gap identified from the secondary data was used to formulate the research questions for the Delphi study.

### 3.9.1 Delphi study sampling

The participants for the Delphi survey were selected using their combined experience. The elements of SC identified from the literature were matched, re-worded and used to compile the initial list presented to the experts in pilot test, external to the Delphi panel. The pilot study was conducted with 21 experts outside the main panel to review and validate the elements to ensure the robustness of the factors (Niederberger & Spranger, 2020). The pilot experts were recruited from industry (14% of quantity surveyors and project managers respectively, 24% of architects, and 19% of engineers), governmental institution (14% of environmental protection officer, and 5% of quality control officers), and academia (10% of university professors) using a purposive sampling technique based on five years' minimum experience in SC. This sampling method was adopted because the panellists were chosen based on their professional qualification, experience, knowledge, and readiness to participate in the survey (Ameyaw *et al.*, 2016). The pilot panellists were invited to suggest additions to the initial questions or indicate options, which were used to design the questionnaire for the Delphi panel of experts who were identified and selected from the relevant stakeholders in GCI, who were involved in SC practices, to participate in a three-round Delphi survey.

**Table 3.4: Pilot Delphi sample**

| Experts | Professional area | Number | Percentage (%) |
|---|---|---|---|
| Industry | Quantity surveyor | 3 | 14 |
| | Project / Construction manager | 3 | 14 |
| | Architect | 5 | 24 |
| | Engineer | 4 | 19 |
| Government/ regulatory body | Environmental officer | 3 | 14 |
| | Quality control officer | 1 | 5 |
| Academia | University Professor | 2 | 10 |
| **Total** | | **21** | **100%** |

(Source: Field data, 2022)

The main Delphi panel was selected after the Delphi pilot study. The Delphi expert panel selection depended on the size of the panel and the qualifications of the experts, which were the two critical considerations for inviting the experts. The panel of experts was chosen using a purposive sampling approach since they were chosen for their expertise in SC and their readiness to take part in the study. The "purposeful sampling" involves selecting individuals specifically such that they meet a range of predetermined criteria. According to Faryadi (2019), purposive sampling is centred on personal preference and judgment where only participants who will provide the needed information are selected based on the researcher's opinion and decision. 18 Delphi experts were recruited from academia (33% of university professors and research fellows), industry (6% from green building council, 11% from the construction firms, and 33% from the consulting firms), and governmental institution (11% from regulatory bodies, and 6% from works and housing ministry).

**Table 3.5: Delphi expert sample**

| Experts | Professional area | Number | Percentage (%) |
|---|---|---|---|
| Academia | University professors and research fellows | 6 | 33 |
| Industry | Green Building Council | 1 | 6 |
| | Construction firm | 2 | 11 |
| | Consulting firm | 6 | 33 |
| Government | Regulatory bodies | 2 | 11 |
| | Ministry of Works and Housing | 1 | 6 |
| **Total** | | **18** | **100%** |

(Source: Field data, 2022)

#### *3.9.1.1 The Delphi panel size*

The maximum participants to be selected to form a panel size for Delphi technique research has not been fully ascertained (Habibi, 2014). However, the adequacy of the panel size for Delphi survey is determined by the validity of the findings and varies based on the scope of the problem and the available resources (Avella, 2016). McBride (2015) assembled an expert panel of 10 individuals to achieve a reasonable result (Avella, 2016). Joyner and Smith (2015) also conducted a modified Delphi study successfully with 21 experts in a dairy industry. Therefore, a purposive sampling technique was used to constitute a Delphi panel size of 18 highly qualified experts in sustainable construction from industry, academia and government institutions for this study based on their experiences.

#### *3.9.1.2 Qualification and selection of Delphi participants*

There are various sets of rules and criteria to determine a minimum requirement for selection as an expert in Delphi survey (Ogbeifun *et al*., 2017). Delphi participants should meet at least three or four out of the eight requirements established to qualify as an expert (Avella, 2016). The selection of experts for both the pilot panel and Delphi panel was in accordance with the requirements set by Hallowell and Gambatese (2010), where 50% of the requirements qualify the participant to be selected as follows:

1. Minimum of five years of academic, professional or industrial experience;
2. Advanced degree from higher institution of learning (minimum of Master’s Degree);
3. Author of a peer-reviewed journal article on sustainable construction;
4. Invited to a conference to present on sustainable construction;

5. Author of a reviewed book or book chapter in sustainable construction;
6. A member of a recognised higher institution of learning in the area of sustainable construction;
7. Member of a related professional body (GIE, GIA, GhIS etc.);
8. Member of green building council or facilitator of training workshops in sustainable construction.

It is important that experts for a Delphi panel are ready to paticipate in a study to meet the objectives of the research successfully. In all, 30 potential experts in SC from different parts of Ghana were selected by email. This was because the developed roadmap is specific to Ghana. However, the roadmap could be used in other developing countries in the sub-region to improve sustainable construction.

The invited panellists were informed about the study objectives, time commitment required, and general information about the study. In all, 18 experts voluntarily responded to the study. The experts comprised academics, policy makers, and industry practitioners. Due to Covid-19 pandemic, the experts agreed to participate using electronic media such as emails which have proven to be successful and efficient.

***3.9.1.3 The Delphi questionnaire***

The Delphi questionnaire started with a letter requesting the participation of experts in the study panel. The letter included an introductory questionnaire of structured questions to collect demographic data, including qualifications, experience and other information that was used to establish that the participants were experts in the field of SC.

During Delphi Round 1, a well-structured questionnaire was presented to the 18 identified panel members. All segment of the survey was well explained, such as the objectives of the research and guidelines for completing the questions. The panellists were requested to evaluate the significance of the identified elements of SC practices. All 18 selected experts responded in Round 1 ($n$ = 18).

During the Round 2 Delphi survey, the experts were given a summarised, controlled response from Round 1 in the form of median scores for the factors rated, including the individual ratings, and were requested to do two things: 1) to review their judgement/initial ratings in view of the consolidated results and make changes if necessary; 2) to rate the additional elements that were recommended. In all, 17 panel members responded in Round 2 (*n* = 17).

During the final Delphi Round 3, no factor was dropped. The experts were presented with their responses and were urged to review their answers relative to the group median and to give written reasons if their response changed a unit below or above the collective median for each factor. This was to provide an equal opportunity to rate each factor in all three rounds because of the attrition of the experts. All 17 experts from Round 2 responded to the Round 3 questions, representing a 100% response rate.

The panellists rated the elements using a five-point Likert Scale (5 = extremely important; 4 = very important; 3 = important; 2 = somewhat important; 1 = not important) and an importance scale (1 = 0 - 10%; 2 = 11 – 20%; 3 = 21 – 30%; 4 = 31 – 40%; 5 = 41 – 50%; 6 = 51 – 60%; 7 = 61 – 70%; 8 = 71 – 80%; 9 = 81 – 90%; 10 = 91 – 100%) in all the Delphi rounds. The questionnaires were emailed to the experts as a Microsoft Word file and were returned via email. The elements of SC presented to the experts were terminated at the third Round. The Delphi survey to the expert panel consisted of a list of elements/leading indicator metrics based on a methodical review of relevant literature from journal articles, professional reports, conference proceedings, governmental documents, and relevant SC books. The elements/indicator metrics were categorised into five main headings, namely:

1. Sustainable construction practices;
2. Sustainable building design;
3. Low impact materials;
4. Energy efficiency and reduction of emission/pollution;
5. Waste management.

The questions for the Delphi rounds are indicated in Appendix B. The purpose of the instrument was to establish the importance of the elements/leading metrics to improving SC practices in GCI.

### 3.9.2 The survey sampling

The quantitative results gathered reinforced the qualitative results collected using Delphi study. A self-administered survey questionnaire using closed-ended questions were used to collect the quantitative results as shown in Appendix E. The contractors registered with MWRWH who were actively working on construction sites were selected using purposive sampling approach. Purposive sampling is based on the personal preference, opinion, decision, and judgment of the researcher to select suitable participants (Faryadi, 2019). In all, 800 questionnaires were administered and 405 responses were received, representing a 50.63% response rate.

The questionnaire survey was in a written form, self-administered, and sent through the traditional mail system and by email to raise the the level of response. The survey was written clearly as well as self-explanatory to ensure that the respondents fully completed the questionnaire mailed to them. The email survey technology greatly facilitates communication and collaboration between people of similar interest and allows information to be sent directly to one or more people at the same time. A questionnaire survey is less expensive to administer and covers a wide geographical location. It helps the researcher to collect sensitive data which the respondent might be unwilling to provide during a face-to-face survey and allows respondents time to answer questions without the pressure of the researcher waiting for answers.

**Table 3.6: Survey sample**

| **Profile** | **Count** | **Percentage (%)** |
|---|---|---|
| Architect | 28 | 6.9 |
| Engineer | 31 | 7.7 |
| Managing Director | 12 | 3.0 |
| Owner | 15 | 3.7 |
| Project Manager | 106 | 26.2 |
| Quantity Surveyor | 72 | 17.8 |
| Site Foreman/supervisor | 135 | 33.3 |
| Others | 6 | 1.5 |
| **Total** | **405** | **100%** |

(Source: Field data, 2022)

#### *3.9.2.1 Survey questionnaire*

A pilot questionnaire survey was adopted for the study and administered to construction companies after the Delphi consensus process. The questionnaire for the study was evaluated thoroughly before final administration. The questions were formulated or adapted and developed to the full after repeated testing. The questionnaire was tried and tested to ensure its suitability for the intended purpose of the research. Pilot testing is to evaluate the questions, using a minimal replica of the actual survey to be undertaken (Mohaddesi & Harteveld, 2020). Considerable effort would be wasted on questions producing unquantifiable responses and uninterrupted results if studies are not piloted adequately.

The objective of the pilot study was to ensure the suitability of the survey questionnaire to determine whether the questions were understood correctly and the range of responses. It also provided an indication of the response rate and probable cost and time of the study. The testing of the pilot questionnaire helped to detect uncertainties of administering the final questionnaire. Therefore, a pilot study was conducted from October to November 2021 to increase understanding and correct any hitches. The pilot questionnaire was sent to the promoter of this study and the statistician from South Africa, who scrutinised the questions for clarity and suggested some changes. The promoter suggested the correction of grammatical errors and reduction of the lengthy elements/indicator metrics. The statistician, on the other hand, suggested that the wording of some questions and elements/indicator metrics be improved.

A total of 50 respondents, who were working on building construction projects, were selected at random from construction companies. As a result of time and financial resource constraints it was impossible to test the pilot questionnaire on a large number of respondents (Mohaddesi & Harteveld, 2020). The respondents were selected from D4K4 to D1K1 contractors who were similar to those in the main study. The questionnaires were sent to each construction company by email and hand delivery to invite upper management employees or personnel knowledgeable in sustainable construction in the company to participate in the study. The fact that this was a pilot survey, the respondents were urged to share any challenge encountered in completing the survey. Emails and telephone calls were used to follow up and remind the respondents to submit the completed questionnaire.

The survey was divided into six segments, including a cover letter explaining the study and actions required by the respondents to complete the survey, as indicated in Appendix D1. The Section A contained the respondent's background information and the companies for which they worked. Section B referred to the sustainable construction practices, whilst Section C referred to sustainable building design. Sections D and E referred to low-impact building materials and reduction of carbon emission/pollution and energy efficiency, respectively. Section F, on the other hand, referred to solid waste management. The questions were based on the degree of agreement and disagreement using a 5-point Likert scale.

The pilot-tested questionnaire results had implications for the main research questionnaire, including response rate, inadequate response options and duplicate questions. The survey was anonymous, which reduced the tendency for biased responses. The respondents did not make any comments that indicated that they found it difficult to understand and interpret the questions.

**Table 3.7: Pilot survey sample**

| **Demographic profile** | **Category** | **Frequency** | **Percentage** |
|---|---|---|---|
| Academic qualification | HND/Diploma | 10 | 31.2 |
| | BSc Degree | 14 | 43.8 |
| | Master's Degree | 8 | 25.0 |
| **Total number of participants** | | **32** | **100.00** |
| Years of experience | 0-5 years | 2 | 6.2 |
| | 6-10 years | 8 | 25.0 |
| | 11-15 years | 6 | 18.8 |
| | 16-20 years | 12 | 37.5 |
| | Above 20 years | 4 | 12.5 |
| **Total number of participants** | | **32** | **100.00** |
| Position in the company | Architect | 2 | 6.3 |
| | Engineer | 4 | 12.5 |
| | Owner/Managing Director | 8 | 25.0 |
| | Project manager | 6 | 18.8 |
| | Quantity surveyor | 4 | 12.6 |
| | Site foreman | 8 | 25.0 |
| **Total number of participants** | | **32** | **100.00** |

(Source: Field data, 2022)

In all, the pilot survey received 32 responses out of 50 questionnaires which constituted a response rate of 64%. A response rate of approximately 60% was expected in the final survey, as studies with construction firms have recorded low response rates (Emuze & Smallwood, 2014). To ensure that a robust analysis is conducted, using structural equation modelling, it was anticipated that the study would receive 400 completed questionnaires. The pilot study guided the calcution of the sample size as follows:

| | |
|---|---|
| Number of respondents after pilot survey | = 32 responses |
| Number of questionnaires sent out for pilot survey | = 50 questionnaires |
| Number of responses anticipated from the final questionnaire | = 400 responses |

32 = 50

400 = X

X = 50*400/32

**X = 625 questionnaires to be distributed to the respondents**

An additional 175 questionnaires were added to improve the probability of the responses. Consequently, the construction companies were given 800 surveys by email and drop-and-collect method to improve the response rate. From the results of the pilot survey, additional cost would be incurred to receive the expected 400 responses and the duration for data collection might take a longer period of three to six months.

## 3.10 DATA ANALYSIS

There are numerous ways for researchers to analyse a study data collected. The understanding of the appropriate study design to be adopted to analyse data for a study is key. According to Yin (2014: 142), researchers must adopt a general analytical strategy to analyse data collected for a study. For this study, a professional statistician from South Africa was engaged as an expert to analyse the data collected. The conceptual framework was examined using a PLS-SEM approach, which comprises confirmatory composite analysis, structural model results, importance performance map analysis (IPMA) and the Statistical Package for the Social Science (SPSS).

### 3.10.1 Structural Equation Modelling (SEM)

The research model or framework (i.e., the conceptual framework) and its related hypotheses were assessed using structural equation modelling (SEM). As a statistical methodology, SEM serves to dissect data in instances where several interconnected equations are contemporaneously approximated with the intention of probing the linkages among a cluster of variables (Ringle et al., 2020). Utilizing a plethora of model types, SEM seeks to delineate the intricate relationships among tangible variables, uniformly driven by the objective of offering a numerical validation of a theoretical model posited by an investigator. Two key methodologies within SEM, widely accessible to investigators, are Covariance-based SEM (CB-SEM) and variance-based Partial Least Squares (PLS-SEM) (Hair & Alamer, 2022; Hair Jr. et al., 2017). Predominantly, CB-SEM is employed for substantiating pre-existing theoretical constructs (that is, for explanatory purposes). In contrast, PLS-SEM is fundamentally a prediction-centric method within SEM, rendering it suitable for deployment in both exploratory as well as confirmatory research scenarios (Ringle et al., 2020).

Particularly in the context of this research, the predictive and exploratory orientation demanded the usage of the PLS-SEM method (implemented via SmartPLS 4). As Hair et al. (2019) suggested, the superior statistical power of PLS-SEM makes it particularly apt for research work dealing with nascent or evolving theories, as is the case in this study. Moreover, given the predictive intent of this research, the PLS-SEM technique was deemed most appropriate. Essentially, the deployment of PLS-SEM is highly compatible with the research objectives at hand (Lim, 2018). Hence, the PLS-SEM method, due to its predictive prowess, was deemed apt for achieving the study's objectives. Thus, PLS-SEM enhances the explained variance of all dependent variables and bolsters the focus on prediction (Henseler et al., 2009).

The PLS-SEM analysis involved assessing both the measurement model (which encompasses the reliability and validity of latent variables) and the structural model (Hair et al., 2019; Hair Jr., 2021). This commenced with evaluating the reliability and convergent validity of the measures, followed by a discriminant validity assessment employing the Fornell-Larcker criterion and Heterotrait-Monotrait (HTMT) ratio (Fornell & Larcker, 1981; Hair et al., 2019; Henseler et al., 2015). Subsequently, an examination of the structural model was conducted, complemented by the IPMA analysis. IPMA analysis, a forward-looking procedure in PLS-SEM, is employed to gain an in-depth understanding of the predictors in the examined model. Such an evaluation is integral to effective prioritization of management efforts (Ramayah et al., 2018; Ringle & Sarstedt, 2016; Valaei & Jiroudi, 2016).

### 3.10.2 Quantitative data analysis

The results gathered from the research were calculated with the PLS-SEM comprising confirmatory composite analysis, structural model results, and importance performance map analysis (IPMA). The quantitative data were collected using closed-ended questions which were self-administered to construction companies to evaluate the conceptual framework that was developed. The quantitative results calculated were used to test the Mean and Standard Deviations of the respondents' ratings of the elements by using analytical or descriptive statistical procedures to gain meaningful insight into the responses.

### 3.10.3 Qualitative data analysis

The qualitative research is the process of reducing information to gain new insight by revealing its characteristic elements (Gray, 2014). The process of analysing the qualitative data collected, using the Delphi study approach, involved categorisation, tabulation, testing, and assembling the data for the analysis and explaining the results. The Statistical Package for the Social Science (SPSS) was used to calculate the qualitative data. The Standard Deviation and Median were determined for this study. The Median was adopted in the Delphi survey to assign numerical values to the perceived situations and respondents' ratings of the importance of the variables.

### 3.10.4 Data triangulation

The triangulation method is adopted as a mixed method research approach for collection of quantitative and qualitative information to respond to research questions (Creswell & Clark 2018: 3). The triangulation will help the data collected from multiple sources to converge and support a particular theory or hypothesis. The Delphi survey method was adopted for sustainable construction experts, and a questionnaire survey for construction professionals to answer over-arching research questions. The Delphi survey method is a constructivist approach to knowledge and falls between a qualitative and quantitative approach. The selection of elements and indicator metrics to develop a sustainability roadmap called for value judgements from construction experts.

There has been scarce research on the important indicator metrics and perceived impact of construction activity on sustainability using the Delphi technique.

This gap identified in the literature resulted in the selection of Delphi techniques as being suitable methods to validate and refine the leading indicator metrics of the conceptualised sustainable construction framework. Furthermore, a questionnaire survey that was quantitative was selected to understand how construction companies are contributing to sustainability to validate the sustainability conceptual framework and develop the best roadmap for sustainable construction.

### 3.10.5 Limitation

- There might be sampling biases and corresponding limitations, as non-probability or convenience sampling was used to select the participants.
- Many participants might have avoided selecting the extreme measures, strongly disagree or strongly agree on the Likert Scale, and preferred to choose middle measures such as agree and disagree.
- There might be missing data as a result of respondents' withdrawal or failure to complete the whole questionnaire.
- The study was focused on a questionnaire survey and Delphi techniques to collect data without conducting interviews and case studies to gain in-depth appreciation of the issues.

## 3.11 INTEGRATION OF THE RESEARCH OBJECTIVES

The development of a conceptual framework to address the research problem that the lack of a roadmap hinders the reduction of the carbon and ecological footprint of construction activity in GCI. The six study objectives included:

- Research Objective 1: To identify why sustainability cannot be ignored by GCI.
- Research Objective 2: To determine how design should respond to sustainability requirements in GCI.
- Research Objective 3: To determine how construction materials should respond to sustainability requirements in GCI.
- Research Objective 4: To explore the effects of energy efficiency on the construction process in GCI.

* Research Objective 5: To evaluate the modalities employed to reduce construction site solid waste in GCI.
* Research Objective 6: To develop a SC roadmap that would reduce the carbon and ecological footprints of activities in GCI.

The research findings from the first to the fifth research objectives were used to develop a sustainable construction roadmap. The research objectives were achieved by adopting the research strategy of a Delphi study, and a survey, as shown in Table 3.8

**Table 3.8: Research process adopted to achieve the research objectives**

| **Strategy** | **Methods** | **Research objectives** | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| Delphi study | Expert survey | X | X | X | X | X | |
| Survey | Self-administered questionnaire (Hypotheses) | X | X | X | X | X | |
| | Self-administered questionnaire (Roadmap) | | | | | | X |

## 3.12 RELIABILITY AND VALIDITY OF RESEARCH DATA

The research reliability and validity are key issues to be considered in the conduct of any research. According to Creswell (2014: 201), research validity and reliability are concerned with the research design, the measuring instruments and overall research findings. The quality of research demonstrated is the basis on which researchers should judge assimilated research knowledge (Yin, 2014: 45).

### 3.12.1 Validity

The qualification, experience, current designation, publication in conferences and journals, chapters or books written, and facilitation of training in sustainable construction were examined to select the panellists of the Delphi survey to ensure confidence in the data collected. The precision with which the conclusions precisely match the data has been defined as the measure of study validity (Noble & Smith, 2015: 34) Therefore, the content validity was achieved by the pilot study, and the face validity established by the Delphi study for the developed instrument (Hair *et al*., 2019). The data were controlled by the statistician as an expert and the Promoter of the research to obtain accurate feedback in the successive rounds to increase validity. The respondents were informed accordingly in the case of missing data, and the importance scale was used for consensus building to help to achieve the internal consistency of the elements.

### 3.12.2 Reliability

The efficacy of the data obtained, and the analysis or interpretation, to be predictable, uniform, trustworthy, and repeatable, is defined as the research reliability (Ringle *et al*., 2020). The research instrument is deemed to be reliable when results are reproducible using a similar approach, accurately represent the study's entire population, and remain consistent over time (Henseler *et al*., 2015). The reliability scale is the correlation between two scores on a scale from 0 to 1.00, with the most used consistency measure being Cronbach's alpha. In exploratory research, 0.60 lenient cut-off is frequently used. Hair *et al*., (2019) agreed upon a lower limit of 0.7 for alpha. Therefore, empirical reliability tests were conducted for this study and a cut-off alpha of 0.70 was adopted and measures below 0.70 were eliminated. The Cronbach's alpha was used to achieve a consistency reliability test as indicated in Table 3.9.

**Table 3.9: Cronbach's alpha**

| **Construct** | **Cronbach's alpha** |
|---|---|
| Sustainable construction activities | 0.745 |
| Barriers to sustainable practices on construction sites | 0.901 |
| Drivers of sustainable construction | 0.909 |
| Challenges of sustainable construction | 0.744 |
| Environmental sustainability criteria | 0.871 |
| Importance/benefits of sustainable construction – environmental | 0.932 |
| Importance/benefits of sustainable construction – social | 0.920 |
| Importance/benefits of sustainable construction – economics | 0.916 |
| Environmental sustainable design component | 0.898 |
| Design requirements | 0.813 |
| Low-impact material selection criteria | 0.888 |
| Low-impact material incorporation measures | 0.848 |
| Protection of resources for ecological sustainability | 0.892 |
| Water efficiency measures | 0.895 |

| Construct | Cronbach's alpha |
|---|---|
| Emission reduction (reduction of $CO_2$ emission/pollution) | 0.813 |
| Energy efficiency component | 0.912 |
| Energy efficiency measures | 0.915 |
| Energy-efficient equipment utilisation | 0.928 |
| Dimension of waste management | 0.872 |
| Waste minimisation measures | 0.951 |

## 3.13 ETHICAL CONSIDERATIONS

Th research ethics refers to carrying out a research in a way that transcends simply selecting the best research methodology and instead involves undertaking study in a way that is ethically sound (Metzler (2014: 49). Research ethics promote the research quality and guard against impropriety and protect the participants and their organisations (Creswell, 2014: 92). Ethics are sets of moral principles or norms that are used to guide moral choices of behaviour and relationships with others. Ethical consideration in this research is concerned with principles of integrity, sincerity, privacy and conforming to acceptable engineering standards for the purpose of professional conduct. Principles, such as informed consent, openness, the right to privacy, honesty and confidentiality, were adhered to during this study when collecting both qualitative and quantitative data. The researcher provided a consent letter to the participants when collecting the qualitative data and explained the consent to the interviewees and assured them that all the information provided would be treated as being highly confidential and would not reveal their identity. During the collection of quantitative data using survey, the cover page of the questionnaire included the consent letter that outlined the survey's objectives, protection of the participants' identity, and the confidentiality of the information provided.

## 3.14 CHAPTER SUMMARY

In this chapter, the research methodology that was used for the study was thoroughly described. To accomplish the research goals, a mixed method strategy was used, integrating the quantitative and qualitative data through a Delphi survey. The following chapter contains the data gathered from the Delphi survey.

## CHAPTER FOUR: DELPHI SURVEY RESULTS

### 4.1 INTRODUCTION

The Delphi survey was conducted to obtain experts' views on the factors that influence and impact SC practices in GCI. Three rounds of the survey were conducted for experts to achieve agreement on the issues that were presented to. This chapter summarizes the outcomes of the three rounds and provides an analysis of the data gathered. The chapter ends with a summary of the results based on the goals of the Delphi research.

### 4.2 PRESENTATION OF DELPHI RESULTS

A modified Delphi design was adopted using experts in sustainable construction to gather knowledgeable opinions on the topic. by distributing a number of questionnaires. The relevant stakeholders in the GCI, who were involved in sustainability of infrastructure, were identified and selected to participate in the Delphi survey to confirm the proposed factors. Additionally, the panelists were urged to contribute to the list in light of their personal experiences, which precluded the researcher from controlling or limiting the alternatives.

The results of the data analysis from the Delphi study is presented in the sequence of the secondary research questions as follows:

1. Why is sustainability a focus area that cannot be ignored by GCI?
2. How should design respond to sustainability requirements in GCI?
3. How should construction materials respond to sustainability requirements in GCI?
4. How is utilisation of energy efficiency influencing the construction process in GCI?
5. What modalities are employed to manage the reduction of solid waste on construction sites in GCI?
6. What SC roadmap would reduce the carbon and ecological footprints of activities in GCI?

The above questions helped to achieve the objectives based on an approach to eliminate non-coherent dialogue about carbon and ecological footprints reduction of construction practices to achieve overall SC in Ghana. The successful achievement of the objectives led to the identification of crucial elements and concepts that are of significant importance to construction practices to attain sustainability, and to develop a holistic roadmap for carbon and ecological footprints reduction of construction activity in Ghana.

### 4.3 FOCUS ON SUSTAINABILITY (OBJECTIVE 1)

In response to the first, secondary research question: Why is sustainability a focus area that cannot be ignored by GCI?, the experts highlighted the benefits of adopting SC practices in GCI. The experts reached consensus on 33 identified benefits of implementing sustainability practices after three rounds of iterations.

#### 4.3.1 Delphi Round 1

**Table 4.1: First round of Delphi survey – benefits of adopting sustainability in GCI**

| Code | Benefits | Median | SD | Rank |
|---|---|---|---|---|
| BSC1 | Protect land, water, air, and ecosystems | 10 | 0.825 | 15 |
| BSC2 | Protect natural materials | 10 | 0.478 | 4 |
| BSC3 | Preserve genetic diversity and animal species | 9 | 0.877 | 16 |
| BSC4 | Conserve the biosphere | 10 | 0.663 | 11 |
| BSC5 | Utilise renewable natural resources | 9 | 0.772 | 13 |
| BSC6 | Reduce waste generation or disposal | 9 | 0.978 | 20 |
| BSC7 | Decrease $CO_2$ emission and pollution | 10 | 0.667 | 12 |
| BSC8 | Sustain life support system and ecological processes | 9 | 0.883 | 17 |
| BSC9 | Adopt vigorous re-cycling | 9 | 0.983 | 21 |
| BSC10 | Conserve the natural environment | 9 | 0.476 | 3 |
| BSC11 | Avoid global warming | 10 | 0.487 | 6 |
| BSC12 | Enhance quality of life for all | 9 | 0.589 | 10 |
| BSC13 | Alleviate poverty | 9 | 0.997 | 23 |
| BSC14 | Satisfy the needs of human | 9 | 0.782 | 14 |
| BSC15 | Consider local information when developing | 8 | 1.122 | 28 |
| BSC16 | Optimise social benefits | 9 | 1.076 | 25 |
| BSC17 | Improve health, comfort and well-being | 9 | 0.473 | 1 |
| BSC18 | Have concern for inter-generational equity | 7 | 1.181 | 30 |
| BSC19 | Minimise cultural disturbances | 8 | 1.114 | 27 |
| BSC20 | Provide educational services | 8 | 1.239 | 33 |
| BSC21 | Promote unism among society, humanity and nature | 9 | 0.475 | 2 |
| BSC22 | Understand the advantges of cultural and social capital | 8 | 1.207 | 31 |
| BSC23 | Understand multi-disciplinary societies | 8 | 1.177 | 29 |
| BSC24 | Improve economic development | 9 | 0.483 | 5 |
| BSC25 | Reduce cost of energy consumption | 9 | 0.579 | 8 |
| BSC26 | Raise real revenue | 9 | 0.952 | 19 |

| | | | | |
|---|---|---|---|---|
| BSC27 | Improve productivity | 9 | 0.497 | 7 |
| BSC28 | Reduce cost of infrastructure | 9 | 1.097 | 26 |
| BSC29 | Reduce cost of environmental impact | 9 | 0.585 | 9 |
| BSC30 | Reduce cost of water consumption | 9 | 1.897 | 18 |
| BSC31 | Lower health costs | 9 | 0.985 | 22 |
| BSC32 | Decrease absenteeism in organisations | 8 | 1.223 | 32 |
| BSC33 | Improve return on investments (ROI) | 9 | 1.068 | 24 |

(Source: Field data, 2022)

The findings from Round 1 showed that, out of the 33 benefits presented to the experts, 26 factors were believed to influence adoption of SC practices. However, 7 factors were less significance in the implementation of SC practices. These factors were BSC15, BSC18, BSC19, BSC20, BSC22, BSC23, and BSC32. Their median values ranged from 7.00 to 8.00. The standard deviation value for the 33 ranked factors of benefits in Round 1, ranged from SD = 1.239 for BSC 20 (provide educational service) to SD = 0.473 for BSC17 (improving health, comfort, and well-being). The results for Round 1 are presented in Table 4.2

**4.3.2 Delphi Round 2**

**Table 4.2: Second round of Delphi survey – benefits of adopting sustainability in GCI**

| Code | Benefits | Median | SD | Rank |
|---|---|---|---|---|
| BSC1 | Protect land, water, air, and ecosystems | 10 | 0.825 | 15 |
| BSC2 | Protect natural materials | 10 | 0.477 | 4 |
| BSC3 | Preserve genetic diversity and animal species | 9 | 0.877 | 16 |
| BSC4 | Conserve the biosphere | 10 | 0.663 | 11 |
| BSC5 | Utilise renewable natural resources | 9 | 0.772 | 13 |
| BSC6 | Reduce waste generation or disposal | 9 | 0.978 | 20 |
| BSC7 | Decrease $CO_2$ emission and pollution | 10 | 0.667 | 12 |
| BSC8 | Sustain life support system and ecological processes | 9 | 0.883 | 17 |
| BSC9 | Adopt vigorous re-cycling | 9 | 0.983 | 21 |
| BSC10 | Conserve the natural environment | 9 | 0.475 | 3 |
| BSC11 | Avoid global warming | 10 | 0.487 | 6 |
| BSC12 | Enhance quality of life for all | 9 | 0.589 | 10 |
| BSC13 | Alleviate poverty | 9 | 0.997 | 23 |
| BSC14 | Satisfy the needs of human | 9 | 0.782 | 14 |
| BSC15 | Consider local information when developing | 8 | 1.122 | 28 |
| BSC16 | Optimise social benefits | 9 | 1.076 | 25 |
| BSC17 | Improve health, comfort and well-being | 9 | 0.471 | 1 |
| BSC18 | Have concern for inter-generational equity | 7 | 1.181 | 30 |

| Code | Benefits | Median | SD | Rank |
|---|---|---|---|---|
| BSC19 | Minimise cultural disturbances | 8 | 1.114 | 27 |
| BSC20 | Provide educational services | 8 | 1.239 | 33 |
| BSC21 | Promote unism among society, humanity and nature | 9 | 0.475 | 2 |
| BSC22 | Understand the advantges of cultural and social capital | 8 | 1.207 | 31 |
| BSC23 | Understand multi-disciplinary societies | 8 | 1.177 | 29 |
| BSC24 | Improve economic development | 9 | 0.482 | 5 |
| BSC25 | Reduce cost of energy consumption | 9 | 0.579 | 8 |
| BSC26 | Raise real revenue | 9 | 0.952 | 19 |
| BSC27 | Improve productivity | 9 | 0.497 | 7 |
| BSC28 | Reduce cost of infrastructure | 9 | 1.097 | 26 |
| BSC29 | Reduce cost of environmental impact | 9 | 0.585 | 9 |
| BSC30 | Reduce cost of water consumption | 9 | 1.897 | 18 |
| BSC31 | Lower health costs | 9 | 0.985 | 22 |
| BSC32 | Decrease absenteeism in organisations | 7 | 1.224 | 32 |
| BSC33 | Improve return on investments (ROI) | 9 | 1.068 | 24 |

(Source: Field data, 2022)

The number of panellists who participated in Round 2 reduced by 1. In the second round of the Delphi survey, the degree of expert agreement grew. The respondents improved their prior evaluation of the 33 factors, as evidenced by the ranking of some of the factors. The ranking of some factors was improved during the second round, while the ranking of decreasing absenteeism in an organisation was reduced from a median value of 8.00 to 7.00. The remaining factors retained their ranking. There was no significant change in the rating of the factors. Agreement was still not achieved on 7 of the factors. These factors were BSC15, BSC18, BSC19, BSC20, BSC22, BSC23, and BSC32. However, there were slight changes in the SD for 5 factors, 4 downwards and 1 upwards. The downwards factors were BSC2 (0.477), BSC10 (0.475), BSC17 (0.471), and BSC24 (0.482). BSC32 (1.224) had an upwards rating. The results for Round 2 are presented in Table 4.3.

### 4.3.3 Delphi Round 3

**Table 4.3: Third round of Delphi survey – benefits of adopting sustainability in GCI**

| Code | Benefits | Median | SD | Rank |
|---|---|---|---|---|
| BSC1 | Protect land, water, air, and ecosystems | 10 | 0.825 | 15 |
| BSC2 | Protect natural materials | 10 | 0.476 | 4 |
| BSC3 | Preserve genetic diversity and animal species | 9 | 0.877 | 16 |
| BSC4 | Conserve the biosphere | 10 | 0.663 | 11 |
| BSC5 | Utilise renewable natural resources | 9 | 0.772 | 13 |

| Code | Benefits | Median | SD | Rank |
|---|---|---|---|---|
| BSC6 | Reduce waste generation or disposal | 9 | 0.978 | 20 |
| BSC7 | Decrease $CO_2$ emission and pollution | 10 | 0.667 | 12 |
| BSC8 | Sustain life support system and ecological processes | 9 | 0.883 | 17 |
| BSC9 | Adopt vigorous re-cycling | 9 | 0.983 | 21 |
| BSC10 | Conserve the natural environment | 9 | 0.474 | 3 |
| BSC11 | Avoid global warming | 10 | 0.487 | 6 |
| BSC12 | Enhance quality of life for all | 9 | 0.589 | 10 |
| BSC13 | Alleviate poverty | 9 | 0.997 | 23 |
| BSC14 | Satisfy the needs of human | 9 | 0.782 | 14 |
| BSC15 | Consider local information when developing | 8 | 1.122 | 28 |
| BSC16 | Optimise social benefits | 9 | 1.076 | 25 |
| BSC17 | Improve health, comfort and well-being | 9 | 0.470 | 1 |
| BSC18 | Have concern for inter-generational equity | 7 | 1.181 | 30 |
| BSC19 | Minimise cultural disturbances | 8 | 1.114 | 27 |
| BSC20 | Provide educational services | 8 | 1.239 | 33 |
| BSC21 | Promote unism among society, humanity and nature | 9 | 0.473 | 2 |
| BSC22 | Understand the advantges of cultural and social capital | 8 | 1.207 | 31 |
| BSC23 | Understand multi-disciplinary societies | 8 | 1.177 | 29 |
| BSC24 | Improve economic development | 9 | 0.482 | 5 |
| BSC25 | Reduce cost of energy consumption | 9 | 0.579 | 8 |
| BSC26 | Raise real revenue | 9 | 0.952 | 19 |
| BSC27 | Improve productivity | 9 | 0.497 | 7 |
| BSC28 | Reduce cost of  infrastructure | 9 | 1.097 | 26 |
| BSC29 | Reduce cost of environmental impact | 9 | 0.585 | 9 |
| BSC30 | Reduce cost of water consumption | 9 | 1.897 | 18 |
| BSC31 | Lower health costs | 9 | 0.985 | 22 |
| BSC32 | Decrease absenteeism in organisations | 7 | 1.224 | 32 |
| BSC33 | Improve return on investments (ROI) | 9 | 1.068 | 24 |

(Source: field data, 2022)

The results from Round 3 revealed that the 17 panellists who participated in Round 2, participated in Round 3, as indicated in Table 4.1. One of the major goals of a Delphi survey is to achieve agreement among the expert panel at the end of the rounds of the survey. At the end of Round 3, the process was terminated with no significant change in the rating of the factors. The data were analysed using the median score value of the 33 identified factors and the standard deviation after the Round 3 of the Delphi study. The median rating of 7 factors remained unchanged [BSC15

(8.00), BSC18 (7.00), BSC19 (8.00), BSC20 (8.00), BSC22 (8.00), BSC23 (8.00), and BSC32 (7.00)]. No consensus was attained on 7 factors in the third round as opposed to 26 factors that were rated extremely important. A strong agreement was reached among the expert panel. Out of the 33 factors, consensus on 26 factors was attained with a median value of 9.00 to 10.00, indicating a rating of extremely important.

### 4.3.4 Summary of benefits of adopting SC practices in Ghana

The benefits to be derived from using a technology will engender its adoption. Based on the results, 26 factors on which consensus was reached were categorised as important benefits that require the consideration and attention of construction stakeholders in order to fully implement sustainable building practices. These factors were grouped under the three main pillars of sustainability: economic benefits, environmental benefits, and social benefits, as shown in Figure 4.1.

**Table 4.4: Summary of the significant benefits in descending order of significance**

| Code | Benefits | Rank |
|---|---|---|
| BSC17 | Improve health, comfort and well-being | 1 |
| BSC21 | Promote unism among society, humanity and nature | 2 |
| BSC10 | Conserve the natural environment | 3 |
| BSC2 | Protect natural materials | 4 |
| BSC24 | Improve economic development | 5 |
| BSC11 | Avoid global warming | 6 |
| BSC27 | Improve productivity | 7 |
| BSC25 | Reduce cost of energy consumption | 8 |
| BSC29 | Reduce cost of environmental impact | 9 |
| BSC12 | Enhance quality of life for all | 10 |
| BSC4 | Conserve the biosphere | 11 |
| BSC7 | Decrease $CO_2$ emission and pollution | 12 |
| BSC5 | Utilise renewable natural resources | 13 |
| BSC14 | Satisfy the needs of human | 14 |
| BSC1 | Protect land, water, air, and ecosystems | 15 |
| BSC3 | Preserve genetic diversity and animal species | 16 |
| BSC8 | Sustain life support systems and ecological processes | 17 |
| BSC30 | Reduce cost of water consumption | 18 |
| BSC26 | Raise real revenue | 19 |
| BSC6 | Reduce waste generation and disposal | 20 |
| BSC9 | Adopt vigorous recycling | 21 |
| BSC31 | Lower health costs | 22 |

| Code | Benefits | Rank |
|---|---|---|
| BSC13 | Alleviate poverty | 23 |
| BSC33 | Improve return on investment | 24 |
| BSC16 | Optimise social benefits | 25 |
| BSC28 | Reduce cost of infrastructure | 26 |

(Source: Field data, 2022)

### 4.3.5 Discussion on importance of sustainable construction

The importance of SC and the environmental benefits it can provide for mankind cannot be over-emphasised and have been discussed comprehensively in the literature (Oguntona *et al*., 2019; Ojo-Fafore, 2018). The adoption of sustainability in construction practices was confirmed by the study to have direct benefits related to the environment. Out of the 26 factors confirmed by the experts, 11 benefits were linked to the environment. At the end of Round 3, the significant benefits, scoring high values and ranked 3$^{rd}$, 4$^{th}$, 6$^{th}$, 11$^{th}$ and 12$^{th}$, belong to environmental benefits. The top 5 environmental benefits included: BSC10 (conserve the environment), BSC2 (protect natural materials), BSC11 (avoid global warming), BSC4 (conserve the biosphere), and BSC7 (decrease $CO_2$ emission and pollution). These findings were consistent with previous studies in which environmental benefits were recognised (Shabrin & Kashem, 2017; Darko *et al*., 2013; Nurick & Cattell, 2013). Darko *et al*. (2013) posited that the environmental benefits that can be derived from SC include conservation of natural resources, and protection of ecosystems and biodiversity.

SC is one of the surest ways by which SDGs relevant to the environment can be achieved by 2030. The agenda 2030 for sustainable development represents a new direction for the world and Opoku (2016) argued that the construction sector has a significant responsibility towards the global effort in the realisation of the sustainable development goals by 2030. Thus, it was not surprising that the results of this study confirmed more environmental benefits for adopting SC. Through environmental preservation, economic expansion, and social advancement, the building sector can make a significant contribution to sustainable development (Tupenaite *et al*., 2017). According to Arora & Mishra (2019), the improvement made towards achieving the environment-related goals (SDGs 6, 7, 12, 13, 14, and 15) has been minimal. It is important for stakeholders to pursue SC practices aggressively to enable the attainment of the relevant SDGs. Therefore, the benefits of adopting the sustainability practices of construction projects in the GCI were examined in this study.

Similarly, economic benefits are important for the adoption of SC practices. There are financial benefits derived from the reduced usage of energy and water, and improved productivity and well being. Shabrin and Kashem (2017) reported that SC has several economic benefits, ranging from the indirect to the direct. The major direct economic benefits include: a better repayment period because of less usage of water, energy, and health cost; an increase in revenue; and a quick return on investment. The findings of this study showed 9 economic benefits of SC practices, including: BSC24 (improve economic development), BSC27 (improve productivity), BSC25 (reduce cost of energy consumption), BSC29 (reduce cost of environmental impact), BSC30 (reduce cost of water consumption), BSC26 (raise real revenue), BSC31 (lower health costs), BSC33 (improve return on investments), and BSC28 (reduce cost of infrastructure). These factors were discussed in other studies in the literature as being important economic benefits for adopting SC practices (Oguntona *et al*., 2019; Ojo – Fafore, *et al*., 2018). Also, Darko *et al*. (2013) observed that the main economic benefits of SC include: decrease operating costs; enhanced productivity, and increased economic performance over the lifetime of a building; but BSC20 (provide educational services through the adoption of SC practices) was found not to be an important benefit in Ghana.

The desire to demonstrate commitment to social responsibility can drive the adoption of SC practices. According to Darko *et al*. (2013) SC practices enhance health and comfort for inhabitants and have various social benefits, being aesthetically pleasing. Shabrin and Kashem (2017) postulated that the social components of SC offer more possibilities in terms of creation of job for the local population. Shabrin and Kashem (2017) indicated that SC is a new venture and offers many jobs and alleviates poverty. Consequently, it was found in this study that SC practices will benefit mankind by leading to improved quality of life (BSC12) and poverty alleviation (BSC13). This means that the benefits of SC practices include various savings and financial gains during construction phases to create opportunities resulting from social benefits (Khoshbakht *et al*. 2017). The experts reached consensus on BSC16 (optimise social benefit) as one of the important benefits for adopting of SC practices. Thus, BSC17 (improve health, comfort and well-being) and BSC21 (promotion of harmony among society, humanity and nature) are the 1$^{st}$ and 2$^{nd}$ most important benefits that SC practices offer respectively. In this regard, the House of Lords (2016) affirmed that construction has a lasting effect on quality of life, health, prosperity, happiness, and well-being of inhabitants and communities depending on how a construction project is carried out. Even though construction practices may affect the environment negatively, they have the potential to act as drivers for the realisation of the SDGs when SC practices are adopted.

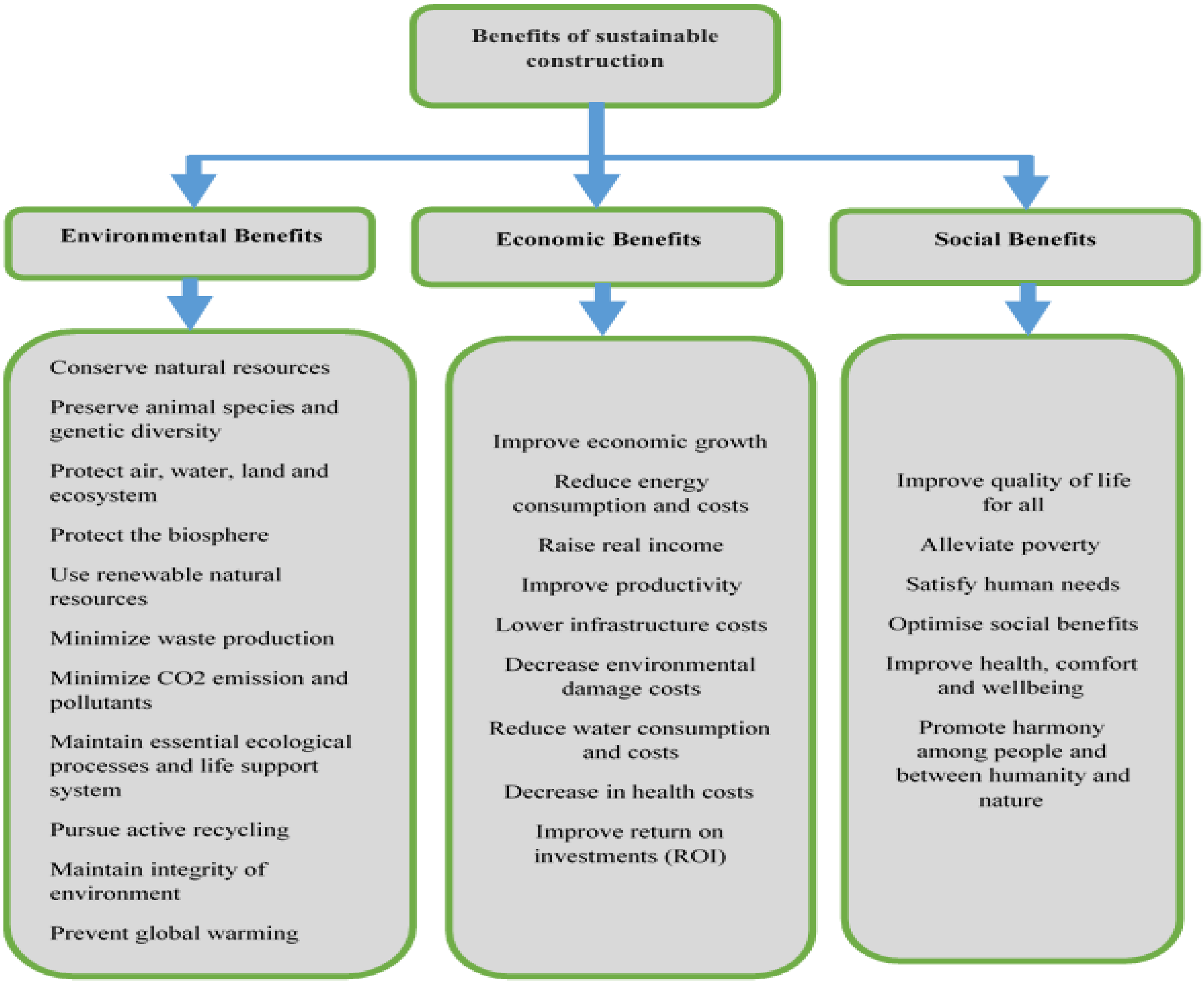


**Figure 4.1: Benefits of sustainable construction**

## 4.4 DESIGNING FOR SUSTAINABILITY (OBJECTIVE 2)

In response to the second, secondary research question: How design should respond to sustainability requirements in GCI?, the experts highlighted the actions that architectural and engineering firms were taking to respond to the call for sustainability requirements through the design of building projects in Ghana. The experts reached consensus on 10 identified variables including sustainable design components and sustainable design requirements after three rounds of iterations.

### 4.4.1 Delphi Round 1

**Table 4.5: First round of Delphi survey – sustainable design in GCI**

| Code | Sustainable design | Median | SD | Rank |
|---|---|---|---|---|
| | **Sustainable design components** | | | |
| ESDC1 | Reduction of energy consumption | 9 | 1.490 | 2 |
| ESDC2 | Reduction of raw materials consumption | 10 | 1.369 | 1 |
| ESDC3 | Reduction of dangerous materials consumption | 9 | 1.621 | 5 |
| ESDC4 | Reduction of water consumption | 9 | 1.502 | 3 |
| ESDC5 | Recycling of waste and return | 9 | 1.770 | 6 |
| ESDC6 | Land conservation | 9 | 1.543 | 4 |
| | **Sustainable design requirements** | | | |
| ESDR1 | Resources conservation | 9 | 1.225 | 1 |
| ESDR2 | Humane adaptation | 9 | 1.334 | 3 |
| ESDR3 | Life-cycle design | 9 | 1.251 | 2 |
| ESDR4 | Cost efficiency | 9 | 1.546 | 4 |

(Source: Field data, 2022)

The Round 1 results indicated that, out of the 6 sustainable design components and 4 sustainable design requirements presented to the experts, all factors were believed to influence the adoption of SC practices extremely. These factors scored a median value of 9 and 10, respectively. The standard deviation value for the factors of sustainable design components in the Round 1 ranged from SD = 1.369 for ESDCC2 (reduction of raw materials consumption) to SD = 1.770 for ESDC5 (recycling of waste and return). The standard deviation value for the factors of sustainable design requirements in the Round 1 ranged from SD = 1.225 for ESDR1 (resources conservation) to SD = 1.546 for ESDR4 (cost efficiency). The results for the Round 1 Delphi study are presented in Table 4.6.

### 4.4.2 Delphi Round 2

**Table 4.6: Second round of Delphi survey – sustainable design in GCI**

| Code | Sustainable design | Median | SD | Rank |
|---|---|---|---|---|
| | **Sustainable design components** | | | |
| ESDC1 | Reduction of energy consumption | 9 | 1.404 | 3 |
| ESDC2 | Reduction of raw materials consumption | 9 | 1.409 | 4 |
| ESDC3 | Reduction of dangerous materials consumption | 9 | 1.409 | 4 |
| ESDC4 | Reduction of water consumption | 10 | 1.074 | 1 |
| ESDC5 | Recycling of waste and return | 9 | 1.237 | 2 |

| Code | Sustainable design | Median | SD | Rank |
|---|---|---|---|---|
| | **Sustainable design components** | | | |
| ESDC6 | Land conservation | 9 | 1.736 | 6 |
| | **Sustainable design requirements** | | | |
| ESDR1 | Resources conservation | 9 | 1.111 | 2 |
| ESDR2 | Humane adaption | 9 | 0.993 | 1 |
| ESDR3 | Life-cycle design | 9 | 1.118 | 3 |
| ESDR4 | Cost efficiency | 9 | 1.498 | 4 |

(Source: Field data, 2022)

In Round 2, the results showed that, out of the 6 sustainable design components and 4 sustainable design requirements presented to the experts, all factors were believed to influence the adoption of SC practices extremely, just as in Round 1. These factors scored a median value of 9 and 10, respectively, similar to Round 1. However, the standard deviation value for the factors improved slightly. The SD value for the factors of sustainable design components in Round 2 of the Delphi survey ranged from SD = 1.074 for ESDCC4 (reduction of water consumption), to SD = 1.736 for ESDC6 (land conservation). The standard deviation value for the factors of sustainable design requirements in Round 2 ranged from SD = 0.993 for ESDR2 (Humane adaption) to SD = 1.498 for ESDR4 (cost efficiency). The findings of the Delphi study for Round 2 are presented in Table 4.7.

### 4.4.3 Delphi Round 3

**Table 4.7: Third round of Delphi survey – sustainable design in GCI**

| Code | Sustainable design | Median | SD | Rank |
|---|---|---|---|---|
| | **Sustainable design components** | | | |
| ESDC1 | Reduction of energy consumption | 9 | 1.136 | 3 |
| ESDC2 | Reduction of raw materials consumption | 9 | 0.786 | 1 |
| ESDC3 | Reduction of dangerous materials consumption | 9 | 1.221 | 4 |
| ESDC4 | Reduction of water consumption | 10 | 1.079 | 2 |
| ESDC5 | Recycling of waste and return | 9 | 1.286 | 5 |
| ESDC6 | Land conservation | 9 | 1.940 | 6 |
| | **Sustainable design requirements** | | | |
| ESDR1 | Resources conservation | 9 | 1.250 | 3 |
| ESDR2 | Humane adaptation | 9 | 1.136 | 2 |
| ESDR3 | Life-cycle design | 9 | 0.982 | 1 |
| ESDR4 | Cost efficiency | 9 | 1.250 | 3 |

(Source: Field data, 2022)

The results from Round 3 revealed that all the factors presented (sustainable design components and sustainable design requirements) influence the adoption of SC practices extremely in Ghana. These factors scored a median value of 9 and 10 respectively. The standard deviation value for the factors of sustainable design components in Round 3 of the Delphi survey ranged from SD = 0.786 for ESDCC2 (reduction of raw materials consumption) to SD = 1.940 for ESDC6 (land conservation). The standard deviation value for the factors of sustainable design requirements in Round 3 of the Delphi survey ranged from SD = 0.982 for ESDR3 (life-cycle design) to SD = 1.250 for ESDR2 (Humane adaptation and ESDR4 (cost efficiency), respectively. The results of the Delphi study for Round 3 are presented in Table 4.8

### 4.4.4 Summary of sustainable design in GCI

The integration of sustainable design into construction activities will support the drive for SC to reduce carbon and ecological footprints in Ghana. The factors on which consensus was reached were significant and extremely important to warrant the consideration and attention of stakeholders to guarantee complete implementation. It is important that the design requirements should focus more on life-cycle design, humane adaption, cost efficiency, and resource conservation to contribute to the achievement of SC. The design component should focus on reduction of raw materials consumption, decrease in energy consumption, and reduction in water usage, respectively, being the highest-ranked factors. Table 4.9 shows the summary of sustainable design requirements in descending order of importance.

**Table 4.8: Summary of sustainable design requirements in descending order of importance**

| Code | Sustainable design | Median | SD | Rank |
|---|---|---|---|---|
| | **Sustainable design component** | | | |
| ESDC2 | Reduction of raw materials consumption | 9 | 0.786 | 1 |
| ESDC4 | Reduction of water consumption | 10 | 1.079 | 2 |
| ESDC1 | Reduction of energy consumption | 9 | 1.136 | 3 |
| ESDC3 | Reduction of dangerous materials consumption | 9 | 1.221 | 4 |
| ESDC5 | Recycling of waste and return | 9 | 1.286 | 5 |
| ESDC6 | Land conservation | 9 | 1.940 | 6 |
| | **Sustainable design requirements** | | | |
| ESDR3 | Life-cycle design | 9 | 0.982 | 1 |
| ESDR2 | Humane adaptation | 9 | 1.136 | 2 |
| ESDR4 | Cost efficiency | 9 | 1.250 | 3 |
| ESDR1 | Resources conservation | 9 | 1.250 | 4 |

### 4.4.5 Discussion on designing for sustainability

The sustainable design approaches adopted by architectural and engineering firms for building projects contribute greatly to SC. The concept of sustainable design has arisen to protect the ecosystem and scarce natural materials for the current and generations to come. Sustainable design is a crucial prerequisite for SC due to the growing demands for resource efficiency and its effects on the ecosystem (Meex *et al*., 2018). At the end of Round 3, the panel reached agreement on the four factors of sustainable design requirements and ranked them according to importance as ESDR3 (life-cycle design), ESDR2 (humane adaptation), ESDR4 (cost efficiency), and ESDR1 (resources conservation). Architects and designers should develop strategies to adopt sustainable design to ensure that there is water efficiency, energy conservation, material use and conservation of land. The findings of this research showed that reduction in raw materials consumption, reduction of water consumption, and decrease in energy usage are the top three sustainable design components that should be considered by the architectural and engineering firms in Ghana during their design process to reduce the carbon and ecological footprint of construction activity and contribute to sustainability of construction projects. Together with the Ghana Green Building Council (GHGBC), Leadership and Excellence in Green Design (LEGD) has created a rating system for evaluating a building's environmental attributes during the planning phase (LEGD, 2015). The sustainable design concept is focused on life-cycle design, economy of resources, and humane design. This is also similar to the sustainable design principles identified by Asman *et al*. (2019) as cost efficiency, resources conservation, and design for humane adaptation. Therefore, architectural and engineering firms can contribute significantly to sustainability requirements through the use of sustainable design of building projects to contribute to the achievement of SC to help reduce carbon and ecological footprints of construction activity in Ghana.

## 4.5 CONSTRUCTION MATERIALS AND SUSTAINABILITY (OBJECTIVE 3)

In response to the third, secondary research question: How should construction materials respond to sustainability requirements in GCI, the experts indicated how low-impact materials are integrated into the construction projects by contractors in Ghana. The experts reached consensus on 16 identified factors, including low impact material selection criteria and incorporation measures after three rounds of iterations.

### 4.5.1 Delphi Round 1

**Table 4.9: First round of Delphi survey – incorporation of low-impact materials in GCI**

| Code | Sustainable design | Median | SD | Rank |
|---|---|---|---|---|
| | **Low-impact material selection criteria** | | | |
| MSC1 | Aesthetic quality of the material | 9 | 1.983 | 8 |
| MSC2 | Durability of the material | 9 | 1.312 | 1 |
| MSC3 | Ecological impact of the material | 9 | 1.625 | 6 |
| MSC4 | Embodied energy of the material | 9 | 1.490 | 3 |
| MSC5 | Performance of the material | 9 | 1.546 | 4 |
| MSC6 | Re-usable/renewable potential of the material | 9 | 1.572 | 5 |
| MSC7 | Social impact of the material | 9 | 1.372 | 2 |
| MSC8 | Cost of the material | 9 | 1.944 | 7 |
| | **Low-impact material incorporation measures** | | | |
| MIM1 | Materials use are renewable, recyclable or re-usable | 9 | 2.181 | 3 |
| MIM2 | Materials with organic origin | 9 | 2.446 | 5 |
| MIM3 | Permeable materials to allow dissipation of storm water into the ground | 9 | 2.531 | 7 |
| MIM4 | Conserve water by using compost and mulch for landscaping | 8 | 2.528 | 6 |
| MIM5 | Include water-efficient trees, rain gardens and green roofs | 9 | 2.562 | 8 |
| MIM6 | Adopt durable materials that can easily be maintained | 9 | 2.078 | 2 |
| MIM7 | Materials of minimum adverse impact on the environment | 9 | 2.373 | 4 |
| MIM8 | Usage of locally available materials | 9 | 1.345 | 1 |

(Source: Field survey, 2022)

The findings from Round 1 showed that all 8 factors of low-impact material selection criteria presented to the experts were ranked as extremely important and were believed to influence the adoption of SC practices in Ghana. These factors scored a median value of 9. The standard deviation value for the factors of low-impact material selection criteria in Round 1 ranged from SD = 1.312 for MSC2 (durability of material) to SD = 1.983 for MSC1 (aesthetic quality of the material). Also, out of the 8 factors of low-impact material incorporation measures presented to the experts, 7 were ranked as extremely important and 1 was ranked as very important. These factors scored a median value of 8 and 9, respectively. The standard deviation value for the low-impact material incorporation measures in Round 1 ranged from SD = 1.345 for MIM8 (usage of locally available materials) to SD = 2.562 for MIM5 (use of green roofs, rain gardens, and water-efficient trees) as shown in Table 4.10.

### 4.5.2 Delphi Round 2

**Table 4.10: Second round of Delphi survey – incorporation of low-impact materials in GCI**

| Code | Sustainable design | Median | SD | Rank |
|---|---|---|---|---|
| | **Low-impact material selection criteria** | | | |
| MSC1 | Aesthetic quality of the material | 9 | 1.845 | 8 |
| MSC2 | Durability of the material | 9 | 0.993 | 1 |
| MSC3 | Ecological impact of the material | 9 | 1.498 | 5 |
| MSC4 | Embodied energy of the material | 8 | 1.419 | 4 |
| MSC5 | Performance of the material | 9 | 1.663 | 6 |
| MSC6 | Re-usable/renewable potential of the material | 9 | 0.993 | 1 |
| MSC7 | Social impact of the material | 8 | 1.328 | 3 |
| MSC8 | Cost of the material | 9 | 1.805 | 7 |
| | **Low-impact material incorporation measures** | | | |
| MIM1 | Materials use are renewable, recyclable or re-usable | 9 | 1.985 | 2 |
| MIM2 | Materials with organic origin | 9 | 2.288 | 5 |
| MIM3 | Permeable materials to allow dissipation of storm water into the ground | 9 | 2.536 | 8 |
| MIM4 | Conserve water by using compost and mulch for landscaping | 8 | 2.443 | 6 |
| MIM5 | Include water-efficient trees, rain gardens and green roofs | 9 | 2.512 | 7 |
| MIM6 | Adopt durable materials that can easily be maintained | 9 | 2.002 | 3 |
| MIM7 | Materials of minimum adverse impact on the environment | 9 | 2.085 | 4 |
| MIM8 | Usage of locally available materials | 9 | 1.323 | 1 |

(Source: Field data, 2022)

In Round 2, the results of the 8 factors of low-impact material selection criteria presented to the experts were ranked, with 2 being very important and 6 extremely important. The experts believed that the factors are significant and influence the adoption of SC practices in Ghana. These factors scored a median value of 8 and 9, respectively. The standard deviation value for the factors of low-impact material selection criteria in Round 2 ranged from SD = 0.993 for MSC6 (re-usable/renewable potential of the material) to SD = 1.845 for MSC1 (aesthetic quality of the material). Also, out of the 8 factors of low-impact material incorporation measures presented to the experts, 7 were ranked as extremely important and 1 was ranked very important, as in Round 1. These factors scored a median value of 8 and 9, respectively. The standard deviation value for the low impact material incorporation measures in Round 2 of the Delphi survey ranged from SD = 1.323 for MIM8 (use of local materials such as thatch, wood, bamboo, laterite, etc.) to SD = 2.536 for MIM3 (use of permeable materials for landscaping to allow dissipation of storm water into the ground) as shown in Table 4.11.

### 4.5.3 Delphi Round 3

**Table 4.11: Third round of Delphi survey – incorporation of low-impact materials in GCI**

| Code | Sustainable design | Median | SD | Rank |
|---|---|---|---|---|
| | **Low-impact material selection criteria** | | | |
| MSC1 | Aesthetic quality of the material | 9 | 1.612 | 6 |
| MSC2 | Durability of the material | 9 | 1.027 | 2 |
| MSC3 | Ecological impact of the material | 9 | 1.508 | 5 |
| MSC4 | Embodied energy of the material | 9 | 1.502 | 4 |
| MSC5 | Performance of the material | 9 | 1.814 | 7 |
| MSC6 | Re-usable/renewable potential of the material | 9 | 1.000 | 1 |
| MSC7 | Social impact of the material | 9 | 1.293 | 3 |
| MSC8 | Cost of the material | 9 | 1.814 | 7 |
| | **Low-impact material incorporation measures** | | | |
| MIM1 | Materials used are recyclable, renewable, or re-usable | 9 | 1.000 | 1 |
| MIM2 | Materials with organic origion | 9 | 1.578 | 7 |
| MIM3 | Permeable materials to allow dissipation of storm water into the ground | 9 | 1.601 | 8 |
| MIM4 | Conserve water by using compost and mulch for landscaping | 9 | 1.537 | 5 |
| MIM5 | Include water-efficient trees, rain gardens and green roofs | 8 | 1.549 | 6 |
| MIM6 | Adopt durable materials that can easily be maintained | 9 | 1.206 | 2 |
| MIM7 | Materials of minimum adverse impact on the environment | 9 | 1.272 | 3 |
| MIM8 | Usage of locally available materials | 9 | 1.433 | 4 |

(Source: Field data, 2022)

In Round 3, the experts reached consensus on all the 8 factors of low-impact material selection criteria presented to the panel and ranked them as extremely important in influencing the implementation of SC in GCI. All the factors scored a median value of 9. The standard deviation value for the factors of low-impact material selection criteria in Round 3 ranged from SD = 1.000 for MSC6 (re-usable/renewable potential of the material) to SD = 1.814 for MSC5 and MSC8 (performance of the material and cost of the material, respectively). Also, out of the 8 factors of low-impact material incorporation measures presented to the experts, 7 were ranked as extremely important and 1 was ranked as very important, as in Round 1. These factors scored a median value of 8 and 9, respectively. The standard deviation value for the low-impact material incorporation measures in Round 3 of the Delphi survey ranged from SD = 1.323 for MIM8 (usage of locally available materials) to SD = 2.536 for MIM3 (Permeable materials to allow dissipation of storm water into the ground) as shown in Table 4.12.

### 4.5.4 Summary of low impact material incorporation in GCI

The low-impact materials selection criteria and incorporation measures into construction activities will support the drive for SC to decrease carbon and ecological footprints of construction activity in GCI. The factors on which consensus was reached were significant and necessitate the consideration of stakeholders to fully implement sustainable building practices. It is important that the architects, engineers and contractors should focus on the usage of low-impact building materials for building activities in GCI. The highest ranked, low-impact materials selection criteria include re-usable/renewable potential of the material, durability of the material, social impact of the material, embodied energy of the material, and ecological impact of the material. Table 4.13 shows the summary of low-impact material selection in sustainable design requirements in descending order of significance.

**Table 4.12: Summary of low-impact materials incorporation in descending order of significance**

| Code | Sustainable design | Rank |
|---|---|---|
| | **Low-impact material selection criteria** | |
| MSC6 | Re-usable/renewable potential of the material | 1 |
| MSC2 | Durability of the material | 2 |
| MSC7 | Social impact of the material | 3 |
| MSC4 | Embodied energy of the material | 4 |
| MSC3 | Ecological impact of the material | 5 |
| MSC1 | Aesthetic quality of the material | 6 |
| MSC5 | Performance of the material | 7 |
| MSC8 | Cost of the material | 8 |

| Code | Sustainable design | Rank |
|---|---|---|
| | **Low-impact material selection criteria** | |
| | **Low-impact material incorporation measures** | |
| MIM1 | Materials used are renewable, recyclable or re-usable | 1 |
| MIM6 | Adopt durable materials that can easily be maintained | 2 |
| MIM7<br>MIM8 | Materials of minimum adverse impact on the environment<br>Usage of localy available materials | 3<br>4 |
| MIM5 | Include water-efficient trees, rain gardens, and green roofs | 5 |
| MIM4 | Conserve water by using compost and mulch for landscaping | 6 |
| MIM2 | Use of materials with organic origin/natural materials | 7 |
| MIM3 | Permeable materials to allow dissipation of storm water into the ground | 8 |

(Source: Field data, 2022)

### 4.5.5 Discussion of incorporation of low-impact materials in the construction process

Minimising the environmental impact associated with construction projects is receiving growing interest. The low-impact materials have reduced damage to the ecology on which humans depend for survival (Chen *et al*., 2015). The low-impact materials contribute significantly to the decrease of ecological and carbon footprints for sustainability. The top, low-impact material selection criteria established in this study include: MSC6 (re-usable/renewable potential of the material), MSC2 (durability of the material), MSC7 (social impact of the material), MSC4 (embodied energy of the material), and MSC3 (ecological impact of the material). Also, the main low-impact material incorporation measures established in this study include: MIM1 (materials used are renewable, recyclable or re-usable); MIM6 (adopt durable materials that can easily be maintained); MIM7 (materials of minimum adverse impact on the environment); and MIM 8 (usage of locally available materials). The incorporation of low-impact materials will make radical improvement in embodied energy reduction, recycling/re-use of building materials.

## 4.6 ENERGY EFFICIENCY UTILISATION (OBJECTIVE 4)

To address the fourth, secondary research question: What are the effects of energy efficiency on the construction process in GCI, the experts suggested 6 factors during Round 1 that can influence the use of low energy machinery in the GCI, as indicated in Table 4.14.

### 4.6.1. Delphi Round 1

During Round 1, the experts suggested 6 elements that influence the usage of energy-efficient equipment in construction activities as shown in Table 4.14. These factors were indicated in Round 2 for the consideration of the experts.

**Table 4.13: First round of Delphi survey –influence of energy efficient equipment utilisation on construction projects as suggested by the expert panel**

| Code | Factor |
|---|---|
| EEEU1 | Reduce fuel usage |
| EEEU2 | Reduce emission levels and protect the environment |
| EEEU3 | Minimise energy consumption |
| EEEU4 | Upgrade/replace equipment with energy-saving devices |
| EEEU5 | Improve productivity and increase value |
| EEEU6 | Reduction in energy cost |

(Source: Field data, 2022)

### 4.6.2 Delphi Round 2

All 6 factors that influence the use of energy-efficient equipment presented to the experts in Round 2 were ranked as extremely important and were believed to influence the adoption of SC practices in Ghana. These factors scored a median value of 9 and 10, respectively. The standard deviation value for the elements that affect the usage of energy-efficient equipment in building activities in Round 2 of the Delphi survey ranged from SD = 0.507 for EEEU2 and EEEU3 (reduce emission level and protect the environment, and minimise energy consumption) to SD = 0.985 for EEEU4 (upgrade/replace equipment with energy-saving devices), as indicated in Table 4.15.

**Table 4.14: Second round of Delphi survey – influence of energy efficient equipment utilisation in GCI**

| Code | Factor | Median | SD | Rank |
|---|---|---|---|---|
| EEEU1 | Reduce fuel usage | 10 | 0.624 | 4 |
| EEEU2 | Reduce emission levels and protect the environment | 9 | 0.507 | 1 |
| EEEU3 | Minimise energy consumption | 9 | 0.507 | 1 |
| EEEU4 | Upgrade/replace equipment with energy-saving devices | 9 | 0.985 | 6 |
| EEEU5 | Improve productivity and increase value | 9 | 0.928 | 5 |
| EEEU6 | Reduction in energy cost | 9 | 0.618 | 3 |

(Source: Field data, 2022)

#### 4.6.3 Delphi Round 3

In Round 3, all the 6 factors that influence the use of energy-efficient equipment presented to the experts were ranked as extremely important and were believed to influence the adoption of SC practices in Ghana. These factors scored a median value of 9 and 10, respectively. The standard deviation value for the elements that affect the usage of energy-efficient equipment in building activities reduced slightly and ranged from SD = 0.505 for EEEU1 (reduce fuel usage) to SD = 0.944 for EEEU4 (upgrade/replace equipment with energy-saving devices) as indicated in Table 4.16.

**Table 4.15: Third round of Delphi survey – influence of energy efficient equipment utilisation in GCI**

| Code | Factor | Median | SD | Rank |
|---|---|---|---|---|
| EEEU1 | Reduce fuel usage | 10 | 0.505 | 1 |
| EEEU2 | Reduce emission levels and protect the environment | 9 | 0.522 | 3 |
| EEEU3 | Minimise energy consumption | 9 | 0.522 | 3 |
| EEEU4 | Upgrade/replace equipment with energy-saving devices | 9 | 0.944 | 6 |
| EEEU5 | Improve productivity and increase value | 9 | 0.786 | 5 |
| EEEU6 | Reduction in energy cost | 10 | 0.522 | 2 |

(Source: Field Data, 2022)

#### 4.6.4 Summary of the usage of energy-efficient equipment on construction projects in GCI

The usage of energy-efficient equipment in building activities will support the drive for SC to decrease ecological and carbon footprints of construction activity in GCI. The factors on which consensus was reached were significant and extremely important for implementation of SC practices. It is important that the stakeholders focus on the use of energy-efficient equipment in construction activities in Ghana. The top-ranked influence of the use of energy-efficient equipment includes EEEU1 (reduction in fuel usage), EEEU2 (reduction in energy cost), EEEU3 (reduce emission level and protect the environment), EEEU4 (minimise energy consumption), EEEU 5 (improve productivity and increase value), and EEEU6 (upgrade/replace equipment with energy-saving devices). Table 4.17 indicates the summary of the influence of the usage of energy-efficient equipment on the construction process in descending order of significance.

**Table 4.16: Summary of influence of energy efficient equipment utilisation on construction projects in GCI**

| Code | Factor | Rank |
|---|---|---|
| EEEU1 | Reduce fuel usage | 1 |
| EEEU6 | Reduction in energy cost | 2 |
| EEEU2 | Reduce emission levels and protect the environment | 3 |
| EEEU3 | Minimise energy consumption | 3 |
| EEEU5 | Improve productivity and increase value | 5 |
| EEEU4 | Upgrade/replace equipment with energy-saving devices | 6 |

(Source: Field data, 2022)

### 4.6.5 Discussion of the usage of energy-efficient equipment on construction projects in GCI

At every step of a building project, from planning and construction to operation and demolition, buildings use energy and other resources. The on-site construction works of building projects consume approximately 40% of energy for construction activities (Edeoja & Edeoja, 2015: 112). Energy utilisation on construction sites is concerned with mechanical plants and equipment used for transportation, earthworks, concreting, lifting and levelling works. The panellists reached consensus on all 6 factors that influence the usage of energy-efficient equipment on construction projects at the end of Round 3. The results of this study, with the highest ranked factors being EEEU1 (reduce in fuel usage), EEEU2 (reduction in energy cost), EEEU3 (reduce emission level and protect the environment), EEEU4 (minimise energy consumption), EEEU5 (improve productivity and increase value), and EEEU6 (upgrade/replace equipment with energy-saving devices) was confirmed by the results of the literature review. The literature showed that 688 million gallons of gasoline and 5,968 million gallons of diesel were used by construction machinery and have high $CO_2$ emission levels (Huang *et al*., 2018). A reduction in the huge amount of energy consumed in construction, as a result of transportation, demolition, excavation, and hoisting, will contribute to the decrease of CF and EF of construction activity. The efficient use of construction equipment will lead to reduced fuel usage, reduction in energy cost, reduced emission levels and protection of the environment, minimise energy consumption, improve productivity, and increase value. Energy can be used efficiently on construction sites when construction method statements are well known and require construction to be done in a sustainable manner to ensure sustainable development in Ghana.

## 4.7 SOLID WASTE MANAGEMENT (OBJECTIVE 5)

To address the fifth, secondary research question: What modalities are employed to manage the reduction of solid waste on construction sites in GCI, the experts in sustainable construction highlighted the modalities that contractors employ to reduce production and discharge of solid waste on construction sites in Ghana. The experts reached consensus on 26 identified factors that contractors employ to reduce production and discharge of solid waste on construction sites after three rounds of iterations.

### 4.7.1 Delphi Round 1

The experts' views on waste management measures in Round 1 are presented in Table 4.18. The findings from Round 1 showed that all 26 factors of waste management measures presented to the experts were ranked as extremely important and were believed to influence the adoption of SC practices in GCI. All these factors scored a median value of 9. The standard deviation value for the factors of waste management in the Round 1 ranged from SD = 1.147 for WMM2 (using technology that is more efficient) to SD = 2.128 for WMM3 (purchase just enough raw components).

**Table 4.17: First round of Delphi survey – modalities contractors employ to manage waste and reduce solid waste production on construction sites in GCI**

| Code | Waste management measures | Median | SD | Rank |
|---|---|---|---|---|
| WMM1 | Utilise resources before they expire | 9 | 1.448 | 5 |
| WMM2 | Using equipment that are more efficient | 9 | 1.147 | 1 |
| WMM3 | Purchase just enough raw components | 9 | 2.128 | 26 |
| WMM4 | Adopt effective site management techniques | 9 | 1.539 | 11 |
| WMM5 | Ensure effective co-ordination to avoid over-buying | 9 | 1.801 | 21 |
| WMM6 | Minimise changes in design | 9 | 1.835 | 22 |
| WMM7 | Training of construction workers and employees | 9 | 1.625 | 15 |
| WMM8 | Appropriate storage of materials on site | 9 | 1.938 | 25 |
| WMM9 | Employ skilled workers | 9 | 1.730 | 19 |
| WMM10 | Ensure accurate materials specifications | 9 | 1.345 | 3 |
| WMM11 | Ensure materials are provided in the amount and volumes stated | 9 | 1.498 | 10 |
| WMM12 | Transform the attitudes of workers towards handling of materials | 9 | 1.328 | 2 |
| WMM13 | Supervisors should be vigilant | 9 | 1.455 | 7 |

| | | | | |
|---|---|---|---|---|
| WMM14 | Know different kinds of materials available | 9 | 1.730 | 19 |
| WMM15 | Accurate batching of materials | 9 | 1.855 | 23 |
| WMM16 | Weekly task planning | 9 | 1.654 | 16 |
| WMM17 | Efficient method contract administration | 9 | 1.490 | 8 |
| WMM18 | Appropriate handling of concrete | 9 | 1.572 | 12 |
| WMM19 | Followed standardised measurements | 9 | 1.663 | 17 |
| WMM20 | A person should be responsible for waste control | 9 | 1.611 | 13 |
| WMM21 | Scheduling delivery time promptly | 9 | 1.498 | 10 |
| WMM22 | Practice just-in-time procedures | 9 | 1.935 | 24 |
| WMM23 | Appropriate usage of equipment and tools on site | 9 | 1.625 | 15 |
| WMM24 | Promote re-use of constrction waste materials for projects | 9 | 1.772 | 20 |
| WMM25 | Adopt low-waste technology measures | 9 | 1.409 | 4 |
| WMM26 | Recycle some waste materials on site | 9 | 1.455 | 7 |

(Source: Field data, 2022)

### 4.7.2 Delphi Round 2

In Round 2, the results of the 26 factors of waste management measures presented to the experts were ranked as extremely important (Table 4.19). The experts believed that the factors are significant and influence the adoption of SC activities in GCI. All these factors scored a median value of 9. The standard deviation value for the factors of waste management in Round 2 reduced slightly from the Round 1 values and ranged from SD = 0.899 for WMM2 (using technology that is more efficient) to SD = 1.770 for WMM15 (accurate batching of materials).

**Table 4.18: Second round of Delphi survey – modalities contractors employ to manage waste and reduce solid waste production on construction sites in GCI**

| | | Second Round | | |
|---|---|---|---|---|
| **Code** | **Waste management measures** | **Median** | **SD** | **Rank** |
| WMM1 | Utilise resources before they expire | 9 | 1.121 | 6 |
| WMM2 | Using equipment that are more efficient | 9 | 0.899 | 1 |
| WMM3 | Purchase just enough raw components | 9 | 1.404 | 16 |
| WMM4 | Adopt effective site management techniques | 9 | 1.219 | 8 |
| WMM5 | Ensure effective co-ordination to avoid over-buying | 9 | 1.412 | 17 |
| WMM6 | Minimise changes in design | 9 | 1.118 | 5 |
| WMM7 | Training of construction workers and employees | 9 | 1.359 | 14 |
| WMM8 | Appropriate storage of materials on site | 9 | 0.993 | 2 |
| WMM9 | Employ skilled workers | 9 | 1.275 | 11 |

| | | | | |
|---|---|---|---|---|
| WMM10 | Ensure accurate materials specifications | 9 | 1.131 | 7 |
| WMM11 | Ensure materials are provided in the amount and volumes stated | 10 | 1.334 | 13 |
| WMM12 | Transform the attitudes of workers towards handling of materials | 9 | 1.312 | 12 |
| WMM13 | Supervisors should be vigilant | 9 | 1.417 | 18 |
| WMM14 | Know different kinds of materials available | 9 | 1.502 | 20 |
| WMM15 | Accurate batching of materials | 9 | 1.770 | 26 |
| WMM16 | Weekly task planning | 9 | 1.572 | 22 |
| WMM17 | Efficient method contract administration | 9 | 1.380 | 15 |
| WMM18 | Appropriate handling of concrete | 9 | 1.543 | 21 |
| WMM19 | Followed standardised measurements | 9 | 1.437 | 19 |
| WMM20 | A person should be responsible for waste control | 9 | 1.602 | 24 |
| WMM21 | Scheduling delivery time promptly | 9 | 1.237 | 9 |
| WMM22 | Practice just-in-time procedures | 9 | 1.611 | 25 |
| WMM23 | Appropriate usage of equipment and tools on site | 9 | 1.579 | 23 |
| WMM24 | Promote re-use of constrction waste materials for projects | 9 | 1.269 | 10 |
| WMM25 | Adopt low-waste technology measures | 9 | 1.111 | 4 |
| WMM26 | Recycle some waste materials on site | 9 | 1.088 | 3 |

(Source: Field data, 2022)

**4.7.3 Delphi Round 3**

The results of the 26 factors of waste management measures presented to the experts in Round 3 were ranked as extremely important (Table 4.20). The experts believed that the factors are significant and influence the implementation of SC practices in Ghana. The median value of some of the factors increased from 9 to 10. The standard deviation value for the factors of waste management in Round 3 reduced slightly from the Round 2 values and ranged from SD = 0.688 for WMM25 (adopt low-waste technology measures) to SD = 1.640 for WMM15 (accurate batching of materials).

**Table 4.19: Third round of Delphi survey – modalities contractors employ to manage waste and reduce solid waste production on construction sites in GCI**

| Code | Waste management measures | Median | SD | Rank |
|---|---|---|---|---|
| WMM1 | Utilise resources before they expire | 9 | 1.079 | 16 |
| WMM2 | Using equipment that are more efficient | 10 | 0.823 | 6 |
| WMM3 | Purchase just enough raw components | 9 | 1.446 | 24 |
| WMM4 | Adopt effective site management techniques | 10 | 1.009 | 11 |
| WMM5 | Ensure effective co-ordination to avoid over-buying | 9 | 1.009 | 12 |
| WMM6 | Minimise changes in design | 9 | 0.924 | 8 |
| WMM7 | Training of construction workers and employees | 9 | 1.044 | 15 |
| WMM8 | Appropriate storage of materials on site | 9 | 0.905 | 7 |
| WMM9 | Employ skilled workers | 10 | 0.934 | 9 |
| WMM10 | Ensure accurate materials specifications | 10 | 0.934 | 9 |
| WMM11 | Ensure materials are provided in the amount and volumes stated | 10 | 1.206 | 18 |
| WMM12 | Transform the attitudes of workers towards handling of materials | 9 | 1.250 | 19 |
| WMM13 | Supervisors should be vigilant | 9 | 1.300 | 22 |
| WMM14 | Know different kinds of materials available | 9 | 1.514 | 25 |
| WMM15 | Accurate batching of materials | 10 | 1.640 | 26 |
| WMM16 | Weekly task planning | 9 | 1.348 | 23 |
| WMM17 | Efficient method contract administration | 9 | 1.272 | 20 |
| WMM18 | Appropriate handling of concrete | 9 | 1.183 | 17 |
| WMM19 | Followed standardised measurements | 10 | 1.027 | 13 |
| WMM20 | A person should be responsible for waste control | 9 | 1.272 | 20 |
| WMM21 | Scheduling delivery time promptly | 9 | 0.820 | 4 |
| WMM22 | Practice just-in-time procedures | 10 | 0.820 | 3 |
| WMM23 | Appropriate usage of equipment and tools on site | 9 | 0.820 | 4 |
| WMM24 | Promote re-use of constrction waste materials for projects | 9 | 1.027 | 14 |
| WMM25 | Adopt low-waste technology measures | 10 | 0.688 | 1 |
| WMM26 | Recycle some waste materials on site | 9 | 0.751 | 2 |

(Source: Field data, 2022)

### 4.7.4 Summary of modalities employ to manage solid waste on construction sites

The Delphi expert survey reached consensus on all 26 factors of waste management measures employed by contractors to reduce solid waste production and discharge on construction sites in Ghana. The experts believed that the waste management measures will support the implementation of SC to reduce CFand EF of construction activity in GCI. The factors on which consensus was reached were significant and extremely important to warrant the adoption of SC practices. It is important that the stakeholders focus on the modalities that contractors should undertake to decrease the production and discharge of solid waste on construction sites in GCI. The top-ranked modalities on which the contractors should focus to reduce solid waste production and discharge on construction sites include WMM25 (use of low waste technology), WMM26 (recycle of some waste materials on site), WMM22 (practice just-in-time procedures), WMM21 (scheduling delivery time promptly), WMM23 (appropriate usage of tools and equipment on site), WMM2 (using technology that is more efficient), and WMM8 (appropriate storage of materials on site). Table 4.21 shows the summary of modalities that contractors use to decrease the production and discharge of solid waste on construction sites.

**Table 4.20: Summary of modalities contractors employ to manage solid waste in GCI**

| Code | Waste management measures | Rank |
|---|---|---|
| WMM25 | Adopt low waste technology measures | 1 |
| WMM26 | Recycle some waste materials on site | 2 |
| WMM22 | Practice just-in-time procedures | 3 |
| WMM21 | Scheduling delivery time promptly | 4 |
| WMM23 | Appropriate usage of equipment and tools on site | 4 |
| WMM2 | Using technology that is more efficient | 6 |
| WMM8 | Appropriate storage of materials on site | 7 |
| WMM6 | Minimise changes in design | 8 |
| WMM9 | Employ skilled workers | 9 |
| WMM10 | Ensure accurate materials specifications | 9 |
| WMM4 | Adopt effective site management techniques | 11 |
| WMM5 | Ensure effective co-ordination to avoid over-buying | 12 |
| WMM19 | Follow standardised measurements | 13 |
| WMM24 | Promote re-use of construction waste materials for projects | 14 |
| WMM7 | Training of construction workers and employees | 15 |
| WMM1 | Utilise resources before the expire | 16 |
| WMM18 | Appropriate handling of concrete | 17 |
| WMM11 | Ensure materials are provided in the amount and volumes stated | 18 |
| WMM12 | Transform the attitudes of workers towards handling of materials | 19 |
| WMM17 | Efficient method of contract administration | 20 |
| WMM20 | A person should be responsible for waste control | 20 |
| WMM13 | Supervisors should be vigilant | 22 |
| WMM16 | Weekly task planning | 23 |
| WMM3 | Purchase just enough raw components | 24 |
| WMM14 | Know different kinds of materials available | 25 |
| WMM15 | Accurate batching of materials | 26 |

### 4.7.5 Discussion of solid waste management on construction sites

The concept of management of construction waste encompasses: minimising waste where feasible; eliminating waste where possible; and re-using materials which might otherwise become waste to achieve sustainability. Construction waste directly affects a project's productivity, material loss, and finishing time, costing the project a sizable sum of money (Mohammed *et al*., 2020). Construction waste can be hazardous and, therefore, requires appropriate and well-defined policy and technology to manage it. Effective construction waste management would contribute to the attainment of SC. The results in this research indicated that the highest-ranked modalities on which contractors should focus to reduce solid waste production and discharge on construction sites include: WMM25 (use of low waste technology), WMM26 (recycle of some waste materials on site), WMM22 (practice just-in-time procedures), WMM21 (scheduling delivery time promptly), WMM23 (appropriate usage of tools and equipment on site), WMM2 (using technology that is more efficient), and WMM8 (appropriate storage of materials on site). This result is confirmed by Ayarkwa *et al*. (2017) that recycling of construction and demolition waste and low-waste technology support sustainable waste management but are among the measures that are least practised by contractors in Ghana because these actions are perceived as raising rather than lowering their manufacturing costs. However, utilizing materials before their expiration dates, buying just enough raw materials, and using more efficient building tools are all practices that reduce waste GCI. Therefore, contractors should adopt the highest-ranked modalities of this study to reduce solid waste production and discharge on construction sites in Ghana.

## 4.8 CHAPTER SUMMARY

In this chapter, the qualitative data collected from the Delphi were presented. The information collected were examined using SPSS to determine the consensus level of the experts in the three rounds of iterations. The median and standard deviation of the factors were determined and ranked in order of importance. The qualitative data from the Delphi study made it possible to achieve Research Objectives 1, 2, 3, 4, and 5 of the research. The quantitative data gathered from a survey questionnaire were used to strengthen the data. The information received from the survey research are presented in the next chapter.

## CHAPTER FIVE: QUESTIONNAIRE SURVEY RESULTS

### 5.1 INTRODUCTION

The statistical analyses, together with their interpretation, are presented in this chapter. The goal of this study was to advance a roadmap for carbon and ecological footprints reduction to achieve environmental sustainability in GCI. Consequently, the analysis and interpretation covered background information, influence of stakeholders on reduction of carbon and ecological footprints of construction activity, key sustainability issues, SC practices, drivers of SC, challenges of SC, and environmental sustainability criteria. Other issues covered are the benefits of sustainable construction, response of design of structures to sustainability requirement, extent to which construction materials respond to sustainability, effects of energy-efficiency on the construction process, and modalities employed to reduce solid waste production and discharge on construction sites. Lastly, the developed roadmap is examined using a PLS-SEM approach which includes confirmatory composite analysis (i.e. measurement model assessment), structural model results and importance-performance map analysis (IPMA) to develop the SC roadmap. This questionnaire survey results are based on the Delphi results presented in chapter four where the variables on which consensus are reached in the Delphi study are used for the questionnaire survey.

### 5.2 BACKGROUND INFORMATION

In this section, the background information of the analyses is reported. This covers the respondents' profiles and firms' profiles. Tables 5.1 and 5.2 show the findings. As presented in Table 5.1, 39.5% of the respondents were holders of first degrees, 34.8% were HND/diploma holders, 25.4% were Master's Degree holders and 0.2% had Doctorate Degrees. Regarding affiliation to professional bodies, 20.5% of the respondents were affiliated to the Ghana Institution of Surveyors, 13.1% were affiliated to the Ghana Institution of Engineers, and 7.9% were affiliated to the Ghana Institution of Architects. In addition, 2.7% of the respondents were affiliated to the Chartered Institute of Builders and 2% were affiliated to the Ghana Institution of Construction. However, it was apparent that the majority (53.8%) of the respondents were either affiliated to other professional bodies or not affiliated to any professional body.

**Table 5.1: Respondents' profile**

| Profile | Count | Percentage (%) |
|---|---|---|
| **Highest academic qualification** | | |
| HND/diploma | 141 | 34.8 |
| First degree | 160 | 39.5 |
| Master's Degree | 103 | 25.4 |
| Doctorate | 1 | 0.2 |
| **Professional body of affiliation** | | |
| Chartered Institute of Builders | 11 | 2.7 |
| Ghana Institution of Architects | 32 | 7.9 |
| Ghana Institution of Consultants | 8 | 2.0 |
| Ghana Institution of Engineers | 53 | 13.1 |
| Ghana Institution of Surveyors | 83 | 20.5 |
| Others | 218 | 53.8 |
| **Position** | | |
| Architect | 28 | 6.9 |
| Engineer | 31 | 7.7 |
| Managing Director | 12 | 3.0 |
| Owner | 15 | 3.7 |
| Project Manager | 106 | 26.2 |
| Quantity Surveyor | 72 | 17.8 |
| Site Foreman | 135 | 33.3 |
| Others | 6 | 1.5 |
| **Years of experience in the construction industry** | | |
| 0-5 Years | 38 | 9.4 |
| 6-10 Years | 99 | 24.4 |
| 11-15 Years | 112 | 27.7 |
| 16-20 Years | 93 | 23.0 |
| Above 20 Years | 63 | 15.6 |
| **Years of experience in the particular construction company** | | |

| Profile | Count | Percentage (%) |
|---|---|---|
| 0-5 Years | 178 | 44.0 |
| 6-10 Years | 127 | 31.4 |
| 11-15 Years | 88 | 21.7 |
| 16-20 Years | 3 | 0.7 |
| Above 20 Years | 9 | 2.2 |

(Source: Field data, 2022)

In terms of position, 33.3% of the respondents were site foremen, 26.2% were project managers, 17.8% were quantity surveyors, 7.7% were engineers, 6.9% were architects, 3.7% and 3% were owners and managing directors, respectively. It was also evident that most respondents (27.7%) had been working in the building sector for 11 to 15 years, 6 to 10 years (24.4%), 16 to 20 years (23%), above 20 years (15.6%), and 0 to 5 years (9.4%). However, 44% of the respondents had 0 to 5 years' experience with their current construction firm, followed by 6 to 10 years (31.4%), 11 to 15 years (21.7%), above 20 years (2.2%) and the rest (0.7%) had 16 to 20 years' experience with their current construction firm.

**Table 5.2: Respondents' company profile**

| Characteristics | Count | Percentage (%) |
|---|---|---|
| **Company category registered** | | |
| Enterprise | 95 | 23.5 |
| Limited Liability | 259 | 64.0 |
| Partnership | 51 | 12.6 |
| **Company Classification** | | |
| D1K1 | 250 | 61.7 |
| D2K2 | 64 | 15.8 |
| D3K3 | 87 | 21.5 |
| D4K4 | 4 | 1.0 |
| **Nature of business activity** | | |
| General Contractor | 356 | 87.9 |
| Specialist Contractor | 17 | 4.2 |

| Characteristics | Count | Percentage (%) |
|---|---|---|
| Sub-Contractor | 24 | 5.9 |
| Others (Self-Contractor) | 8 | 2.0 |
| **Whether the companies adopt sustainable practices in their construction activities** | | |
| No | 6 | 1.5 |
| Yes | 399 | 98.5 |
| **Awareness of the existence of a sustainable construction roadmap for Ghana that guides the construction activity of companies** | | |
| No | 183 | 45.2 |
| Yes | 222 | 54.8 |
| **If yes, state** | | |
| No response | 319 | 78.8 |
| Environmental Protection Agency | 86 | 21.2 |

(Source: Field data, 2022)

Table 5.2 shows the profile of the firms. Three types of construction companies participated in the study, with most being limited liability firms (64%), 23.5% were enterprises and 12.6% were partnership firms. Furthermore, firms most (61.7%) fell within D1K1 company classification. The rest were D2K2 (15.8%), D3K3 (21.5%) and D4K4 (1%). Regarding the nature of business, 87.9% of the firms were involved in general construction, 4.2% in specialist construction, 5.9% were sub-contractors and 2% were involved in other forms of construction, including self-contractors.

The results also revealed that 98.5% of the firms adopted sustainable practices, such as green house or building practices, sustainable building practices, use of sustainable materials and water conservation in their construction activities. Moreover, not all the firms were aware of the availability of a SC roadmap for Ghana that guides the construction activities of companies. Specifically, 54.8% of the firms were aware, while 45.2% were not cognisant of the availability of a SC roadmap for Ghana that guides the construction activities of companies. Lastly, a follow-up question revealed that 21.2% of firms indicated the Environmental Protection Agency (EPA) as being the body in Ghana that provides a sustainable construction roadmap that guides the construction activities of companies.

## 5.3 PERCEPTION OF REDUCTION OF CARBON AND ECOLOGICAL FOOTPRINTS

In this section, the respondents' perceptions of the influence of stakeholders to reduce CF and EF of building activity are examined. The findings are presented in Table 5.3. The findings in Table 5.3 indicated that the respondents recognised several stakeholders that influence the decrease of CF and EF of building projects. Among the stakeholders, media (*M* = 4.34; *SD* = 0.655), Environmental Protection Agency (*M* = 4.30; *SD* = 0.790) and contractors (*M* = 4.20; *SD* = 0.756) emerged as the top-three stakeholders influencing the decrease in CF and EF of building projects. These were followed by green building councils (*M* = 4.16; *SD* = 0.729), government (*M* = 4.13; *SD* = 0.833), academia (*M* = 4.10; *SD* = 0.664), clients or developers (*M* = 3.98; *SD* = 0.831) and consultants (*M* = 3.90; *SD* = 0.850).

**Table 5.3: Influence of stakeholders on reduction of CF and EF of building projects**

| Stakeholder | Mean | Std Deviation |
|---|---|---|
| Media | 4.34 | 0.655 |
| Environmental Protection Agency | 4.30 | 0.790 |
| Contractor | 4.20 | 0.756 |
| Green Building Council | 4.16 | 0.729 |
| Government | 4.13 | 0.833 |
| Academia | 4.10 | 0.664 |
| Client/Developer | 3.98 | 0.831 |
| Consultant | 3.90 | 0.850 |

(Source: Field data, 2022)

## 5.4 PERCEPTION OF KEY SUSTAINABILITY ISSUES

In this section, the key sustainability issues are analysed. The respondents evaluated ten issues that were identified in the literature study. The findings are presented in Table 5.4 and show the respondents' perceptions of the 10 key sustainability issues. According to the results, waste (*M* = 4.34; *SD* = 0.655), pollution and nuisance (*M* = 4.30; *SD* = 0.790), energy use (*M* = 4.20; *SD* = 0.756), material use (*M* = 4.16; *SD* = 0.729) and land use (*M* = 4.13; *SD* = 0.833) were the top-five sustainability issues. Climate change (*M* = 4.10; *SD* = 0.664), bio-diversity (*M* = 4.01; *SD* =

0.867), water use (*M* = 4.01; *SD* = 0.793), drainage and flooding (*M* = 3.98; *SD* = 0.931), and health, safety and well-being (*M* = 3.90; *SD* = 0.850) seemed to be the five sustainability issues with lowest priority.

**Table 5.4: Key sustainability issues**

| Key sustainability issues | Mean | Std Deviation |
|---|---|---|
| 1. Waste | 4.34 | 0.655 |
| 2. Pollution and nuisance | 4.30 | 0.790 |
| 3. Energy use | 4.20 | 0.756 |
| 4. Material use | 4.16 | 0.729 |
| 5. Land use | 4.13 | 0.833 |
| 6. Climate change | 4.10 | 0.664 |
| 7. Bio-diversity | 4.01 | 0.867 |
| 8. Water use | 4.01 | 0.793 |
| 9. Drainage and flooding | 3.98 | 0.831 |
| 10. Health, safety and well-being | 3.90 | 0.850 |

(Source: Field data, 2022)

## 5.5 SUSTAINABLE CONSTRUCTION PRACTICES

Table 5.5 shows the 10 sustainable construction practices or activities that were examined. The findings in Table 5.5 indicated that the participants generally had positive perceptions (mean ranging from 3.67 to 4.04) of the sustainable construction practices or activities. Specifically, the top-five SC practices are minimisation of carbon emissions in construction (*M* = 4.04; *SD* = 0.775), use of forestry-authority–certified timber (*M* = 3.97; *SD* = 0.757), regenerating used natural vegetation (*M* = 3.91; *SD* = 0.879), recycling construction waste (*M* = 3.89; *SD* = 0.725), and minimization of dust during construction (*M* = 3.89; *SD* = 0.725). The other sustainable construction practices the construction firms engaged in are use of renewable construction material (*M* = 3.88; *SD* = 0.797), ensuring efficiency in water usage during construction (*M* = 3.79; *SD* = 0.792), doing selective construction waste disposal (*M* = 3.75; *SD* = 0.763), reducing distance of transportation of people (*M* = 3.67; *SD* = 0.931), and ensuring efficiency in energy usage for construction works (*M* = 3.67; *SD* = 0.879).

**Table 5.5: Sustainable construction practices**

| Practice | Mean | Std Deviation |
|---|---|---|
| 1. Minimise carbon emissions in construction | 4.04 | 0.775 |
| 2. Use of forestry-authority–certified timber | 3.97 | 0.757 |
| 3. Regenerate used natural vegetation | 3.91 | 0.879 |
| 4. Recycle construction waste | 3.89 | 0.725 |
| 5. Minimise dust during construction | 3.89 | 0.725 |
| 6. Use renewable construction material | 3.88 | 0.797 |
| 7. Ensure efficiency in water usage during construction | 3.79 | 0.792 |
| 8. Do selective construction waste disposal | 3.75 | 0.763 |
| 9. Reduce distance of transportation of people | 3.67 | 0.931 |
| 10. Ensure efficiency in energy usage for construction works | 3.67 | 0.879 |

(Source: Field data, 2022)

## 5.6 DRIVERS OF SUSTAINABLE CONSTRUCTION

Table 5.6 shows the perceptions related to the drivers of SC. The respondents evaluated nineteen (19) SC drivers that were identified from the literature study. The results in Table 5.6 suggested that most respondents had positive perceptions of all the drivers of sustainable construction. Availability of a measurement tool (M = 4.10; SD = 0.901), co-operation from technical experts (M = 4.10; SD = 0.767), sustainable building codes and regulations (M = 4.07; SD = 0.687), creation of public awareness (M = 4.04; SD = 0.773), and moral obligation to protect the environment (M = 4.00; SD = 0.958) were observed as being the major drivers of sustainable construction. However, the minor drivers were client demand and requirements (M = 3.77; SD = 0.765), availability of life-cycle cost analysis (M = 3.77; SD = 0.931), stakeholder influence (M = 3.76; SD = 0.766), legislation (M = 3.69; SD = 0.704), willingness to incorporate sustainable building practices (M = 3.66; SD = 0.929), and competitive advantage (M = 3.66; SD = 0.880).

**Table 5.6: Drivers of sustainable construction**

| Driver | Mean | Std Deviation |
|---|---|---|
| 1. Availability of a measurement tool | 4.10 | 0.901 |
| 2. Co-operation from technical experts | 4.10 | 0.767 |
| 3. Sustainable building codes and regulations | 4.07 | 0.687 |
| 4. Creation of public awareness | 4.04 | 0.773 |
| 5. Moral obligation to protect the environment | 4.00 | 0.958 |
| 6. Availability of acceptable sustainable construction roadmap | 3.97 | 0.754 |
| 7. Professional knowledge in sustainable construction | 3.91 | 0.879 |
| 8. Sustainability practices in educational curricula | 3.90 | 0.930 |
| 9. Cost efficiency | 3.90 | 0.726 |
| 10. Sustainable design guidelines and construction standards | 3.87 | 0.797 |
| 11. Government commitment and support | 3.86 | 0.866 |
| 12. Economic incentives (tax rebates, high profit margin) | 3.82 | 0.772 |
| 13. Top management commitment | 3.79 | 0.784 |
| 14. Client demand and requirements | 3.77 | 0.765 |
| 15. Availability of life-cycle cost analysis | 3.77 | 0.831 |
| 16. Stakeholder influence | 3.76 | 0.766 |
| 17. Legislation | 3.69 | 0.704 |
| 18. Willingness to incorporate sustainable building practices | 3.66 | 0.929 |
| 19. Competitive advantage | 3.66 | 0.880 |

(Source: Field data, 2022)

## 5.7 CHALLENGES OF SUSTAINABLE CONSTRUCTION

Table 5.7 contains a summary of the respondents' views of 12 challenges of SC that were identified from the literature review. The findings are shown in Table 5.7 and it is evident that most respondents agreed with the 12 challenges of SC. Comparatively, lack of public awareness (*M* = 4.22; *SD* = 0.536), lack of research (*M* = 4.20; *SD* = 0.701), high cost of environmental services (*M* = 4.07; *SD* = 0.707), lack of financial incentives (*M* = 3.98; *SD* = 0.844), and lack of building codes and regulations (*M* = 3.91; *SD* = 0.913) were the five major challenges of SC. However, the five least challenging aspects were competitive pressure (*M* = 3.74; *SD* = 0.899), lack of professional knowledge and expertise (*M* = 3.70; *SD* = 0.801), lack of green products (*M* = 3.53; *SD* = 1.098), lack of green technology (*M* = 3.48; *SD* = 1.035), and lack of client demand (*M* = 3.24; *SD* = 1.096).

**Table 5.7: Challenges of sustainable construction**

| Challenge | Mean | Std Deviation |
|---|---|---|
| 1. Lack of public awareness | 4.22 | 0.536 |
| 2. Lack of research | 4.20 | 0.701 |
| 3. High cost of environmental services | 4.07 | 0.707 |
| 4. Lack of financial incentives | 3.98 | 0.844 |
| 5. Lack of building codes and regulations | 3.91 | 0.913 |
| 6. Lack of investment | 3.88 | 0.859 |
| 7. Initial investment cost | 3.88 | 0.802 |
| 8. Competitive pressure | 3.74 | 0.899 |
| 9. Lack of professional knowledge and expertise | 3.70 | 0.801 |
| 10. Lack of green products | 3.53 | 1.098 |
| 11. Lack of green technology | 3.48 | 1.035 |
| 12. Lack of client demand | 3.24 | 1.096 |

(Source: Field data, 2022)

## 5.8 ENVIRONMENTAL SUSTAINABILITY CRITERIA

Table 5.8 shows the opinions of the participants on a set of environmental sustainability criteria that were described in the literature. The table shows that most respondents agreed to the 15 environmental sustainability criteria. The results suggested that the top-five environmental sustainability criteria are re-use of existing built assets (M = 4.02; SD = 0.734), environmental impact (process and product) (M = 4.01; SD = 0.826), energy conservation (M = 3.95; SD = 0.580), waste minimisation and management (M = 3.94; SD = 0.734), and water conservation (M = 3.90; SD = 0.674). When compared with the other criteria, minimising pollution (M = 3.73; SD = 0.961), resource utilisation (M = 3.71; SD = 0.760), creating a non-toxic, healthy environment (M = 3.68;

SD = 1.053), materials conservation – re-use and recycling (M = 3.58; SD = 0.916), and visual impact (M = 3.50; SD = 1.043) revealed the five least important environmental sustainability criteria.

**Table 5.8: Environmental sustainability criteria**

| Criteria | Mean | Std Deviation |
|---|---|---|
| 1. Re-use existing built assets | 4.02 | 0.734 |
| 2. Environmental impact (process and product) | 4.01 | 0.826 |
| 3. Energy conservation | 3.95 | 0.580 |
| 4. Waste minimisation and management | 3.94 | 0.734 |
| 5. Water conservation | 3.90 | 0.674 |
| 6. Transport – including provision of public transport | 3.88 | 0.725 |
| 7. Land conservation | 3.87 | 0.538 |
| 8. Protect and enhance sensitive landscapes – cultural and historic sites | 3.83 | 0.868 |
| 9. Preserve and enhance bio-diversity | 3.79 | 0.900 |
| 10. Consideration of renewable energy | 3.76 | 0.872 |
| 11. Minimise pollution | 3.73 | 0.961 |
| 12. Resource utilisation | 3.71 | 0.760 |
| 13. Create a non-toxic, healthy environment | 3.68 | 1.053 |
| 14. Materials conservation – re-use and recycling | 3.58 | 0.916 |
| 15. Visual impact | 3.50 | 1.043 |

(Source: Field data, 2022)

## 5.9 BENEFITS OF SUSTAINABLE CONSTRUCTION

The assessments of the benefits of SC by the respondents are shown in Table 5.9. Generally, the results in Table 5.9 suggested positive perceptions of the social, environmental, and economic importance of SC. The top-four environmental important aspects of SC were prevention of global warming (M = 4.19; SD = 0.585), maintenance of integrity of environment (M = 4.14; SD = 0.648), usage of renewable natural resources (M = 4.07; SD = 0.653), and minimisation of $CO_2$ emission and pollutants (M = 4.07; SD = 0.735). For the top-four social benefits, the respondents believed SC improves health, comfort and well-being (M = 4.33; SD = 0.587), promotes harmony among people and between humanity and nature (M = 4.26; SD = 0.569), improves quality of life for all

(M = 4.13; SD = 0.597), and satisfies human needs (M = 4.04; SD = 0.573). Economically, the top-four benefits of SC were improving economic growth (M = 4.37; SD = 0.601), decreasing environmental damage costs (M = 4.17; SD = 0.774), reducing energy consumption and costs (M = 4.10; SD = 0.544), and improving productivity (M = 4.09; SD = 0.896). Collectively, it was evident that sustainable construction provides benefits that are of environmental, social and economic importance.

**Table 5.9: Benefits of sustainable construction**

| **Benefit** | **Mean** | **Std Deviation** |
|---|---|---|
| **Environmental** | | |
| 1. Prevent global warming | 4.19 | 0.585 |
| 2. Maintain integrity of environment | 4.14 | 0.648 |
| 3. Use renewable natural resources | 4.07 | 0.653 |
| 4. Minimise $CO_2$ emission and pollutants | 4.07 | 0.735 |
| 5. Conserve natural resources (e.g. fossil fuel) | 4.05 | 0.741 |
| 6. Preserve animal species and genetic diversity | 4.04 | 0.653 |
| 7. Minimise waste production or disposal | 4.01 | 0.805 |
| 8. Maintain essential ecological processes and life support systems | 3.98 | 0.645 |
| 9. Protect air, water, land and ecosystems | 3.97 | 0.915 |
| 10. Pursue active recycling | 3.96 | 0.859 |
| 11. Protect the biosphere | 3.93 | 0.906 |
| **Social** | | |
| 1. Improve health, comfort and well-being | 4.33 | 0.587 |
| 2. Promote harmony among people and between humanity and nature | 4.26 | 0.569 |
| 3. Improve quality of life for all | 4.13 | 0.597 |
| 4. Satisfy human needs | 4.04 | 0.573 |
| 5. Optimise social benefits | 3.97 | 0.631 |
| 6. Alleviate poverty | 3.87 | 0.834 |
| **Economic** | | |
| 1. Improve economic growth | 4.37 | 0.601 |

| Benefit | Mean | Std Deviation |
|---|---|---|
| 2. Decrease environmental damage costs | 4.17 | 0.774 |
| 3. Reduce energy consumption and costs | 4.10 | 0.844 |
| 4. Improve productivity | 4.09 | 0.896 |
| 5. Reduce water consumption and costs | 4.03 | 0.680 |
| 6. Decrease health costs | 4.02 | 0.817 |
| 7. Raise real income | 4.01 | 0.780 |
| 8. Reduce infrastructure costs | 3.97 | 0.670 |
| 9. Improve return on investments (ROI) | 3.97 | 1.032 |

(Source: Field data, 2022)

## 5.10 PERCEPTIONS OF SUSTAINABILITY REQUIREMENTS BY DESIGNERS

How design contribute to the sustainability of construction activities is assessed in this section. The findings in Table 5.10 indicated that the construction firms contribute to the sustainability of construction activities through design of buildings by land conservation (*M* = 4.18; *SD* = 0.745), reduction of consumption of dangerous materials (*M* = 3.99; *SD* = 0.698), and recycling of waste and return (*M* = 3.95; *SD* = 0.844). Other environmentally sustainable design components were reduction of water consumption (*M* = 3.87; *SD* = 0.842), reduction of raw materials consumption (*M* = 3.81; *SD* = 0.704), and reduction of energy consumption (*M* = 3.79; *SD* = 1.031). Furthermore, the construction firms considered, in order, cost efficiency (*M* = 4.15; *SD* = 0.904), life-cycle design (*M* = 4.04; *SD* = 0.983), resources conservation (*M* = 3.97; *SD* = 0.777), and humane adaptation (*M* = 3.84; *SD* = 1.093) as being environmentally sustainable design requirements.

**Table 5.10: How design contribute to sustainability of construction activities**

| Factors | Mean | Std Deviation |
|---|---|---|
| **Environmentally sustainable design component** | | |
| 1. Land conservation | 4.18 | 0.745 |
| 2. Reduction of consumption of dangerous materials | 3.99 | 0.698 |

| Factors | Mean | Std Deviation |
|---|---|---|
| 3. Recycling of waste and return | 3.95 | 0.844 |
| 4. Reduction of water consumption | 3.87 | 0.842 |
| 5. Reduction of raw materials consumption | 3.81 | 0.704 |
| 6. Reduction of energy consumption | 3.79 | 1.031 |
| **Environmentally sustainable design requirements** | | |
| 1. Cost efficiency | 4.15 | 0.904 |
| 2. Life-cycle design | 4.04 | 0.983 |
| 3. Resources conservation | 3.97 | 0.777 |
| 4. Humane adaptation | 3.84 | 1.093 |

(Source: Field data, 2022)

### 5.11 PERCEPTIONS OF CONSTRUCTION MATERIALS TO SUSTAINABILITY

Table 5.11 shows the respondents' assessment of selection criteria for material and measures of material incorporation in construction process. The participants agreed with the selection criteria for low-impact material. The results suggested further that the top-five environmental sustainability criteria are: embodied energy of the material (M = 4.38; SD = 0.674), re-usable/renewable potential of the material (M = 4.38; SD = 0.689), performance of the material (M = 4.12; SD = 0.625), cost of the material (M = 4.06; SD = 0.648), and ecological impact of the material (M = 4.05; SD = 0.741).

Regarding the measures of low-impact material incorporation adopted by the construction firms, usage of materials that are durable and can easily be maintained (M = 4.32; SD = 0.657) emerged as the topmost measure. This was followed by materials of minimum adverse impact on the environment (M = 4.24; SD = 0.772), and materials used are renewable, recyclable, or re-usable (M = 4.24; SD = 0.693). The other measures, in order, were the adoption of permeable materials to permit storm water to get into the ground (M = 4.13; SD = 0.746), application of materials with organic origin (M = 4.01; SD = 0.771), and including water efficient trees, rain gardens, and green roofs, (M = 3.85; SD = 0.859). These results suggested a high extent of incorporation of low-impact building materials by contractors in their construction processes.

**Table 5.11: Selection criteria and incorporation of low-impact building materials**

| Statements | Mean | Std Deviation |
|---|---|---|
| **Low-impact material selection criteria** | | |
| 1. Embodied energy of the material | 4.38 | 0.674 |
| 2. Re-usable/renewable potential of the material | 4.38 | 0.689 |
| 3. Performance of the material | 4.12 | 0.625 |
| 4. Cost of the material | 4.06 | 0.648 |
| 5. Ecological impact of the material | 4.05 | 0.741 |
| 6. Durability of the material | 3.88 | 0.744 |
| 7. Social impact of the material | 3.82 | 0.570 |
| 8. Aesthetic quality of the material | 3.79 | 0.788 |
| **Low-impact material incorporation measures** | | |
| 1. Adopt durable materials that can easily be maintained | 4.32 | 0.657 |
| 2. Materials of minimum adverse impact on the environment | 4.24 | 0.772 |
| 3. Materials used are renewable, recyclable, or re-usable | 4.24 | 0.693 |
| 4. Adoption of permeable materials to permit storm water to get into the ground | 4.13 | 0.746 |
| 5. Apply materials with organic origin | 4.01 | 0.771 |
| 6. Include water-efficient trees, rain gardens, and green roofs | 3.85 | 0.859 |

(Source: Field data, 2022)

## 5.12 PERCEPTIONS OF ENERGY EFFICIENCY

The opinions of the respondents on the effects of energy-efficient equipment on the construction process are presented in this section. As shown in Table 5.12, use of energy-efficient equipment results in the upgrade/replacement of equipment with energy-saving devices (M = 4.21; SD = 0.824) and improved productivity and increased value (M = 4.20; SD = 0.756). In addition, the use of energy-efficient equipment was believed to minimise energy consumption (M = 4.17; SD = 0.619), and reduce fuel usage (M = 4.08; SD = 0.668). Other effects of the use of energy-efficient equipment were to reduce emission levels and protect the environment (M = 3.97; SD = 0.760) as well as the reduction in energy cost (M = 3.96; SD = 0.914).

**Table 5.12: Effects of energy-efficient equipment utilisation**

| Effect | Mean | Std Deviation |
|---|---|---|
| 1. Upgrade/replace equipment with energy-saving devices | 4.21 | 0.824 |
| 2. Improve productivity and increase value | 4.20 | 0.756 |
| 3. Minimise energy consumption | 4.17 | 0.619 |
| 4. Reduce fuel usage | 4.08 | 0.668 |
| 5. Reduce emission levels and protect the environment | 3.97 | 0.760 |
| 6. Reduction in energy cost | 3.96 | 0.914 |

(Source: Field data, 2022)

## 5.13 MANAGEMENT OF SOLID WASTE ON CONSTRUCTION SITES

Table 5.13 shows the modalities employed by contractors to reduce solid waste production and discharge on construction sites. Table 5.13 shows that most respondents agreed with the waste management measures. The results suggested that the top-five waste management measures employed by the construction firms are: ensuring effective co-ordination to prevent over-buying (M = 4.26; SD = 0.679), appropriate storage of materials on site (M = 4.22; SD = 0.714), use of low-waste technology (M = 4.22; SD = 0.730), employing skilled workers (M = 4.16; SD = 0.792), and ensuring accurate specifications of materials to avoid incorrect ordering (M = 4.15; SD = 0.726). Compared with the other waste management measures, effective construction management practices (M = 4.01; SD = 0.854), minimising design changes (M = 4.00; SD = 0.907), recycling some waste materials on site (M = 3.99; SD = 0.787), adherence to standardised dimensions (M = 3.96; SD = 0.837), and early and prompt scheduling of deliveries (M = 3.85; SD = 0.865) were the five waste management measures least employed. This suggested that the construction firms employ a variety of modalities to reduce solid waste production and discharge on construction sites.

**Table 5.13: Waste management measures**

| Measure | Mean | Std Deviation |
|---|---|---|
| 1. Ensure effective co-ordination to prevent over-buying | 4.26 | 0.679 |
| 2. Appropriate storage of materials on site | 4.22 | 0.714 |
| 3. Use low-waste technology | 4.22 | 0.730 |
| 4. Employ skilled workers | 4.16 | 0.792 |
| 5. Ensure accurate materials specifications | 4.15 | 0.726 |
| 6. Promote re-use of construction waste materials for projects | 4.14 | 0.859 |
| 7. Purchase just enough raw components | 4.13 | 0.589 |
| 8. Change the attitudes of workers towards handling of materials | 4.13 | 0.770 |
| 9. Adopt effective site management techniques | 4.12 | 0.691 |
| 10. A person should be responsible for waste control | 4.12 | 0.753 |
| 11. Use of more efficient equipment | 4.11 | 0.605 |
| 12. Know different kinds of materials available | 4.10 | 0.743 |
| 13. Weekly programming of works | 4.09 | 0.818 |
| 14. Appropriate mixing, transportation and placing of concrete | 4.07 | 0.674 |
| 15. Practice just-in-time operations | 4.07 | 0.849 |
| 16. Ensure that materials are provided in the amount and volumes stated | 4.06 | 0.748 |
| 17. Training for construction workers and employees | 4.05 | 0.791 |
| 18. Accurate batching of materials | 4.05 | 0.853 |
| 19. Supervisors should be vigilant | 4.04 | 0.859 |
| 20. Appropriate usage of equipment and tools on site | 4.04 | 0.762 |
| 21. Use materials before expiry dates | 4.02 | 0.698 |
| 22. Effective construction management practices | 4.01 | 0.854 |
| 23. Minimise design changes | 4.00 | 0.907 |
| 24. Recycle some waste materials on site | 3.99 | 0.787 |
| 25. Adherence to standardised dimensions | 3.96 | 0.837 |
| 26. Early and prompt scheduling of deliveries | 3.85 | 0.865 |

(Source: Field data, 2022)

## 5.14 CHAPTER SUMMARY

In this chapter, the findings of the survey were presented with the goal of creating a roadmap for SC in GCI to lower carbon and ecological footprints. Overall, 405 valid responses were received, representing a 50.63% response rate. Using means, standard deviations, frequencies, and percentages, the survey results were analysed. The chapter included a summary of the interviewees' backgrounds and personal characteristics. The outcomes and conclusions of the research and those of the literature review showed a strong correlation.

# CHAPTER SIX: ROADMAP DEVELOPMENT AND TESTING

## 6.1 INTRODUCTION

The development of a roadmap to reduce carbon and ecological footprints based on this study is described in this chapter. The summary of the findings gathered to validate the roadmap is included. The secondary and primary data were used to design the roadmap to reduce carbon and ecological footprints. The roadmap developed was evaluated through a survey given to construction professionals who were specialists in SC and belonged to a relevant professional body in the built environment in order to meet the sixth Research Objective of this study.

## 6.2 BASIS OF THE ROADMAP DEVELOPMENT

A conceptual framework is arranged in a logical structure to explain the main concepts and how the variables relate to each other (Grant & Osanloo, 2014). According to Berman (2013), a conceptual framework offers a model for interactions among variables that might or might not reflect a particular theoretical perspective. A conceptual framework directs and unifies actual research (Yamauchi *et al*., 2017). The framework aids the researcher in identifying and defining the concepts contained in the research issue as well as outlining the approach that will be taken to solving it. According to Ravitch and Riggan (2017), the construction of conceptual framework starts with the research interest and a knowledge gap or the research problem of the study. The framework created for this research had the following primary goals:

1. To recognise the problems of the study by outlining the factors causing carbon and ecological footprints in construction activities;
2. To highlight the key elements of reducing carbon and ecological footprints and how they would lead to SC; and
3. To provide a roadmap to GCI on how lowering the ecological and carbon footprints of construction operations would contribute to achieving SC.

## 6.3 RESEARCH FRAMEWORK AND HYPOTHESES

The hypotheses and the research framework for lowering ecological and carbon footprints for SC are presented below.

### 6.3.1 The research framework for the study

Darko *et al.* (2018) investigated the SC drivers, challenges, promotion strategies, enablers, benefits, and highlighted key impacts that were determinants of SC adoption process which were also adopted in this research. The integration of these theories and frameworks led to the cnstruction of a conceptual framework to reduce carbon and ecological footprints to enhance adoption of SC. The strategies to reduce carbon and ecological footprints, such as energy efficiency, resources conservation, and waste management would positively influence construction practices to ensure environmental sustainability, which would be motivated by benefits and knowledge/awareness to drive the adoption of SC. The literature and this relationship were used to develop the study hypotheses.

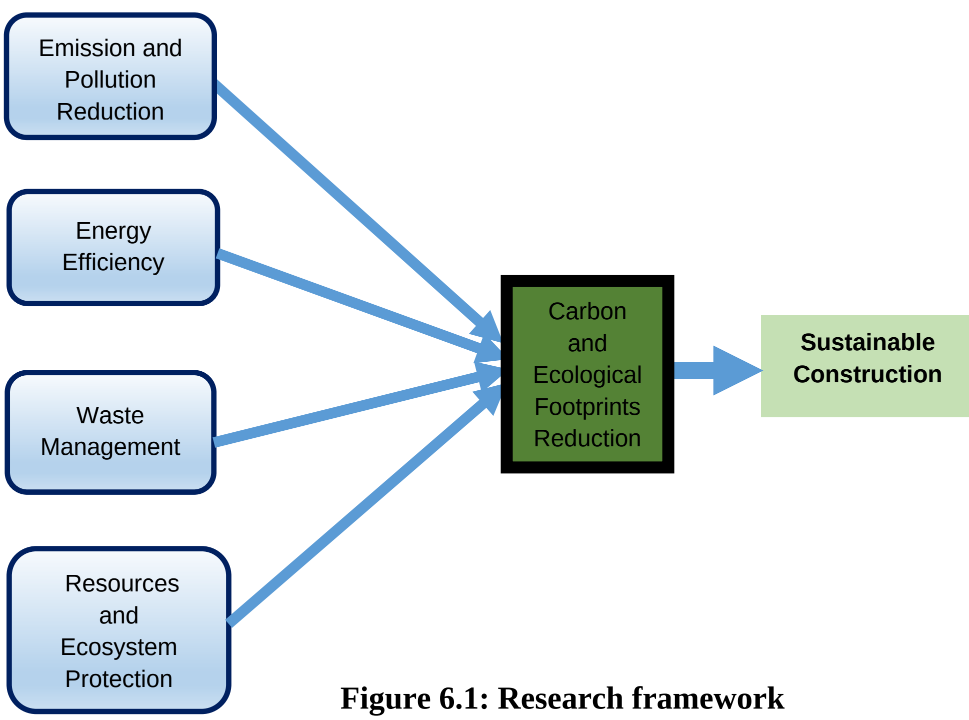


**Figure 6.1: Research framework**

### 6.3.2 The development of hypotheses

It is crucial to create hypotheses to ascertain how the factors affect SC in order to minimize the GCI's ecological and carbon footprints. The conclusions from the literature survey discussed in Chapter Two, the hypothetical framework presented in Figure 6.1, and the conclusions from Chapter Five guided the formulation of the hypotheses in this study. The hypotheses are given in Table 6.1, followed by the different constructs for every variables and their corresponding measurement for the empirical test of the study.

**Table 6.1: Constructs and their measurement variables**

| Construct | Code | Measurement items |
|---|---|---|
| Reduction of Emission/Pollution | ER1 | Restriction of energy utilisation |
| | ER2 | Impact assessment of construction process |
| | ER3 | Construction material production and discharge |
| | ER4 | Adopting low-carbon equipment and technology |
| | ER5 | Adhering to construction standards/policies |
| | ER6 | Limited transportation of material and personnel |
| Energy Efficiency | EEM1 | Provision of efficient lighting controls and fixtures |
| | EEM2 | Usage of photocells and automatic presence sensors |
| | EEM3 | Use of energy-efficient lighting systems |
| | EEM4 | Adequate provision of naturally occuring day-lighting devices |
| | EEM5 | Sufficient shading from extreme heat |
| | EEM6 | Usage of less emission glazing |
| | EEM7 | Solar energy usage for exterior illumination |
| | EEM8 | Usage of materials with low embodied energy |
| | EEM9 | Avoid using Ozone Depleting gas air-conditioning system |
| | EEM10 | Reduce carbon substances |
| | EEM11 | Prioritised renewable energy usage |
| | EEM12 | Use individual metering for separate tenants |
| | EEM13 | Avoid sun-lit glazing to lessen cooling load of AC |
| | EEM14 | Divide the areas to accommodate energy-efficient AC |

| Construct | Code | Measurement items |
|---|---|---|
| Waste Management | WMM1 | Utilize resources before they expire |
| | WMM2 | Using technology that is more efficient |
| | WMM3 | Purchase just enough raw components |
| | WMM4 | Adopt effective site management techniques |
| | WMM5 | Ensure effective co-ordination to avoid over-buying |
| | WMM6 | Minimise changes in design |
| | WMM7 | Training for construction workers and employees |
| | WMM8 | Appropriate storage of materials on site |
| | WMM9 | Employ skilled workers |
| | WMM10 | Ensure accurate material specifications |
| | WMM11 | Ensure materials are provided in the amounts and volumes stated. |
| | WMM12 | Transform the attitudes of workers towards handling of materials |
| | WMM13 | Supervisors should be vigilant |
| | WMM14 | Know different kinds of materials available |
| | WMM15 | Accurate batching of materials |
| | WMM16 | Weekly task planning |
| | WMM17 | Efficient methid of constract administration |
| | WMM18 | Appropriate handling of concrete |
| | WMM19 | Follow standardised measurements |
| | WMM20 | A person should be responsible for waste control |
| | WMM21 | Scheduling delivery time promptly |
| Protection of Resources and Eco-System | PRES1 | Effective land utilisation |
| | PRES2 | Consideration of selected materials |
| | PRES3 | Waste reduction |
| | PRES4 | Energy efficiency |
| | PRES5 | Water conservation |
| | PRES6 | Management of pollution |

| Construct | Code | Measurement items |
|---|---|---|
| | PRES7 | Preservation of bio-diversity |
| | PRES8 | Preservation of amenities and heritage |
| Reduction of Carbon and Ecological Footprints | RCEF1 | Use of materials from renewable sources |
| | RCEF2 | Use bio-degradable materials |
| | RCEF3 | Reduction in air, land and water pollution |
| | RCEF4 | Reduction in materials and water usage |
| | RCEF5 | Aids energy efficiency |
| | RCEF6 | Use locally available materials |
| | RCEF7 | Waste minimisation and re-use of waste products |
| | RCEF8 | Rethink (innovation) sustainable practices |
| | RCEF9 | Energy conservation |
| | RCEF10 | Reduce transportation |
| | RCEF11 | Embodied energy |
| Sustainable construction | SCA1 | Regenerate used natural vegetation |
| | SCA2 | Use renewable construction material |
| | SCA3 | Reduce distance of transportation of people |
| | SCA4 | Use of forestry-authority–certified timber |
| | SCA5 | Minimise carbon emissions in construction |
| | SCA6 | Do selective disposal of construction waste |
| | SCA7 | Recycle construction waste |
| | SCA8 | Ensure efficiency in energy usage for construction works |
| | SCA9 | Ensure efficiency in water usage during construction |
| | SCA10 | Minimise dust during construction |
| | SCA11 | Optimise site planning, building orientation, and configuration |
| | SCA12 | Reduction in the use of resources |
| | SCA13 | Maximising the use of resources |
| | SCA14 | Safeguard the earth |
| | SCA15 | Establish a safe and clean atmosphere |

| Construct | Code | Measurement items |
|---|---|---|
| Sustainable construction | SCA16 | Strivr for excellence when creating the built world |
| | SCA17 | Consider life-cycle costing |

The following hypotheses were made based on the literature study and the research framework in Figure 6.1:

H1: Reduction of emissions and pollution has positive effect on carbon and ecological footprint reduction.

H2: Energy efficiency has a positive influence on carbon and ecological footprint reduction.

H3: Waste management has a positive influence on carbon and ecological footprint reduction.

H4: Protection of resources and eco-system has a positive effect on carbon and ecological footprint reduction.

H5: Reduction of carbon and ecological footprints has a positive influence on the achievement of sustainable construction.

The above hypotheses were tested empirically and the research framework to lessen GCI's ecological and carbon footprints was created using the important findings.

### 6.4 PLS-SEM RESULTS ANALYSIS

The proposed model was tested using a PLS-SEM approach. This was because of the exploratory and predictive nature of the study (Hair *et al*., 2019; Hair Jr., 2021; Ramayah *et al*., 2018). Using Smart PLS 4, the analysis involved measurement model assessment, also known as confirmatory composite analysis, which addresses the reliability and validity of latent variables, and the assessment of the structural model (Hair *et al*., 2019; Hair Jr., 2021; Ringle *et al*., 2020). Subsequently, the structural model was examined using importance-performance map analysis (IPMA) for policy decision directions (Hair *et al*., 2019; Henseler *et al*., 2015; Ringle & Sarstedt, 2016).

### 6.4.1 Confirmatory composite analysis (measurement model assessment)

This stage of the PLS-SEM approach, known as the measurement model assessment or confirmatory composite analysis, addresses the validity and reliability assessment measures (Hair *et al*., 2019; Henseler *et al*., 2015). The loadings, convergent validity, and reliability are recorded in Table 6.2. The discriminant validity, assessed using both the Fornell-Larcker and Heterotrait-Monotrait ratio, is presented in Table 6.2 and Table 6.3, respectively.

**Table 6.2: Loadings, construct reliability and convergent validity**

| **Items** | **Loadings** | ***t*-statistics** | ***p*-values** | **Cronbach's alpha** | **Composite reliability (rho_c)** | **AVE** |
|---|---|---|---|---|---|---|
| **Energy Efficiency (EEM)** | | | | **0.898** | **0.916** | **0.522** |
| EEM1 | 0.705 | 26.396 | 0.000 | | | |
| EEM2 | 0.782 | 33.345 | 0.000 | | | |
| EEM3 | 0.802 | 45.464 | 0.000 | | | |
| EEM4 | 0.763 | 29.525 | 0.000 | | | |
| EEM5 | 0.685 | 16.348 | 0.000 | | | |
| EEM6 | 0.737 | 25.875 | 0.000 | | | |
| EEM7 | 0.626 | 14.823 | 0.000 | | | |
| EEM8 | 0.694 | 22.285 | 0.000 | | | |
| EEM11 | 0.767 | 35.772 | 0.000 | | | |
| EEM14 | 0.640 | 19.531 | 0.000 | | | |
| **Reduction of Emission/Pollution (ER)** | | | | **0.804** | **0.859** | **0.508** |
| ER1 | 0.565 | 8.086 | 0.000 | | | |
| ER2 | 0.655 | 12.022 | 0.000 | | | |
| ER3 | 0.864 | 66.445 | 0.000 | | | |
| ER4 | 0.697 | 22.520 | 0.000 | | | |
| ER5 | 0.646 | 14.405 | 0.000 | | | |
| ER6 | 0.807 | 42.488 | 0.000 | | | |
| **Protection of Resources and Eco-System (PRES)** | | | | **0.854** | **0.883** | **0.562** |

| **Items** | **Loadings** | ***t*-statistics** | ***p*-values** | **Cronbach's alpha** | **Composite reliability (rho_c)** | **AVE** |
|---|---|---|---|---|---|---|
| PRES1 | 0.628 | 11.545 | 0.000 | | | |
| PRES2 | 0.837 | 29.390 | 0.000 | | | |
| PRES3 | 0.818 | 35.345 | 0.000 | | | |
| PRES4 | 0.650 | 12.357 | 0.000 | | | |
| PRES5 | 0.667 | 12.246 | 0.000 | | | |
| PRES7 | 0.861 | 64.902 | 0.000 | | | |
| **Reduction of Carbon and Ecological Footprints (RCEF)** | | | | **0.892** | **0.912** | **0.537** |
| RCEF1 | 0.649 | 20.967 | 0.000 | | | |
| RCEF2 | 0.661 | 16.861 | 0.000 | | | |
| RCEF3 | 0.792 | 36.594 | 0.000 | | | |
| RCEF4 | 0.770 | 26.000 | 0.000 | | | |
| RCEF5 | 0.762 | 37.909 | 0.000 | | | |
| RCEF6 | 0.746 | 31.973 | 0.000 | | | |
| RCEF8 | 0.661 | 18.286 | 0.000 | | | |
| RCEF10 | 0.766 | 42.024 | 0.000 | | | |
| RCEF11 | 0.773 | 53.595 | 0.000 | | | |
| **Sustainable Construction (SC)** | | | | **0.884** | **0.908** | **0.553** |
| SC1 | 0.673 | 23.634 | 0.000 | | | |
| SC2 | 0.797 | 46.137 | 0.000 | | | |
| SC3 | 0.793 | 38.901 | 0.000 | | | |
| SC4 | 0.769 | 30.795 | 0.000 | | | |
| SC5 | 0.691 | 32.023 | 0.000 | | | |
| SC7 | 0.655 | 24.681 | 0.000 | | | |
| SC8 | 0.825 | 61.061 | 0.000 | | | |
| SC9 | 0.729 | 27.563 | 0.000 | | | |
| **Waste Management (WMM)** | | | | **0.956** | **0.960** | **0.559** |
| WMM3 | 0.724 | 28.343 | 0.000 | | | |

| Items | Loadings | *t*-statistics | *p*-values | Cronbach's alpha | Composite reliability (rho_c) | AVE |
|---|---|---|---|---|---|---|
| WMM6 | 0.815 | 47.049 | 0.000 | | | |
| WMM7 | 0.781 | 26.713 | 0.000 | | | |
| WMM8 | 0.727 | 24.375 | 0.000 | | | |
| WMM10 | 0.802 | 52.020 | 0.000 | | | |
| WMM11 | 0.803 | 50.135 | 0.000 | | | |
| WMM12 | 0.677 | 21.584 | 0.000 | | | |
| WMM13 | 0.655 | 21.948 | 0.000 | | | |
| WMM14 | 0.656 | 19.458 | 0.000 | | | |
| WMM15 | 0.731 | 33.720 | 0.000 | | | |
| WMM16 | 0.790 | 43.769 | 0.000 | | | |
| WMM17 | 0.763 | 25.464 | 0.000 | | | |
| WMM18 | 0.791 | 31.566 | 0.000 | | | |
| WMM19 | 0.766 | 35.659 | 0.000 | | | |
| WMM21 | 0.773 | 42.987 | 0.000 | | | |
| WMM22 | 0.738 | 25.863 | 0.000 | | | |
| WMM23 | 0.657 | 19.982 | 0.000 | | | |
| WMM25 | 0.755 | 26.820 | 0.000 | | | |
| WMM26 | 0.766 | 29.659 | 0.000 | | | |

(Source: Field data, 2022)

The results shown in Table 6.2 suggested acceptable construct reliability and convergent validity. Specifically, the reliability and AVE values exceeded the 0.70 and 0.50 minimum limit in addition to significant item loadings ($p < 0.001$). Cronbach's alpha and rho_c values recorded for the reliability of energy efficiency were 0.898 and 0.916, respectively, 0.804 and 0.859 for protection of resources and eco-system, 0.854 and 0.883 for reduction of carbon and ecological footprints, 0.892 and 0.912 for reduction of emission/pollution, 0.884 and 0.908 for sustainable construction, and 0.956 and 0.960 for waste management. Regarding the extraction of convergent validity assessed using the average variance, an AVE of 0.522 was recorded for energy efficiency, 0.508

for protection of resources and eco-system, 0.562 for reduction of carbon and ecological footprints, 0.537 for reduction of emission/pollution, 0.553 for sustainable construction, and 0.559 for waste management. Consequently, all six constructs demonstrated acceptable construct reliability and convergent validity (Hair *et al*., 2019; Shmueli *et al*., 2019). As presented in Table 6.3, the square root of the AVE (given diagonally) for every construct is more than the correlations between all latent variables. Thus, it has been shown that all the latent constructs are discriminantly valid (Fornell & Larcker, 1981).

**Table 6.3: Discriminant validity by Fornell-Larcker criterion**

| **Constructs** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| 1. Energy Efficiency | **0.722** | | | | | |
| 2. Protection of Resources and Eco-System | 0.501 | **0.750** | | | | |
| 3. Reduction of Carbon and Ecological Footprints | 0.639 | 0.464 | **0.733** | | | |
| 4. Reduction of Emission/Pollution | 0.569 | 0.502 | 0.589 | **0.713** | | |
| 5. Sustainable Construction | 0.490 | 0.291 | 0.691 | 0.532 | **0.744** | |
| 6. Waste Management | 0.704 | 0.441 | 0.573 | 0.436 | 0.540 | **0.748** |

The HTMT values regarded as the current ideal criterion for evaluating discriminant validity (Hair *et al*., 2019; Henseler *et al*., 2015) are recorded in Table 6.4. Each of the provided HTMT results falls below the threshold value of 0.85. This is a prerequisite for discriminant validity, since it proves that each variable is distinct from every other (Hair *et al*., 2019; Henseler *et al*., 2015).

**Table 6.4: Discriminant validity by HTMT criterion**

| **Constructs** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| 1. Energy Efficiency | | | | | | |
| 2. Protection of Resources and Eco-System | 0.502 | | | | | |
| 3. Reduction of Carbon and Ecological Footprints | 0.678 | 0.417 | | | | |
| 4. Reduction of Emission/Pollution | 0.634 | 0.631 | 0.666 | | | |
| 5. Sustainable Construction | 0.535 | 0.306 | 0.752 | 0.606 | | |
| 6. Waste Management | 0.747 | 0.440 | 0.571 | 0.477 | 0.577 | |

### 6.4.2 Structural model results

This stage of the PLS-SEM analysis, known as the structural model assessment, is focused on the relationships (i.e. paths) among the latent variables. This includes the direct and indirect paths or effects, as well as the predictive power and relevance of the structural model (Hair *et al*., 2019; Ringle *et al*., 2020). The findings are presented in Tables 6.5 and 6.6.

**Table 6.5: Structural model's predictive power and relevance**

| **Outcome Variables** | **$R^2$** | **$R^2$ adjusted** | **$Q^2$predict** |
|---|---|---|---|
| Reduction of Carbon and Ecological Footprints | 0.512 | 0.507 | 0.494 |
| Sustainable Construction | 0.478 | 0.477 | 0.344 |

The statistics shown Table 6.5 and illustrated in Figure 6.2 indicated that the structural model has strong explanatory power and practical relevance (Hair *et al*., 2019; Usakli & Kucukergin, 2018). Specifically, the $R^2$ values showed that the model explains 51.2% ($Q^2$ = 0.494) of the variance in reduction of carbon and ecological footprints and 47.8% ($Q^2$ = 0.344) of the variance in sustainable construction. This meant that energy efficiency, protection of resources and eco-system, reduction of emission/pollution, and waste management substantially support the reduction of carbon and ecological footprints. Similarly, carbon and ecological footprints reduction profoundly accounts for sustainable construction.

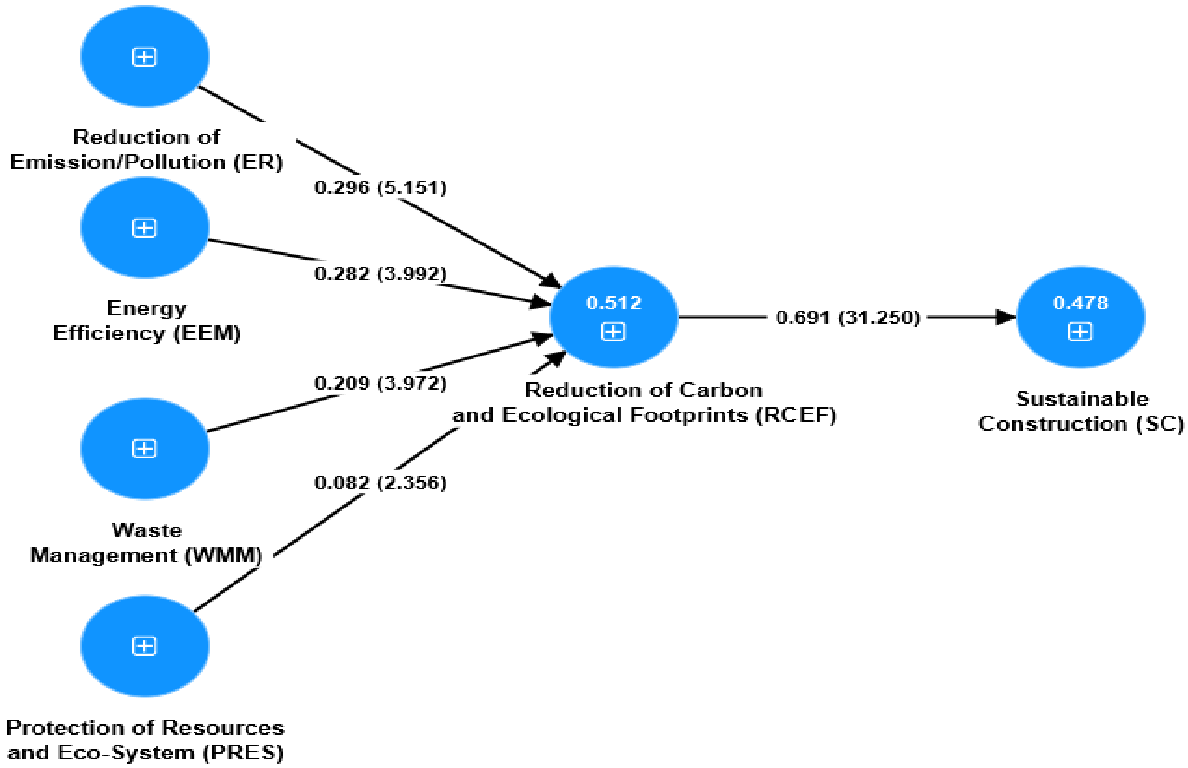


**Figure 6.2: Structural model results**

**Table 6.6: Structural model results**

| **Paths** | **Coefficient (*β*)** | **VIF** | ***t*-statistics** | ***p*-values** | **Confidence Interval** | |
|---|---|---|---|---|---|---|
| | | | | | **2.5%** | **97.5%** |
| **Direct effects** | | | | | | |
| ER -> RCEF | 0.296 | 1.630 | 5.151 | 0.000 | 0.174 | 0.400 |
| EEM -> RCEF | 0.282 | 2.453 | 3.992 | 0.000 | 0.140 | 0.421 |
| WMM -> RCEF | 0.209 | 2.026 | 3.972 | 0.000 | 0.110 | 0.317 |
| PRES -> RCEF | 0.082 | 1.498 | 2.356 | 0.019 | 0.009 | 0.145 |
| RCEF -> SC | 0.691 | 1.000 | 31.250 | 0.000 | 0.645 | 0.732 |
| **Indirect effects** | | | | | | |
| ER -> RCEF -> SC | 0.205 | - | 4.893 | 0.000 | 0.115 | 0.281 |
| EEM -> RCEF -> SC | 0.195 | - | 3.983 | 0.000 | 0.096 | 0.289 |
| WMM -> RCEF -> SC | 0.144 | - | 3.907 | 0.000 | 0.075 | 0.220 |
| PRES -> RCEF -> SC | 0.056 | - | 2.386 | 0.017 | 0.006 | 0.099 |

As presented in Table 6.6 and Figure 6.2, all the direct and indirect effects are statistically significant with no multi-collinearity issues (VIF < 3). Pertaining to the direct effects, reduction of carbon and ecological footprints was significantly predicted by the reduction of emission or pollution ($\beta = 0.296$; $t = 5.151$; $p = 0.000$), energy efficiency ($\beta = 0.282$; $t = 3.992$; $p = 0.000$), waste management ($\beta = 0.209$; $t = 3.972$; $p = 0.000$), and protection of resources and eco-system ($\beta = 0.082$; $t = 2.356$; $p = 0.019$). Similarly, carbon and ecological footprints reduction predicted SC significantly positive ($\beta = 0.691$; $t = 31.250$; $p = 0.000$). This suggested that emission or pollution reduction, waste management, energy efficiency, and protection of resources and eco-system are significant direct drivers of carbon and ecological footprints reduction. Likewise, the carbon and ecological footprints reduction significantly facilitates SC.

Assessing the indirect paths revealed that reduction of emission or pollution ($\beta = 0.205$; $t = 4.983$; $p = 0.000$), energy efficiency ($\beta = 0.195$; $t = 3.983$; $p = 0.000$), waste management ($\beta = 0.144$; $t = 3.907$; $p = 0.000$), and protection of resources and eco-system ($\beta = 0.056$; $t = 2.386$; $p = 0.017$) had significant positive indirect influence on sustainable construction through carbon and ecological footprints reduction. This suggested that carbon and ecological footprints reduction mediates the influence of emission or pollution reduction, waste management, energy efficiency, and protection of resources and eco-system on sustainable construction. Thus, reduction of emission or pollution, energy efficiency, waste management and protection of resources and eco-system lead to reduction of carbon and ecological footprints which, in turn, leads to sustainable construction.

### 6.4.3 Importance-performance map analysis (IPMA)

Understanding the predictors of the examined model further, IPMA was used in this research, a forward-thinking technique employed in PLS-SEM. Effort to prioritise direction of effective management and policy requires such an appraisal (Chawla & Joshi, 2021; Fakfare & Manosuthi, 2022; Ringle & Sarstedt, 2016; Sarstedt *et al*., 2014; Valaei & Jiroudi, 2016). The importance and performance of each predictor of the outcome variable of sustainable construction are thus analysed in this section (Table 6.7 and Figure 6.3).

**Table 6.7: IPMA results**

| Predictors | Performance Index | Importance Index |
|---|---|---|
| Energy Efficiency | 73.418 | 0.195 |
| Protection of Resources and Eco-System | 56.477 | 0.056 |
| Reduction of Carbon and Ecological Footprints | 72.857 | 0.691 |
| Reduction of Emission/Pollution | 70.893 | 0.205 |
| Waste Management | 74.432 | 0.144 |

(Source: Field data, 2022)

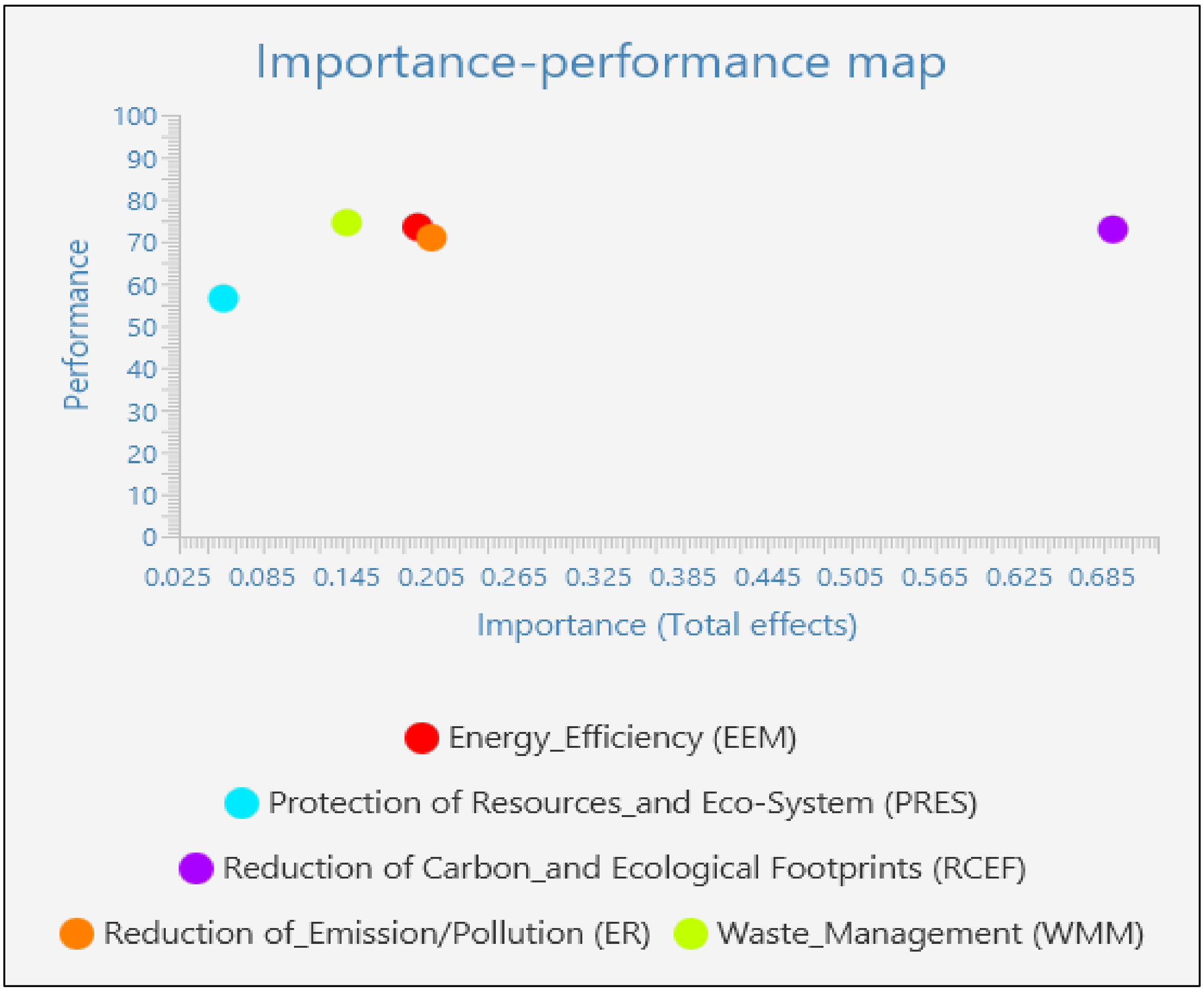


**Figure 6.3: IPMA results**

The IPMA results shown in Table 6.7 and illustrated in Figure 6.3 revealed that the top-four significant predictors of sustainable construction are reduction of carbon and ecological footprints, with importance index of 0.691, reduction of emission/pollution, with importance index of 0.205, energy efficiency, with importance index of 0.195, and waste management, with importance index of 0.144. However, reduction of carbon and ecological footprints, emission/pollution reduction, waste management, and energy efficiency exhibited performance indices of 72.857, 70.893, 73.418 and 74.432, respectively. Thus, reduction of carbon and ecological footprints, reduction of emission/pollution, energy efficiency and waste management are the significant drivers of SC and must be a priority. The implication is that SC policy-makers and practitioners should focus on the carbon and ecological footprints reduction by advocating the reduction of emission/pollution, energy efficiency and waste management in boosting sustainable construction.

## 6.5 DISCUSSION OF PLS-SEM RESULTS

The findings from the PLS-SEM study on emissions and pollution, energy efficiency, waste management, and protection of resources and eco-systems to reduce carbon and ecological footprints for implementation of sustainable construction are presented in this section.

### 6.5.1 Effects of emission/pollution on carbon and ecological footprints

The results for emission/pollution indicated support for hypothesis H1 as far as SC is concerned. In 2009, the global construction sector produced 5.7 billion tons of carbon dioxide (Huang *et al*., 2018).

Building construction and usage account for about 40% of the world's resource and energy use (Edeoja & Edeoja, 2015: 112; Rahim *et al*., 2014: 84), 40% to 50% of the GHG produced, and a quarter of the world's total carbon emissions (Huang *et al*., 2017: 1008; Kim & Rigdon, 2016:1). According to Hong *et al*. (2015), 96% of all carbon emissions in the construction industry were attributable to fuel used in construction equipment. As a result, the focus of research has shifted to how to reduce carbon emissions in order to stop global warming and avert disasters. According to Nasab (2019), the methods used in the construction industry to cut CO2 emissions include controlling waste production, selecting ecologically friendly building materials, and supplying materials from close-by factories.

### 6.5.2 Effects of energy efficiency on carbon and ecological footprint

The results for energy efficiency supported the hypothesis H2 for achievement of SC. From 2000 to 2020, Ghana's residential sector consumed approximately 140% more energy than in the previous decade (Energy Commission, 2021). In the report, it was indicated that industrial and residential sectors consumed energy at respective rates of 33.3% and 47% of the total amount in 2020. In addition, Ghana used 54% of its total energy to power homes. (Asumadu-Sarkodie & Owusu, 2016). Energy-efficient building will reduce the effects of global warming and reduce operational cost.

Yang and Yu (2015) observed that innovations that use the least amount of energy to supply goods and services are considered to be energy efficient. The range and variety of energy-efficiency devices are enormous and remain critical for achieving sustainable construction in the built environment. Energy efficiency is the optimum use of energy to perform tasks and reduce wastage. In comparison to incandescent lights, LEDs and CFLs are 80% to 85% more efficient (Mills & Schleich, 2014). Solar lighting devices likewise improve energy efficiency. Natural lighting illumination systems direct sunlight into living spaces for illumination, which lowers the expense and artificial electricity usage (Whang *et al.*, 2020). A reduction in the huge amount of energy consumed in construction as result of transportation, demolition, excavation, and hoisting will contribute to the carbon and ecological footprints reduction of construction activity. The efficient use of construction equipment will lead to a lower fuel consumption, lower energy cost, lower emission levels to protect the environment, minimisation of energy consumption, and improvement of productivity and an increase in value.

### 6.5.3 Waste management measures for reduction of carbon and ecological footprints

Traditional methods of managing waste continue to be applied in the built environment and the ensuing pollution of land and water has led to increasing concern about the lack of an integrated waste management strategy in the nation (Ayarkwa *et al*., 2017). The building sector should work with appropriate government organisations to create appropriate guidelines for formulating waste management plans for the building sector (Osmani & Villoria-Sáez, 2019). At all levels of building projects, the waste management plan should foster a positive attitude toward waste minimisation.

Waste generation from construction activities continues to be a problem in emerging economies such as Ghana (Hamid *et al*., 2016). According to Mohammed *et al*. (2020), mistakes in contract documents, errors when ordering materials, changes to design, accidents, lack of waste management systems, lack of site control, and damage during transportation are the main causes of construction waste generation. Measures such as legislative control, controlling landfill areas, providing sorting facilities on site, implementing an environmental management system, implementing a framework for a waste reduction plan, and standardising design to reduce the quantity of cutting waste promote sustainable waste management. Approaches to waste prevention are basic efforts in reducing waste in construction activities, which is the highest level of sustainability. The prevention of waste requires careful co-ordination, positive relationships and effective communication between the stakeholders involved in the construction process (Mohammed *et al*., 2020). However, the three actions that are thought to add most significantly to waste minimization are buying just enough raw materials, using materials before their expiration dates, and using more efficient construction equipment. Minimisation of construction waste is one of the key factors for achieving sustainability (Hamid *et al*., 2016). Re-use, recycling and recovery from waste are important construction waste management strategies. Most developing countries, such as Ghana, already face a dearth of suitable land for landfills. Construction waste can be hazardous and, therefore, requires appropriate and well-defined policies and technology to manage it. Demolition waste management and sustainable construction are important to protect the environment, and conserve natural resources.

### 6.5.4 Protection of resources and eco-systems from carbon and ecological footprints

The extraction and processing of raw materials, the production of building materials, the cycle of a construction project from inception to demolition, and the administration and operation of the built environment are categorised as construction activities. One of the most resource-intensive sectors, which is thought to be a major source of environmental pollution is the built environment. However, the sustainability approach can help to conserve natural resources and the ecology (Yeheyis *et al*., 2013). Effective management of natural resources is crucial if we are to maximise benefits for the current generation without jeopardising our ability to meet their requirements in the future. Conservation of resources entails achieving more with less materials. CI is arguably a major consumer of resources globally. Construction projects should use less non-renewable materials and contribute to improving the efficiency of consuming resources.

## 6.6 ROADMAP FOR REDUCTION OF CARBON AND ECOLOGICAL FOOTPRINTS

The development of a roadmap for carbon and ecological footprints reduction is to provide a solution for the research problem stated in this study. It comprises vital issues that influence SC in GCI. The roadmap has been organised into five main stages. The first stage of the roadmap indicates the need to create awareness to close the knowledge gap established in the study. This is followed by the engagement of stakeholders on sustainability issues that depend on behaviour, concepts, legislation, practices and tools for acceptance of SC technology that leads to the adoption of the innovation to implement SC practices. Once these are established, the third stage of the roadmap is for the stakeholders to exploit the significant factors that will drive the implementation of SC to reduce carbon and ecological footfrints. The fourth stage is to remove the barriers identified to engender the implementation of SC and attract other stakeholders in the CI to adopt sustainability measures to reduce carbon and ecological footprints in GCI, as presented in Figure 6.4.

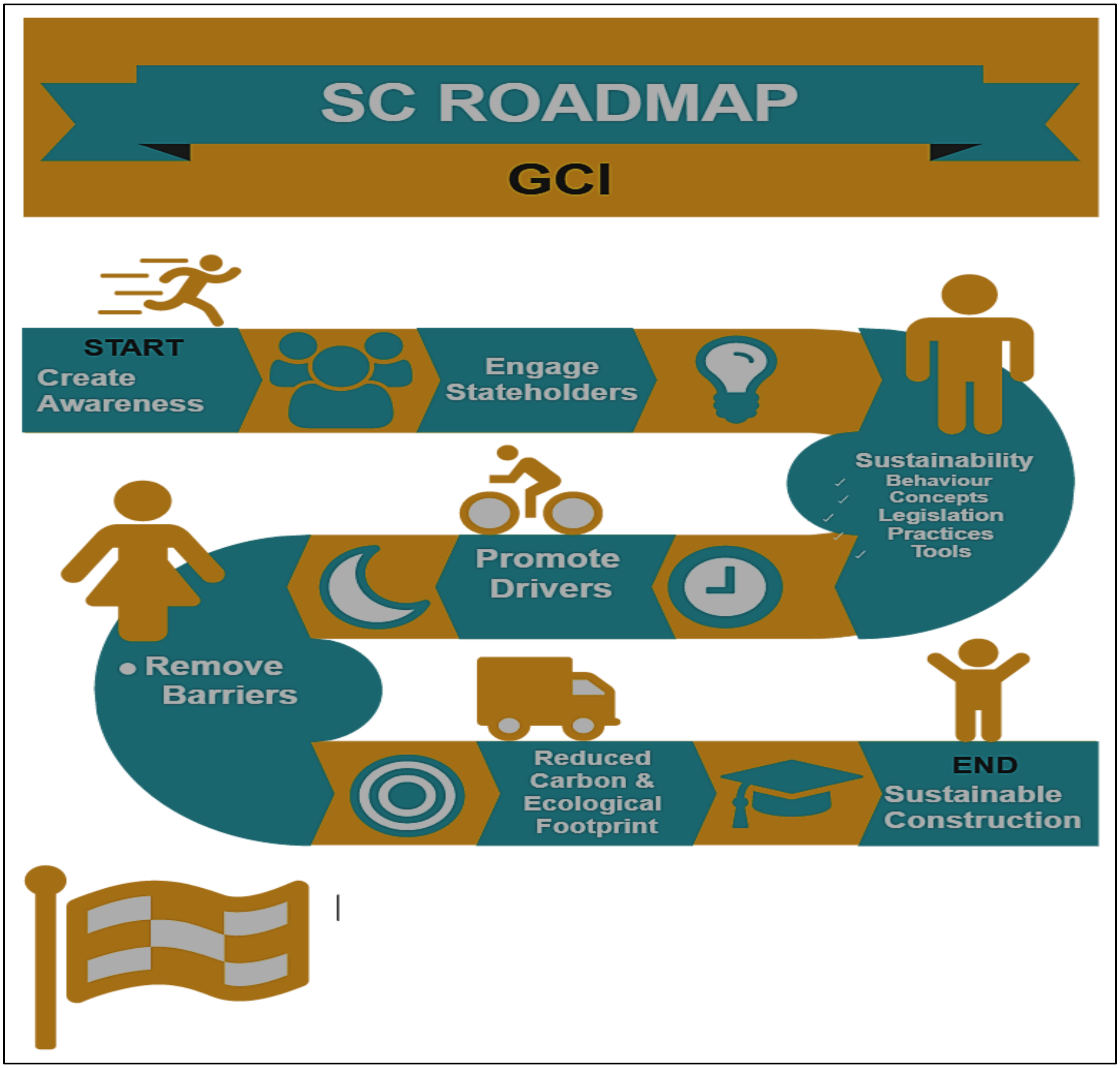


**Figure 6.4:** Roadmap to reduce carbon and ecological footprints

## 6.7 TESTING THE ROADMAP

The reliability and validity of research results are important in determining the robustness of the s tudy (Hair *et al*., 2019; Henseler *et al*., 2015). Validation of the results ensures that the method used is credible and acceptable. According to Henseler *et al*. (2015), the validation process should address construct validity, external validity, and internal validity of the study to ensure that the goals of the research are achieved. The experts for the present study were selected from respondents who participated in the main survey, and those who did not take part in the main study.

The data collected from the respondents provided the foundation for the developed roadmap to achieve external and internal validity. The responses from participants who participated in the main survey established the internal validity, whilst responses from the participants who did not take part in the main research were used to evaluate the external validity and possible generalisation of the proposed roadmap.

To ensure internal consistency, the participants were encouraged to indicate their overall impressions of the developed roadmap. Because the constructs are difficult to assess using a quantitative survey, the suggested roadmap developed was validated using qualitative survey (Hu *et al*., 2016). Semi-structured, closed-ended, and open-ended inquiries made up the instrument to evaluate the quality of the proposed roadmap based on similar criteria used by Corbin and Strauss (2008) as follows: Depth (level of coverage of the main issues and contents within each section of the roadmap; Logic (the logical flow of the roadmap); Fit (the clarity and ease of understating of the roadmap); and Applicability (the overall usefulness of the roadmap). The respondents were asked to provide their level of agreement using a five-point Likert Scale (5 = strongly agree, 4 = agree, 3 = somewhat agree, 2 = disagree, 1 = strongly disagree). In all, 10 experts were selected to validate the proposed roadmap, comprising 4 from the academia and 6 from the industry. The roadmap was sent to the respondents for them to study before the interview was conducted. The results of the interviews to validate the roadmap are presented below.

**Table 6.8: Demographics of Experts/Assessors**

| **Characteristics** | | **Count** | **Percentage (%)** |
|---|---|---|---|
| **Highest academic qualification** | BSc Degree (Building Technology) | 1 | 10.0 |
| | BSc Degree (Civil Engineering) | 1 | 10.0 |
| | Master's Degree (Construction Project Management) | 2 | 20.0 |
| | Master's Degree (Engineering Project Management) | 1 | 10.0 |
| | Master's Degree (Real Estate Management) | 1 | 10.0 |
| | PGDip (Architecture) | 1 | 10.0 |
| | PhD (Civil Engineering) | 1 | 10.0 |
| | PhD (Construction Management) | 1 | 10.0 |
| | PhD (Services Engineering) | 1 | 10.0 |
| **Profession/area of expertise** | Architect | 2 | 20.0 |
| | Civil Engineer | 1 | 10.0 |

| Characteristics | | Count | Percentage (%) |
|---|---|---|---|
| | Construction Engineer | 1 | 10.0 |
| | Project Manager | 3 | 30.0 |
| | Quantity Surveyor | 2 | 20.0 |
| | Site Engineer | 1 | 10.0 |
| **Type of organisation** | Private construction firm | 6 | 60.0 |
| | University/Private construction firm | 3 | 30.0 |
| | University/Private consultancy firm | 1 | 10.0 |
| **Institution (Academia/industry)** | Academia | 4 | 40.0 |
| | Construction Industry | 6 | 60.0 |

(Source: Field data, 2022)

The statistics in Table 6.8 showed that all the experts had a tertiary educational background in construction. Furthermore, the experts included an architect, civil engineer, construction engineer, project manager, quantity surveyor and site engineer. Lastly, the experts were from both academia and the construction industry.

**Table 6.9: Assessment of validity criteria**

| Criteria | Min. | Max. | Mean | SD |
|---|---|---|---|---|
| 1. The degree to which awareness, drivers, and barriers are covered in the roadmap depicts the overall elements of current situation of sustainable construction in the Ghanaian Construction Industry | 4 | 5 | 4.90 | 0.316 |
| 2. Level of coverage in the roadmap of logical flow is acceptable for easy usage in the Ghanaian Construction Industry | 4 | 5 | 4.80 | 0.422 |
| 3. The Ghanaian construction industry can readily use the roadmap because it is simple to understand. | 4 | 5 | 4.90 | 0.316 |
| 4. The roadmap is inclusive and its appropriate application would enhance the implementation of sustainable construction in Ghana | 4 | 5 | 4.90 | 0.316 |
| 5. 5. You would advise Ghanaian building stakeholders to use the road map to lessen the carbon and ecological footprints of construction activity. | 5 | 5 | 5.00 | 0.000 |

(Source: Field data, 2022)

The findings in Table 6.9 indicated that the experts highly agreed that the roadmap depicts the present state of affairs of sustainable construction in GCI ($M$ = 4.90; $SD$ = 0.316). They also agreed that the logical flow of the roadmap is acceptable for easy usage in the Ghanaian Construction

Sector (*M* = 4.80; *SD* = 0.422). Additionally, the experts concurred that the roadmap is easy to understand and can be used easily in the construction industry in Ghana (*M* = 4.90; *SD* = 0.316), that the roadmap for the carbon and ecological footprints reduction is inclusive, and appropriate application of the roadmap would enhance the implementation of SC in Ghana (*M* = 4.90; *SD* = 0.316). Lastly, the experts agreed very strongly that the roadmap could be recommended to stakeholders in GCI to reduce carbon and ecological footprints of construction activity (*M* = 5.00; *SD* = 0.000).

**Table 6.10: Level of agreement using Fleiss's Multi-rater Kappa**

| **Overall Kappa** | | | | | | |
|---|---|---|---|---|---|---|
| | **Kappa** | **Asymptotic Standard Error** | **Z** | ***p*-value** | **Lower 95% Asymptotic CI Bound** | **Upper 95% Asymptotic CI Bound** |
| Overall | .333 | .100 | 3.333 | .001 | .137 | .529 |

| **Kappas for Individual Categories** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Rating Category** | **Conditional Probability** | **Kappa** | **Asymptotic Standard Error** | **Z** | ***p*-value** | **Lower 95% Asymptotic CI Bound** | **Upper 95% Asymptotic CI Bound** |
| 4 | .400 | .333 | .100 | 3.333 | .001 | .137 | .529 |
| 5 | .933 | .333 | .100 | 3.333 | .001 | .137 | .529 |

(Source: Field data, 2022)

Fleiss's Multi-rater Kappa was used to find out if there was consensus by the experts of the validity of appropriateness of the roadmap. As shown in Table 6.10, the Fleiss's Kappa exhibited a reasonable consensus among the experts' decisions, K = 0.333 (95% CI, 0.137 to 0.529), $p = 0.001$.

## 6.8: CHAPTER SUMMARY

The roadmap for reduction of carbon and ecological footprints created to meet the study's goal was presented in this chapter. The roadmap will help in the implementation of SC in the GCI to reduce ecological and carbon footprints. The roadmap comprises five main stages of: awareness creation, stakeholder engagement on sustainability issues, promotion of significant drivers, and removal of barriers to SC in the GCI. The developed roadmap will be introduced to the stakeholders to encourage them to use it to encourage the adoption of sustainability in the GCI.

# CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

## 7.1 INTRODUCTION

This chapter contains the key research results, conclusions drawn from the research, and recommendations for industry practitioners, policy-makers, and academic community. The chapter includes responses of the participants in line with the goals of this study to contribute significantly to practice, policy and research based on sound methodology and the study's limitations are acknowledged as well as areas for future research.

## 7.2 SUMMARY

This thesis, in which a roadmap for the carbon and ecological footprints reduction of building projects in Ghana was developed, consists of seven chapters. In Chapter One, which is the introduction, the direction of the research is indicated, including the background of the research. A critique of the literature is then presented in Chapter Two, regarding global carbon emission, the concept of sustainability, the GCI and the theoretical framework of the study. The literature review revealed that the implementation of SC in Ghana is slow and in a stage of infancy. Also, there are limited studies and research plans about SC practices in the emerging countries, including Ghana, with most studies being focused mainly on developed countries. It is difficult to identify SC roadmaps, models and codes for Ghana that are accepted by all stakeholders and can be followed to implement SC in Ghana. Most emerging countries, including Ghana, are not taking the implementation of sustainability seriously despite the numerous advantages it offers. The Chapter Three explained the sequential, mixed method, study design framework that was used for the research. The qualitative data and interpretations collected from a Delphi survey were presented in Chapter Four. In all, 18 experts from the GCI participated in the Delphi survey and the data were analysed using SPSS to gain consensus on the significant elements influencing the implementation of SC in the GCI. The analysis of quantitative data from the 405 valid responses to the survey questions, was presented in Chapter Five. The findings that influence the various variables of SC were analysed by PLS-SEM technique to identify the most significant variable in order to propose a roadmap for the carbon and ecological footprints reduction, as presented in Chapter Six. The roadmap was refined and validated for its potential for implementation in GCI, using qualitative, structured interviews with construction industry practitioners.

This study contributed to the field of SC knowledge. How to evolve a roadmap for SC in GCI was explored through analysis and evaluation of relevant data. The conceptual framework and eventual roadmap contain sustainable practices that construction practitioners should carry out to reduce carbon and ecological footprints. This roadmap has the potential to help in the realisation of goals beyond the construction site. The social impact of the roadmap is to impact the attainment of SGDs, which include:

- ✓ SDG 9: Industry, Innovation, and Infrastructure – build robust infrastructure, advance inclusive and sustainable industrialisation and support innovation.
- ✓ SDG 12: Responsible Consumption and Production – ensure sustainable consumption and production trends.
- ✓ SDG 13: Climate Action – take immediate action to fight climate change and its effects.

## 7.3 CONCLUSIONS OF THE STUDY

The conclusions related to the research objectives are presented in this section. The six study goals were formulated to achieve the aim of developing a SC roadmap for the carbon and ecological footprints reduction in the GCI.

### 7.3.1 Sustainability is a focus area that cannot be ignored by GCI – Objective 1

This objective was achieved because it was discovered that Ghana has not accomplished much with regard to SC practices which is proceeding very slowly and its adoption is at infancy stage. The results of the literature analysis showed that benefits influenced the adoption of SC practices in construction projects. The consensus from the Delphi studies attributed the benefits to three aspects of sustainability. The GCI stakeholders have a high knowledge of SC concept and technologies.

A questionnaire survey was developed from the Delphi study and received 405 valid responses from stakeholders in GCI to investigate their knowledge of SC practices, including the drivers, benefits, and the challenges militating against the implementation of SC. The previous findings were confirmed after the findings from the descriptive study showed that the participants assert to have a high level of knowledge and awareness of SC. The level of stakeholders' knowledge of SC does not commiserate with the rate of adoption and implementation of SC practice in Ghana.

Therefore, SC adoption is key to ensuring that social sustainability is achieved to improve the health, comfort, and well-being of the citizenry, alleviate hardship, which is the priority of most emerging economies including Ghana. The direct economic benefits of SC include: a better payback period; an increase in revenue; and a quick return on investment. Environmental benefits include: restoration and conservation of natural resources; protection of ecosystems and biodiversity; improved energy efficiency and minimised $CO_2$ emissions which contribute immensely to global warming; enhanced and protected ecosystems; and preserved and restored natural and renewable resources. The stakeholders including Ghana Green Building Council, have a major responsibility to make GCI sustainable using television and radio stations, internet, and curriculum of the schools to deepen knowledge and awareness of sustainable construction in Ghana.

### 7.3.2 Response of design to sustainability requirements in GCI – Objective 2

To address this goal, an extensive literature review was carried out. From the review, the variables for sustainable building design practices were adapted, amongst others, and validated by the experts in the Delphi study. These were later developed into a questionnaire using a five-point Likert measuring scale, from strongly disagree (1) to strongly agree (5) to assess their influence and contribution to SC. The survey was administered to stakeholders in both the building sector and academia to ensure validity. The PLS-SEM technique which was used to analyse the data revealed the important factors to determine how architectural and engineering firms are contributing to SC practices through the design of buildings and were incorporated into the roadmap for carbon and ecological footprints reduction in the GCI. The key results of the PLS-SEM, which were incorporated, were conservation of resources, humane adaptation, life-cycle design, and cost efficiency. The results from this objective provided empirical evidence and understanding that are of significant importance to the adoption of sustainable construction, as they will help stakeholders who are desirous of promoting sustainable construction in Ghana. The improved behavioural control of engineering and architectural firms to incorporate sustainability in their design to conserve resources and save costs will guarantee the adoption of SC. The perceived behavioural control of engineers and architects will influence significantly the likelihood of their adoption of SC in Ghana

### 7.3.3 Use of low-impact materials for sustainability requirements in GCI – Objective 3

To achieve this goal, an extensive literature review was carried out. The variables for low impact building materials for SC practices were adapted from the review, amongst others, and validated by the 18 experts of the Delphi panel selected from the CI. These variables were later developed into a survey to gather quantitative data from 405 participants, using a five-point Likert measuring scale, from strongly disagree (1) to strongly agree (5) to identify how construction firms incorporate low-impact building materials in their building projects to achieve SC. The survey was administered to stakeholders in both the building sector and academia to ensure validity. The PLS-SEM technique, which was used to analyse the data, revealed the important factors that influence how construction companies incorporate low-impact building materials to ensure sustainable construction practices, and incorporated into the roadmap for SC in the GCI. The five top factors on which the experts reached consensus and were incorporated include: the materials used are renewable, recyclable or re-usable (1.000); use of materials that are long lasting and easy to maintain (1.206); use of materials with minimum adverse impact on the environment (1.272); use of local materials (wood, thatch, laterite, bamboo, etc.) (1.433); and use of water-efficient trees, green roofs and rain gardens (1.537). The results from this objective provided empirical evidence and understanding that are of significant importance for SC adoption because they will help stakeholders desirous of promoting SC in Ghana. The incorporation of low-impact building materials in construction projects will contribute to the reduction of carbon and ecological footprints in GCI.

### 7.3.4 Influence of using energy efficiency on the construction process in GCI – Objective 4

In order to achieve this goal, a critical review of literature was carried out about the effects of using energy-efficient equipment on the construction process for sustainability in the GCI. From the Delphi study, experts reached consensus on 7 identified factors after three rounds of iteration. The median and standard deviation (SD) was calculated using descriptive analysis to identify the factors of using energy-efficient equipment that have the most important influence on the construction process in GCI. The top-five most important effects of using energy-efficient equipment on the construction process, according to the ranking by the expert panel, are: reduced use of fuel (0.505), reduction in energy cost (0.522), reduced emission level and protection of the environment (0.522), minimised energy consumption (0.522), and improved productivity and increased value (0.786). The government's policies on efficient use of energy can result in the reduction of energy usage in buildings. The findings in previous studies that responsible use of energy and conservation can reduce costs and ensure sustainability were confirmed.

### 7.3.5 Management of solid waste on construction sites in GCI – Objective 5

Through a thorough study of literature, this goal was accomplished. The review showed that the contractors employed several modalities to reduce solid waste production and discharge on construction sites to achieve SC practices in GCI. The 18 experts on the Delphi panel reached consensus on 26 factors to manage solid waste on construction sites for SC. A questionnaire survey that received 405 valid responses from the participants was analysed. The main waste management elements that promote SC practices include: low-waste technology usage (0.688); just-in-time procedures (0.820); scheduling delivery time promptly (0.820); proper handling of equipment on site (0.820); and use of more efficient equipment (0.823). The findings in previous studies were confirmed after the findings revealed that the 4R approach – reduce, re-use, recovery and recycle – is an effective way to manage construction waste. In recent years, it has been highlighted in previous studies that construction and demolition waste can be hazardous. The hierarchy of waste management is acknowledged as the best choice for handling construction waste because it boosts the nation's economy and has a smaller negative impact on the environment. The waste avoidance and minimisation together with the 4Rs are important in managing construction waste. Therefore, sustainable waste management is key to ensuring that social, economic and environmental sustainability is achieved to alleviate poverty and improve health, comfort, and well-being of the citizenry, to use construction materials effectively for future generations also to have their materials available to use. The Ghana Green Building Council, consultants, and Government, including the Environmental Protection Agency of Ghana have the highest responsibility to ensure that construction waste is managed sustainably in Ghana through education, using internet, television and radio stations, and curriculum of the schools to deepen knowledge and awareness of sustainable construction waste management in Ghana.

### 7.3.6 Roadmap for sustainable construction that would reduce carbon and ecological footprints of construction activity in GCI – Objective 6

A roadmap for reducing carbon and ecological footprints to implement SC in GCI has been developed. The results from Objectives 1 to 5 were integrated to create the SC roadmap in the sixth stage of the study process. The outcome of the Delphi survey and PLS-SEM analysis findings for Objectives 1, 2, 3, 4 and 5, were used to develop the roadmap, which significantly influence the practice of SC in Ghana. In order to get feedback on the credibility, applicability, and ease of the roadmap, semi-structured, qualitative interviews with academic and industry professional were conducted. The roadmap and its layout were supported by the experts who indicated that it would help stakeholders to implement SC in the GCI.

## 7.4 CONTRIBUTION OF THE RESEARCH

The contribution made to the SC body of knowledge is outlined in this section. The main drivers, challenges and benefits of SC provide valuable implications for adoption and promotion of SC in Ghana and other developing countries with similar conditions.

### 7.4.1 Contributions to scholarship

The knowledge gaps determined from the existing literature provided the foundation for this research. The results provided the theoretical framework for the study in explaining the concept of SC, reduction of carbon and ecological footprints through waste management, energy efficiency, emission reduction, and protection of resources and eco-system.

Also, this research has provided empirical evidence of the implementation of strategies to reduce carbon and ecological footprints to ensure SC in Ghana, which is unavailable in most developing countries such as Ghana. Most developing countries are struggling with the implementation of SC which is emerging as a phenomenon being studied around the world. The contribution of this research will enhance the implementation of SC concepts which are at a stage of infancy in Ghana to appreciable levels to achieve the SDGs.

Furthermore, the awareness/knowledge of the benefits to be accrued is vital in determining the adoption of SC by stakeholders in the GCI. The contextualised drivers, challenges and the benefits of SC would contribute to the achievement of the objective to promote the acceptance and implementation of SC practices in emerging countries like Ghana.

As was stated in Chapter Three, the study used sequential, exploratory, mixed method study design and a pragmatic research approach to arrive at the results. The study contributes in terms of the methodology that made it possible to collect qualitative data from a three-round Delphi study involving experts in the GCI, which has been scarcely used in previous studies. The experts reached consensus on significant factors that were used to formulate a survey questionnaire administered to the stakeholders in GCI to collect quantitative data. The five hypotheses formulated were tested using quantitative study, and validated with a survey questionnaire administered to professionals in the CI. PLS-SEM was also used as an analytical tool to contribute to the methodology for investigating SC practices, which is being adopted increasingly by researchers. The use of qualitative and quantitative approaches to complement each other helped to ensure that the research methodology demonstrated adequate knowledge required to achieve the objectives of this study.

### 7.4.2 Contributions of the roadmap

The integration of SC measures is low in the GCI and the industry is a major user of natural resources and contributes to global warming. The strategy for carbon and ecological impacts reduction can help to fight global warming. However, publicity and creation of awareness about SC over the years has been slow. This study will promote awareness between stakeholders in the GCI to address the knowledge gap in the SC concept as a means to attaining sustainability in Ghana. The proposed roadmap could be used to support experts in the building sector to identify strategies and knowledge to encourage the adoption of the right attitude towards the implementation of SC practices in Ghana. Other researchers can build on the following findings:

- The current state of SC implementation in Ghana is at a stage of infancy and progressing at a slow pace.
- The study also helps to create awareness and serves as a knowledge base for the stakeholders to adopt and implement SC practices successfully in GCI.
- The study serves as a guide to the manufacturers and suppliers desirous of taking advantage of the SC concept to enhance their competitiveness.
- Furthermore, the significant benefits of SC in GCI are identified in the study. This could motivate the stakeholders to adopt SC practices to derive the needed benefits.
- The developed roadmap serves as an implementation tool for stakeholders to adopt SC practices in GCI. The objective of the roadmap is to provide a direction for SC to reduce carbon and ecological footprints of construction activity.

## 7.5 RESEARCH LIMITATION

This research achieved its objectives, but some identified limitations include:

- This research was conducted in Ghana as emerging country and was focused on building construction projects. The short period of the research made it impossible to consider other areas of the construction industry and other countries to broaden the scope to an international dimension.
- The study was focused on questionnaire survey and Delphi techniques to collect data, without conducting interviews and case studies to obtain in-depth appreciation of SC practices in GCI.
- The developed roadmap has not been tested on a live project but was evaluated by professionals in GCI.

## 7.6 RECOMMENDATIONS

The following suggestions are made for future studies to enhance the sustainability concept and lessen the negative environmental effects of building activities based on the research findings and conclusions in this study:

- Similar studies should be carried out by the academia in other emerging countries in the West African sub-regions to compare findings with this study for a possible, sub-regional roadmap to be developed to promote SC in the sub-region to help to achieve the SDGs.
- This research was focused on building projects only in GCI. Therefore, similar study is suggested to be carried out by academia and industry to expand the coverage to consider the whole construction sector.
- A quantitative survey and Delphi techniques were adopted for the research to gather information from a wide section of stakeholders about SC roadmap to reduce carbon and ecological footprints of construction activity in GCI. Future study should concentrate on case studies and interviews to get a more in-depth understanding of SC in GCI.
- The roadmap could be enhanced further into a commercial package with further research.
- From the study, while there is a high degree of awareness of SC its implementation is immature in Ghana. Further research is recommended to conduct empirical enquiry into

SC practices in the GCI to deepen the level of knowledge to whip interest for implementation of SC in the GCI.

Also, government, academia and industry could adapt the following recommendations to advance the implementation of SC in GCI:

- The roadmap should be used to deepen the adoption of SC practices in GCI to reduce carbon and ecological footprints of construction activity.
- Using the roadmap, innovation should be used by stakeholders to inform construction companies, through workshops, seminars and radio/television programmes in Ghana, about implementing SC practices.
- The stakeholders in the GCI should strive to adopt SC practices to reduce carbon and ecological footprints of construction activity.

The recommendations for policy are as follows:

- The government should open offices of the GGBC in all the Assemblies to intensify the creation of awareness and promote the implementation of SC. SC should be represented in the Physical Development Planning Committee in the various Assemblies to co-ordinate the efforts of the Environmental Protection Agency in development permit processing and provide guidance for adopting SC.
- To lessen the damaging effects of construction activities on the environment, the government of Ghana should implement financial incentives for construction firms and professionals in the CI that adopt the best sustainability practices.

## 7.7. CHAPTER SUMMARY

It can be concluded that the recommendations of this research made and presented in this chapter are insightful. This chapter included the main conclusions from the six objectives of the research and a significance summary of value to both theory and practice. Although the study findings are limited to the built environment in Ghana, analytic generalisation is possible to apply the findings to other African countries that have similar conditions.

**REFERENCES**


Adabre, M. A., & Chan, A. P. (2020). Towards a sustainability assessment model for affordable housing projects: The perspective of professionals in Ghana. *Engineering, Construction and Architectural Management*, *27*(9), 2523-2551.

Adjarko, H., Agyekum, K., Ayarkwa, J., & Amoah, P. (2016). Implementation of environmental sustainable construction principles in the Ghanaian Construction Industry. *International Journal of Engineering and Management. 6*(2). 585-593.

African Development Bank Group. (2013). African Statistical. *Yearbook 2013*: Tunis.

Afzal, F., Lim, B., & Prasad, D. (2017). An investigation of corporate approaches to sustainability in the construction industry. *Procedia Engineering, 180,* pp. 202-210. doi: 10.1016/j.proeng.2017.04.179

Ahiabu, M. K., Emuze, F. A. & Das, D. K. (2023). Perception of the benefits of sustainable construction in Ghana. *Journal of Built Environment Project and Asset Management*. 13(2). 306-323. https://doi.org/10.1108/BEPAM-06-2022-0088.

Ahiabu, M. K., Emuze, F. A., & Das D. K. (2022). A review of sustainable construction practices in Ghana. In: C. Gorse, L. Scott, C. Booth, & M. Dastbaz, (eds), *Climate Emergency – Managing, Building, and Delivering the Sustainable Development Goals*, Springer, Cham. https://doi.org/10.1007/978-3-030-79450-7_9

Ahiabu, M. K., Emuze, F. & Das, D. (2021). Achieving sustainability in construction waste management in the Ghanaian Built Environment: Systemised review. In: *Proceedings of International Sustainable Ecological Engineering Design for Society (SEEDS) Conference 2021: Adapting and Changing Behaviour and Practice*, Leeds Beckett University, Leeds, United Kingdom.

Ahiabu, M. K., Emuze, F., & Das, D. (2019). A framework towards the reduction of the ecological and carbon footprint of construction activity in Ghana. In: *Proceedings of 14th International Postgraduate Research Conference: Contemporary and Future Directions in the Built Environment,* University of Salford, Manchester. pp. 525-537.

Ahmad, T., Thaheem, M. J., & Anwar, A. (2016). Developing a green-building design approach by selective use of systems and techniques. *Architectural Engineering and Design Management*, *12*(1), 29-50.

Ahmed, M., Hatira, L., & Valva, P. (2014). The construction industry in Ghana, West Africa: How can the construction industry in Ghana become sustainable? Thesis. Blekinge Institute of Technology, Sweden.

Ahmed, S., & El-Sayegh, S. (2022). The challenges of sustainable construction projects delivery–Evidence from the UAE. *Architectural Engineering and Design Management*, pp. 1-14.

Ahn, Y. H., Pearce, A. R., & Wang, G. (2013). Drivers and barriers of sustainable design and construction: The perception of green building experience. *International Journal of Sustainable Building Technology and Urban Development*, *4*(1), pp. 35-45.

Akinradewo, O., Aigbavboa, A., Oke, A., & Coffie, H. (2019). The Ghanaian Construction Industry and road infrastructure development: A review, in *Proceedings of 14th International Postgraduate Research Conference: Contemporary and Future Directions in the Built Environment,* University of Salford, Manchester, pp. 340-349.

Aktas, B., & Ozorhon, B. (2015). Green building certification process of existing buildings in developing countries : Cases from Turkey. *Journal of Management in Engineering*, *31*(6). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000358.

Ali, A., Mahfouz, A., & Arisha, A. (2017). Analysing supply chain resilience: Integrating the constructs in a concept mapping framework via a systematic literature review, *Supply Chain Management: An International Journal*, *22*(1), 16-39.

Alsanad, S. (2015). Awareness, drivers, actions, and barriers of sustainable construction in Kuwait. *Procedia Engineering 118*, pp. 969–983). Elsevier B. V. https://doi.org/10.1016/j.proeng.2015.08.538.

Ametepey, S. O., & Ansah, S. K. (2015). Impact of construction activity on the environment: The case of Ghana. *Journal of Environment and Earth Sciences*, pp. 18-26

Ameyaw, E. E., Hu, Y., Shan, M., Chan, A. P., & Le, Y. (2016). Application of Delphi method in construction engineering and management research: a quantitative perspective. *Journal of Civil Engineering and Management*, *22*(8), 991-1000.

Ampratwum, G., Agyekum, K., Adinyira E., & Duah, D. (2019). A framework for the implementation of green certification of buildings in Ghana, *International Journal of Construction Management*, doi: 10.1080/15623599.2019.1613207

Anzagira, L. F., Badu, E., & Duah, D. (2019a). Towards an uptake framework for the green building concept in Ghana: A theoretical review. *International Journal on Proceedings of Science and Technology*, 57-76.

Arora, N. K., & Mishra, I. (2019). United Nations Sustainable Development Goals 2030 and environmental sustainability: Race against time. *Environmental Sustainability*, *2*(4), 339-342.

Asamoah, R. O., & Decardi-Nelson, I. (2014). Promoting trust and confidence in the construction industry in Ghana through the development and enforcement of ethics. *Information and Knowledge*, *3*(4), 63-68.

Asman, G. E., Kissi, E., Agyekum, K., Baiden, B. K., & Badu, E. (2019). Critical components of environmentally sustainable buildings design practices of office buildings in Ghana. *Journal of Building Engineering*, *26*, 100925.

Atif, A., Richards, D. & Bilgin, A. (2013). A student retention model: Emperical, theoretical and pragmatic considerations. In: *Proceedings of the 24th Australasian Conference on Information Systems*. Melbourne, Australia

Atombo, C., Dzantor, J. C. K., & Agbo, A. A. (2015). Integration of sustainable construction in project management: A case study in Ghana. *International Journal of Construction and Management*, *4*(1), 13-25.

Avella, J. R. (2016). Delphi panels: Research design, procedures, advantages and challenges. *International Journal of Doctoral Studies, 11*, 305-321

Ayarkwa, J., Acheampong, A., Wiafe, F., & Boateng B. E. (2017). Factors affecting the implementation of sustainable construction in Ghana: The architect's perspective. In: *Proceedings* of *International Conference on Infrastructure Development in Africa, 6*, pp. 377-386.

Ayarkwa, J., Opoku, D. G. J., Antwi-Afari, P., & Li, R. Y. M. (2022). Sustainable building processes' challenges and strategies: The relative important index approach. *Cleaner Engineering and Technology*, *7*, 100455.

Bahr, C. M. (2022). Change the way we live. WWF-Hong Kong. https://www.wwf.org.hk/en/cities/footprint/

Baker, D. J. (2016). The purpose, process, and methods of writing a literature review. *AORN Journal.* 3(103), 265-269.

Bangdome-Dery, A., & Kootin-Sanwu, V. (2013). Analysis of barriers (factors) affecting architects in the use of sustainable strategies in building design in Ghana. *Research Journal in Engineering and Applied Sciences, 2*(6). 418-426.

Bash, E., & Hakkinen, T. (2015). Barriers and drivers for sustainable building. PhD Proposal, 1.

Berman, J. J. (2013). *Principles of Big Data: Preparing, Sharing, and Analyzing Complex Information*. Newnes.

Borrego, M., Foster, M. J., & Froyd J. E. (2014). Systematic literature reviews in engineering education and other developing interdisciplinary fields. *Journal of Engineering Education, 103*, pp. 45-76

Bridgewater, P. (2016). The Man and Biosphere programme of UNESCO: Rambunctious child of the sixties, but was the promise fulfilled? *Current Opinion in Environmental Sustainability, 19*, pp. 1–6. doi: 10.1016/j.cosust.2015.08.009

Carmichael, D. G., Malcolm, C. J. & Balatbat, M. C. A. (2014). Carbon abatement and its cost in construction activities. In: *Proceedings of the construction research congress*, University of New South Wales, Sydney Australia, pp. 534-542.

Chau, C. K., Leung, T. M., & Ng, W. Y. (2015). A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings. *Applied energy*, *143*, 395-413.

Chawla, D., & Joshi, H. (2021). Importance-performance map analysis to enhance the performance of attitude towards mobile wallet adoption among Indian consumer segments. *Aslib Journal of Information Management*, *73*(6), 946-966. https://doi.org/10.1108/AJIM-03-2021-0085

Chen, X., Yang, H., & Lu, L., (2015). A comprehensive review on passive design approaches in green building rating tools. *Renewable and Sustainable Energy Reviews, 50*, pp. 1425-1436.

Connell, E., Bakel, A. V., & Emuze, F. (2016). Global sustainable perspective X3: North America, Europe, and Africa. In: *Proceedings of the 20th CIB World Building Congress, Intelligent Built Environment for Life*, Tampere, Finland, pp. 152-162.

Crawford, R. H., Mathurb, D., & Gerritsen, B. (2017). Barriers to improving the environmental performance of construction waste management in remote communities, *Procedia Engineering 196*, pp. 830 – 837.

Creswell, J. W. (2014). *Research design: Qualitative, Quantitative, & Mixed Methods Approaches*. 4th edition. California: SAGE Publications.

Creswell, J. W., & Clark, V. P. 2018. *Designing and Conducting Mixed Method Research*. 3rd edition. Thousand Oaks: SAGE Publications.

Darko, A., & Chan, A. P. C. (2016). Critical analysis of green building research trend in construction journals. *Habitat International, 57*, pp. 53-63. https://doi.org/10.1016/j.habitatint.2016.07.001.

Darko, A., Chan, A. P. C., & Owusu, E. K. (2018). What are the green technologies for sustainable housing development? An empirical study in Ghana. *Business Strategy & Development, 1*(2), 140-153. https://doi.org/10.1002/bsd2.18

Darko, A., Zhang, C., & Chan, A. P. C. (2017). Drivers for green building: A review of empirical studies, *Habitat International, 60*, pp. 34-49. http://dx.doi.org/10.1016/j.habitatint.2016.12.007

Darko, E., Nagrath, K., Niaizi, Z., Scott, A., Varsha, D., & Vijaya Lakshmi, K. (2013). *Green building: case study*, Overseas Development Institute.

Das, O., Bera, P., & Moulick, S. (2015). Water conservation aspects of green buildings. Int. J. Res. Eng. Technol, 4, pp. 75-79.

Djokoto, S., Dadzie, J., & Ohemeng-Ababio, E. (2014). Barriers to sustainable construction in the Ghanaian Construction Industry: consultants' perspective", *Journal of Sustainable Development*, *.7*, pp. 134-143.

ECG. (2015). National energy statistics 2005-2014, April 2015. http://energycom.gov.gh/file792s/Energy%20statistics_2015.pdf (accessed October 30, 2017)

Edeoja, J. A., & Edeoja, A. O. (2015). Carbon emission management in the construction industry-Case studies of Nigerian Construction Industry. *American Journal of Engineering Research*, *4*, pp. 112-122.

El-Hassan, H., & Kianmehr, P. (2016). Pervious concrete pavement incorporating GGBS to alleviate pavement runoff and improve urban sustainability. *Road Materials and Pavement Design*, *19*(1), 167-181.

Emuze, F. A. (2015). Behaviourism versus leadership: A transformational need for sustainability in the built environment. In *Leadership and Sustainability in the Built Environment*, pp. 32-46. Routledge.

Emuze F. A., & Saurin, T. A. (2016). Waste in construction: Concepts and type. In: F. A. Emuze. *Value and Waste in Lean Construction*, pp. 7-14. New York: Routledge.

Emuze, F., & Smallwood, J. J. (2014). Collaborative working in South African construction: Contractors' perspectives. *Journal of Engineering, Design and Technology*.

Emuze, F., & Smallwood, J. (2013). The integration of health and safety (H&S), lean and sustainability in construction: A literature review. In: *Proceedings of the 21st Conference of the International Group of Lean Construction* (IGLC), Fortaleza, Brazil, pp. 853-862.

Fakfare, P., & Manosuthi, N. (2022). Examining the influential components of tourists' intention to use travel apps: The importance–performance map analysis. *Journal of Hospitality and Tourism Insights*. https://doi.org/10.1108/JHTI-02-2022-0079

Faryadi, Q. (2019). PhD thesis writing process: A systematic approach -- How to write your methodology, results and conclusion. *Online Submission*, *10*, 766-783.

Flint, R. W. (2013). *Basics of Sustainable Development. Practice of Sustainable Community Development*, pp. 25-54. doi:10.1007/978-1-4614-5100-6_2

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, *18*(1), 39-50. https://doi.org/10.20546/ijcrar.2016.409.006

Franceschinis, C., Thiene M., Scarpa, R., Rose, J., Moretto, M., & Cavalli, R. (2017). Adoption of renewable heating systems: An empirical test of the diffusion of innovation theory, *Energy*, *125*(C), 313-326. Elsevier. doi: 10.1016/j.energy.2017.02.060

Garcia-Olivares, A. (2015). Sustainability of electricity and renewable materials for fossil fuels in a post-carbon economy. *Energies 8*(12), 13308-13343.

Ghana Green Building Council (GHGBC). (2019). About Us. [Accessed 2019 July 17]. http://www.ghgbc.org/whoweare

Ghana Statistical Service. (2014). Gross Domestic Product, Accra: Ghana Statistical Service, National Account and Economic Indicators Division.

Ghoddousi, P., Nikmehr, B., Hosseini, M. R., Chileshe, N., & Rameezdeen, R. (2015). Barriers to construction and demolition waste management in developing countries: Case of Iran, *Unmaking Waste*, 22-24.

Global Footprint Network. (2019). Advancing the science of sustainability: How ecological footprint accounting helps us recognize that engaging in meaningful climate action is critical

for our own success. https://www.footprintnetwork.org/2017/11/09/ecological-footprint-climate-change/
Goel, A., Ganesh, L. S., & Kaur, A. (2019a). Sustainability assessment of construction practices in India using inductive content analysis of research literature. *International Journal of Construction Management*, pp. 1-14. DOI:10.1080/15623599.2019.1583851
Goel, A., Ganesh, L. S., & Kaur, A. (2019b). Sustainability integration in the management of construction projects: A morphological analysis of over two decades' research literature. *Journal of Cleaner Production. 236* pp. 117676.
Gou, Z., & Xie, X. (2016). Evolving green building: Triple bottom line or regenerative design, *Journal of Cleaner production*, pp. 1-8.
Gray, K. (2014). Harm concerns predict moral judgments of suicide: Comment on Rottman, Kelemen and Young (2014). *Cognition*, *133*(1), 329-331. (GSS, 2014).
Gyamfi, J., Plange-Rhule, J., Iwelunmor, J., Lee, D., Blackstone, S. R., Mitchell, A., & Ogedegbe, G. (2017). Training nurses in task-shifting strategies for the management and control of hypertension in Ghana: A mixed-methods study. *BMC Health Services Research*, *17*(1), 1-9.
Habibi, A., Sarafrazi, A., & Izadyar, S. (2014). Delphi technique theoretical framework in qualitative research. *The International Journal of Engineering and Science*, *3*(4), 8-13.
Hair Jr., J. F. (2021). Next-generation prediction metrics for composite-based PLS-SEM. *Industrial Management & Data Systems*, *121*(1), 5-11. https://doi.org/10.1108/IMDS-08-2020-0505
Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *European Business Review*, *31*(1), 2-24. https://doi.org/10.1108/EBR-11-2018-0203
Hallowell, M. R., & Gambatese, J. A. (2010). Qualitative research: Application of the Delphi method to CEM research. *Journal of construction engineering and management*, *136*(1), 99.
Hamid, Z. A., Zain, M. Z. M. & Roslan, A. F. (2016). Sustainable construction waste management. INGENIEUR, *66*.
Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science*, *43*(1), 115-135. https://doi.org/10.1007/s11747-014-0403-8
Hong, J. K., Shen, G. Q. P., Feng, Y., Lau, W. S. T., & Chao, M. (2015). Greenhouse gas emission during the construction phase of a building: A case study in China. *Journal of Cleaner Production*, *103*, pp. 249-259.
Huang, B., Wang, X., Kua, H., Geng, Y., Bleischwitz, R., & Ren, J. (2018). Construction and demolition waste management in China through the 3R principle. *Resources, Conservation and Recycling, 129, 36-44.* doi: 10.1016/j.resconrec.2017.09
Huang, L., Krigsvoll, G., Johansen, F., Liu, Y., & Zhang, X. (2018). Carbon emission of global construction sector. *Renewable and Sustainable Energy Reviews, 81*, Part 2, 1906-1916. https://doi.org/10.1016/j.rser.2017.06.001
Huang, W., Li, F., Cui, S., Li, F., Huang, L., & Lin, J. (2017). Carbon footprint and carbon emission reduction of urban buildings: A cases in Xiamen City, in Proceedings of Urban Transitions Conference, Shanghai, China, *Procedia Engineering*, *198*, pp. 1007-1017.
Hussin, J. M., Rahman, I. A., & Memon, A. H. (2013). The way forward in sustainable construction: Issues and challenges, *International Journal of Advances in Applied Sciences (IJAAS)*, *2*, No.1, pp. 31-42 ISSN: 2252-8814: http://iaesjournal.com/online/index.php/IJAAS

Joyner, H. S., & Smith, D. (2015). Using Delphi surveying techniques to gather input from non-academics for development of a modern dairy manufacturing curriculum. *Journal of Food Science Education*, *14*(3), 88-115.
Kaklauskas, A., & Gudauskas, R. (2016). Intelligent decision-support systems and the Internet of Things for the smart built environment. In: F. Pacheco-Torgal, E. Rasmussen, C. Granqvist, V. Ivanov, A. Kaklauskas, & S. Makonin, (eds). *Start-Up Creation*, Woodhead Publishing, pp. 413-449, ISBN 9780081005460, https://doi.org/10.1016/B978-0-08-100546-0.00017-0
Kats, G. (2013). Green building cost and financial benefits, Massachusetts Technology Collaborative, Boston, MA
Kee, K. F. (2017). Adoption and Diffusion. In: C. Scott, & L. Lewis, (eds). *The International Encyclopedia of Organizational Communication*, pp. 1–14. Hoboken, NJ: Wiley-Blackwell.
Khoshbakht, M., Gou, Z., & Dupre, K. (2017). Cost-benefit prediction of green buildings: SWOT analysis of research methods and recent applications", *Procedia Engineering*, *180*, pp. 167-178.
Kibert, C. J. (2016). *Sustainable Construction: Green Building Design and Delivery*. John Wiley & Sons.
Kibwami, N., & Tutesigensi, A. (2016). Enhancing sustainable construction in the building sector in Uganda. *Habitat International*, pp 64-73.
Kim, D. D., Wilkinson, C. L., Pope, E. F., Chambers, J. D., Cohen, J. T., & Neumann, P. J. (2017). The influence of time horizon on results of cost-effectiveness analyses. *Expert Review of Pharmacoeconomics & Outcomes Research, 17*(6), 615–623. doi:10.1080/14737167.2017.133143
Kivunja, C., & Kuyini, A. B. (2017). Understanding and applying research paradigms in educational contexts. *International Journal of Higher Education*, *6*(5), 26-41.
Kongela, S. M. (2021). Sustainability potential awareness among built environment stakeholders: Experience from Tanzania, *International Journal of Building Pathology and Adaptation*, (ahead-of-print), https://doi.org/10.1108/IJBPA-09-2020-0082
Kumi, E. N. (2017). The electricity situation in Ghana: Challenges and opportunities. Washington, DC: Center for Global Development. p. 30
Lai, X., Liu, J., Shi, Q., Georgiev, G., & Wu, G. (2017). Driving forces for low carbon technology innovation in the building industry: A critical review, *Renew. Sustain. Energy Rev*. *74*, pp. 299-315
Lee J, Mccuskey Shepley M, & Choi, J. 2019. Exploring the effects of a building retrofit to improve energy performance and sustainability: A case study of Korean public buildings. *J Build Eng*. *25*, 100822.
Li, S., & Wang, H. (2018). Traditional literature review and research synthesis. *The Palgrave Handbook of Applied Linguistics Research Methodology*, pp. 123-144.
Linares-Espinós E., Hernández V., Domínguez-Escrig J. L., Fernández-Pello S., Hevia V., & Mayor, J. (2018). Metodología de una revisión sistemática. Actas Urol Esp. https://doi.org/10.1016/j.acuro.2018.01.010
McBride, M. D. (2015). *A modified Delphi approach to posttraumatic stress disorder and leadership theory*. Doctoral dissertation, University of Phoenix.
Meex, E., Hollberg, A., Knapen, E., Hildebrand, L., & Verbeeck, G. (2018). Requirements for applying LCA-based environmental impact assessment tools in the early stages of building design. *Building and Environment*, *133*, pp. 228-236.
Mello, N. (2022). What is ecological footprint vs carbon footprint? How to calculate both. Carbon and ecological footprint calculator. Urbandesignplanning.blog

Mensah, S., Ayarkwa, J., & Nani, G. (2015). Understanding environmental sustainable construction practices of construction contractors in Ghana. *Proceedings of the 4th international conference on infrastructure development in Africa (ICIDA)*. Ghana, pp. 329-340.

Mersal, A. (2017). Eco city challenge and opportunities in transferring a city in to green city. *Procedia Environmental Sciences*, *37*, pp. 22-33.

Metzler, K. (2014). *An Introduction to Qualitative Research Uwe Flick*. 5th edition. California: SAGE Publications.

Ministry of Water Resources Works and Housing. (2017). Sector Strategic Medium Term Development Plan for 2018-2021).

Mohaddesi, O., & Harteveld, C. (2020, November). The importance of pilot studies for gamified research: Pre-testing gamettes to study supply chain decisions. In *Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play*, pp. 316-320.

Mohammed, M., Shafiq, N., Abdallah, N. A. W., Ayoub, M., & Haruna, A. (2020). A review on achieving sustainable construction waste management through application of 3R (reduction, re-use, recycling): A lifecycle approach, *IOP Conf. Ser.: Earth Environ. Sci.*, *476*(012010) 1-9.

Moradibistouni, M., Vale, B., & Isaacs, N. (2018). Evaluating sustainability of prefabrication methods in comparison with traditional methods. *Smart Innovation, Systems and Technologies*, pp. 228–237. doi:10.1007/978-3-030-04293-6_2

Mustafa, Y., & Bakis, A. (2015). Sustainability in the construction sector. In: *Proceedings of World Conference on Technology, Innovation and Entrepreneurship, Procedia – Social and Behavioural Sciences*, *195*, pp. 2253-2262.

Niederberger, M., & Spranger, J. (2020). Delphi Technique in Health Sciences: A map, *Front. Public Health*, *8*, pp. 457, doi: 10.3389/fpubh.2020.00457

Noble, H. & Smith, J. (2015). Issues of validity and reliability in qualitative research. *Evidence-based nursing*, *18*(2), 34-35.

Nurick, S. D., & Cattell, K. (2013). An investigation into the mechanisms driving large property owning organisations to implement green building features. In *Proceedings of the South African Council for Quantity Surveyors Profession (SACQSP) 2013 Conference*, pp. 20-21.

Ofori-Kuragu, J. K., Owusu-Manu, M., & Ayarkwa, J. (2016). The case for a construction industry council in Ghana. *Journal of Construction in Developing Countries*, *21*(2), 131-149. https://dx.doi.org/10.21315/jcdc2016.21.2.7

Ogbeifun, E., Mbohwa, C., & Pretorius, J. H. C. (2017). Achieving consensus devoid of complicity: Adopting the Delphi technique. *International Journal of Productivity and Performance Management*.

Ogungbile, A. J., & Oke, A. E. (2019). Sustainable construction practices in West African Countries. In: Motoasca E., Agarwal, A., & Breesch, H. (eds). Energy Sustainability in Built Environment. *Energy, Environment, and Sustainability*. Springer, Singapore.

Oguntona, O. A., Akinradewo, O. I., Ramorwalo, D. L., Aigbavboa, C. O., & Thwala, W. D. (2019). Benefits and drivers of implementing green building projects in South Africa. International Conference on Engineering for Sustainable World. *Journal of Physics: Conference Series*. IOP Publishing, doi:10.1088/1742-6596/1378/3/032038

Ojo-Fafore, E., Aigbavboa, C., & Remaru, P. (2018). Benefits of green buildings, *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Bandung, Indonesia, IEOM Society International.

Oke, A. E., & Aigbavboa, C. O. (2017). *Sustainable Value Management for Construction Projects*, Springer, Switzerland.

Oluwunmi, A. O., Oladayo, O. P., Role, B. A., & Afolabi, T. O. (2019). Benefits and barriers to the implementation of green building standards in universities: What are students' view? *1st International Conference on Sustainable Infrastructural Development*, IOP Publishing, 640.

Opoku, A. (2016). SDG2030: A sustainable built environment's role in achieving the post-2015 United Nations Sustainable Development Goals, in P.W. Chan, & C. J. Neilson, (eds), *Proceedings 32nd Annual ARCOM Conference, 5-7 September 2016, Manchester UK*, Association of Researchers in Construction Management, *3*, pp. 1101-1110.

Opoku, A., & Ahmed, V. (2014). Embracing sustainability practices in UK construction organizations: Challenges facing intra-organizational leadership. *Built Environment Project and Asset Management. 4*(1), 90-107.

Opoku, D. G. J., Ayarkwa, J., & Agyekum, K. (2019). Barriers to environmental sustainability of construction projects. *Smart and Sustainable Built Environment*.

Osei, V. (2013). The construction industry and its leakages to the Ghanaian Economic-Policy to improve the sector's performance. European Centre for Research Training and Development, *International Journal of Development and Economic Sustainability, 1*, pp. 56-72.

Osei-Kyei, R., & Chan, A. P. (2015). Review of studies on critical success factors for public private partnership projects from 1990 – 2013, *International Journal of Project Management, 33*(6), 1335-1346.

Osmani, M., & Villoria-Sáez, P. (2019). Current and emerging construction waste management status, trends and approaches. *Waste*, pp. *365-380.*

Pandey, S., & Swaroop, S. (2021). Environmental impact assessment in India and the challenges ahead. *International Journal of Law Management and Humanities*. *4*(3).

Radu, A. L., Scrieciu, M. A., & Caracota, D. M. (2013). Carbon footprint analysis: Towards a projects evaluation model for promoting sustainable development. In: Proceedings of the International Economic Conference of Sibiu Post Crisis Economy: Challenges and Opportunities. *Procedia Economics and Finance*, pp. 353-363.

Rahim, F. A., Muzaffar, S. A., Mohd Yusoff, N. S., Zainon, N., & Wang, C. (2014). *Sustainable construction through life cycle costing.* Malaysia: The Royal Institute of Surveyors, Available online at: http://spaj.ukm.my/jsb/index.php/jbp/index

Rajabi, S., El-Sayegh, S., Romdhane, L. (2022). Identification and assessment of sustainability performance indicators for construction projects. *Jounal of Environmental and Sustainability Indicators*, *15*. https://doi.org/10.1016/j.indic.2022.100193

Ramayah, T., Cheah, J., Chuah, F., Ting, H., & Memon, M. A. (2018). *Partial Least Squares Structural Equation Modeling (PLS-SEM) Using Smartpls 3.0: An Updated Guide and Practical Guide to Statistical Analysis.* 2nd edition. Pearson.

Ravitch, S. M., & Riggan, M. (2017). *Reason & rigor: How conceptual frameworks guide research*. 2nd Edition. SAGE.

Ringle, C. M., & Sarstedt, M. (2016). Gain more insight from your PLS-SEM results the importance-performance map analysis. *Industrial Management and Data Systems*, *116*(9), 1865–1886. https://doi.org/10.1108/IMDS-10-2015-0449.

Ringle, C. M., Sarstedt, M., Mitchell, R., & Gudergan, S. P. (2020). Partial least squares structural equation modeling in HRM research. *International Journal of Human Resource Management*, *31*(12), 1617–1643. https://doi.org/10.1080/09585192.2017.1416655

Robson, C., & Mccartan, K. (2016). *Real World Research*. 4th edition. New York City: John Wiley & Sons Ltd.

Roufechaei, K. M., Bakar, A. H. A., & Tabassi, A. A. (2014). Energy-efficient design for sustainable housing development. *Journal of Cleaner Production, 65*, pp. 380-388.

Sadigov, R. (2022). Rapid growth of the world population and its socioeconomic results. *The Scientific World Journal*, *2022*. https://doi.org/10.1155/2022/8110229

Saleh, M. S., & Alalouch, C. (2015). Towards sustainable construction in Oman: Challenges and opportunity. In: Proceedings of the International Conference on Sustainable Design, Engineering and Construction. *Procedia Engineering*, *118*, pp. 177-184.

Sandanayake, M. S. (2022). Environmental impacts of construction in building industry – A review of knowledge advances, gaps and future directions. *Knowledge*, *2*(1), 139-156.

Sarstedt, M., Ringle, C. M., Smith, D., Reams, R., & Hair, J. F. (2014). Partial least squares structural equation modeling (PLS-SEM): A useful tool for family business researchers. *Journal of Family Business Strategy*, *5*(1), 105-115. https://doi.org/10.1016/j.jfbs.2014.01.002

Saunders, M., Lewis, P., & Thornhill, A. (2019). *Research Methods for Business Students*. 8th edition. Harlow: Pearson Education Limited.

Seo, M., Kim, T., Hong, G., & Kim, H. (2016). On-site measurement of $CO_2$ emission during the construction phase of a building complex. Available online at: http://www.mdpi.com/journal/energy

Shabrin, N., & Kashem, S. B. (2017). A comprehensive cost/benefit analysis of green building, in *Proceedings of 94th IIER International Conference, Dhaka, 1851 Bangladesh, 1-2 February*.

Shen, L., Yan, H., Fan, H., Wu, Y., & Zhang, Y. (2017). An integrated system of text mining technique and case-based reasoning (TM-CBR) for supporting green building design, *Building and Environment*, *124*, pp. 388-401.

Sheth, D. (2017). Water efficient technologies for green buildings. *International Journal of Engineering Innovation and Scientific Research ISSN* (online), pp. 2395-6372.

Sheth, J. (2017). Revitalizing relationship marketing. *Journal of Services Marketing*.

Shmueli, G., Sarstedt, M., Hair, J. F., Cheah, J. H., Ting, H., Vaithilingam, S., & Ringle, C. M. (2019). Predictive model assessment in PLS-SEM: Guidelines for using PLSpredict. *European Journal of Marketing*, *53*(11), 2322–2347. https://doi.org/10.1108/EJM-02-2019-0189

Sichali, M., & Banda, L. J. (2017). Awareness, attitudes and perception of green building practices and principles in the Zambian Construction Industry. *International Journal of Construction Engineering and Management*, *6*(5), 215-220. doi: 10.5923/j.ijcem.20170605.04

Simonen, K., Huang, M., Rodriguez, B. X., & Todaro, L. (2019). *Life Cycle Assessment of Buildings: A Practice Guide*. The Carbon Leadership Forum, Department of Architecture, University of Washington. Version 1.1. www.carbonleadershipforum.org

Simpeh, E. K., & Smallwood, J. (2018). Analysis of the benefits of green building in South Africa, *Journal of Construction Project Management and Innovation*, *8*(2), 1829-1851.

Stanitsas, M., & Kirytopoulos, K. (2021). Investigating the significance of sustainability indicators for promoting sustainable construction project management. *International Journal of Construction Management*, pp. 1-26. doi:10.1080/15623599.2021.18877.

Švajlenka, J., & Kozlovská, M. (2020). Evaluation of the efficiency and sustainability of timber-based construction. *Journal of Cleaner Production*, *259*, 120835.

Tupenaite, L., Lill, I., Geipele, I., & Naimaviciene, J. (2017). Ranking of sustainability indicators for assessment of the new housing development projects: Case of the Baltic States. *Resources*, *6*(4), 55.

Udomsap, A. D., & Hallinger, P. (2020). A bibliometric review of research on sustainable construction, 1994-2018. *Journal of Cleaner Production*, 120073. doi: 10.1016/j.jclepro.2020.1200.

United Nations Department of Economics and Social Affairs, UNDESA, (2017), *The world population prospects: The 2017 revision*, https://www.un.org/development/desa/en/news/population/world-population-prospects, (Accessed 20th July 2020).

United Nations Environmental Programme (UNEP). (2015). Indicators for green economy policymaking – A sysnthesis report of studies in Ghana, Mauritius and Uruguay. pp 1-36.

United Nations Population Fund. (2017). World population trends. http://www.unfpa.org/world-population-trends#sthash.W8sxbe5P.dpuf

Usakli, A., & Kucukergin, K. G. (2018). Using partial least squares structural equation modeling in hospitality and tourism: Do researchers follow practical guidelines? *International Journal of Contemporary Hospitality Management*, *30*(11), 3462–3512. https://doi.org/10.1108/ijchm-11-2017-0753

Valaei, N., & Jiroudi, S. (2016). Job satisfaction and job performance in the media industry: A synergistic application of partial least squares path modelling. *Asia Pacific Journal of Marketing and Logistics*, *28*(5), 984–1014. https://doi.org/10.1108/APJML-10-2015-0160

Valdés, H., Correa, C., Mellado, F. (2018). Proposed model of sustainable construction skills for engineers in Chile. *Sustainability*, *10*, 3093. https://doi.org/10.3390/su10093093

Vatalis, K. I., Manoliadis, O., Charalampides, G., Platias, S., & Savvidis, S. (2013). Sustainability components affecting decisions for green building Projects. *Procedia Economics and Finance*, *5*, pp.747-756.

Vinorkor, M. A. (2020). Evolution of the regions. *Graphic online*. (Retrieved 21 0ctober, 2020).

Whang, A. J. W., Chen, Y. Y., Yang, T. H., Lin, Y. L., Tseng, W. C., & Chen, H. C. (2020). High-efficiency confocal paraboloids coupler design for natural light illumination systems. *Solar Energy*, *195*, pp. 129-137

Whang, S. W., & Kim, S. (2015). Balanced sustainable implementation in the construction industry: The perspective of Korean contractors, *Energy Building*. *96*, 76–85.

Windapo, A. O. (2014). Examination of green building drivers in South African construction industry: economics versus ecology. *Sustainability*, *6*(9), 6088-6106.

World Commission on Environment and Development (WCED). (1987). Our common future: Brundtland Report of the World Commission on Environment and Development, New York: United Nations General Assembly.

Yang, M., & Yu, X. (2015). Energy-Efficient Technologies. In *Energy Efficiency, Green Energy and Technology*, pp. 113-126, doi: 10.1007/978-1-4471-6666-5_10. Springer-Verlag, London.

Yao, R. (2013). Sustainability in the built-environment. In: Yao, R. (ed.). *Design and management of sustainable built environments*. London: Springer-Verlag, pp. 1- 22.
Yeheyis, M., Hewage, M., Alam, M. S., Eskicioglu, C., & Sadiq, R. (2013). An overview of construction and demolition waste management in Canada: A life-cycle analysis approach to sustainability, *Clean Technologies and Environmental Policy*, *15*(1), 81–91.
Yin, R. K. (2014). *Case Study Research: Design and Methods*. 5th edition. Thousand Oaks, California: SAGE Publications.
Yu W-D, Cheng S-T, Ho W-C, Chang Y-H. 2018. Measuring the sustainability of construction projects throughout their lifecycle: A Taiwan lesson. *Sustainability. 10*(5): 1523.
Zainordin, N., & Zahra, D. B. F. (2020). Factors contributing to carbon emission in construction activity. Proceeding of the third international conference on separation technology. *Advances in Engineering Research*. *Atlantis press. 200*, pp. 176-182.
Zou, P., Hardy, R., & Yang, R. (2015). Barriers to building and construction waste reduction, re-use and recycling: A case study of the Australian capital region. In: M. Panko and L. Kestle (eds.). Building today - Saving tomorrow: Sustainability. In: *Construction and Deconstruction Conference Proceedings*, pp. 27-35.
Žukauskas, P., Vveinhardt, J., & Andriukaitienė, R. (2018). Philosophy and paradigm of scientific research. In: P. Žukauskas, J. Vveinhardt, & R. Andriukaitienė. *Management culture and corporate social responsivity*, pp. 121-139. London: IntechOpen
Zuo, J., & Zhao, Z. (2014). Green building research – current status and future agenda: A review, *Renewable and Sustainable Energy Reviews*, *30*, pp. 271-281. https://doi.org/10.1016/j.rser.2013.10.021Zuo et al., 2017).

# APPENDICES

## APPENDIX A: RECRUITMENT OF EXPERTS FOR DELPHI STUDY

**Faculty of Engineering, Built Environment and Information Technology**

May, 2020

**To Whom It May Concern**

Dear Sir/Madam,

**RE: Expert Recruitment for Delphi Study**

This instrument is to be used to recruits sustainable construction experts to participate in Delphi expert survey which is part of doctoral research work by Mr. Moses K. Ahiabu of the Central University of Technology, Free State, South Africa on the topic: ***A Roadmap for the Reduction of Carbon and Ecological Footprint of Construction Activity in Ghana***

The aim of this study is to to develop SC roadmap that helps to reduce the carbon and ecological footprint of construction activities in Ghana. The Delphi Survey will consist of a set of three (3) rounds of questions to be responded by the experts.

This particular instrument is about your demographic information to identify you as expert in sustainable construction and to confirm your availability to take part in the survey. Please note that all responses will be kept ***strictly confidential and exclusively*** for academic use only.

Should you have any queries, please do not hesitate to contact the study promoter Professor F.A. Emuze at femuze@cut.ac.za.

Your participation in this study is highly solicited. Kindly return the completed form to the researcher or obtain any further information relating to the study from the researcher at mosesahiabu@yahoo.com or mobile number 0203223884.

Thank you.

**Moses K. Ahiabu**
**(Doctoral Candidate)**

**Professor F.A Emuze**
**(Promoter)**

**DEMOGRAPHIC INFORMATION**

This section is about your demographic information to confirm you as an expert in the subject area. Please kindly type your response or use (**X**) in the required box that precedes your choice.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Name | | | | | | |
| 2 | Region in which you are working in Ghana | | | | | | |
| 3 | Please indicate your title | | | | | | |
| Professor (Prof.) | | Doctor (Dr) | | Messrs (Mr) | | Others *(Please specify)* | |
| 4 | Gender | | | | | | |
| Male | | | | Female | | | |
| 5 | Please indicate your highest level of educational qualification | | | | | | |
| Diploma/ Bachelors | | Masters | | Doctorates | | Others *(Please specify)* | |
| 6 | Please indicate your professional affiliation | | | | | | |
| GIA | | GIE | | GhIS | | Others *(Please specify)* | |
| 7 | Please select the option that best represent the institution / organisation where you are employed | | | | | | |
| Governmental Institution | | Construction Firm | | Consulting Firm | | Engineering Firm | |
| Non-Governmental Organization (NGO) | | Architectural Firm | | Academic Institution | | Others *(Please specify)* | |
| 8 | In what capacity are you involved in sustainable construction | | | | | | |
| Client / Client's Rep. | | Consultant | | Engineer | | Contractor | |
| Designer / Architect | | Construction Project Manager | | Regulator | | Researcher | |
| Others *(Please Specify)* | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | Please indicate your number of years of experience in the construction industry | | | | | | | |
| 1 – 5 years | | | 6 – 10 years | | 11 – 15 years | | 16 – 20 years | |
| 21 - 25 years | | | | | Above 25 years | | | |
| 10 | Please indicate your level of knowledge of sustainable construction | | | | | | | |
| Low | | | Moderate | | High | | Very high | |
| Are you actively engaged in sustainable construction activities (Research, project etc.) | | | | | Yes | | No | |
| 11 | Please state any construction project(s) you have worked on or know that incorporated sustainability practices to reduce carbon and ecological footprints in Ghana? | | | | | | | |
| | | | | | | | | |
| I'm willing and available to participate in the study | | | | | I will not be available to participate in the study | | | |

THANK YOU.

## APPENDIX B: DELPHI SURVEY ROUND 1

**FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY**

June, 2020

**To Whom It May Concern**

Dear Sir/Madam,

**RE: Expert Participation in Delphi Survey Round 1**

We sincerely thank you for your acceptance to participate in this study. The Delphi questionnaire is for expert survey which is part of doctoral research work by Mr. Moses K. Ahiabu of the Central University of Technology, Free State, South Africa on the topic: ***A Framework towards the Reduction of Carbon and Ecological Footprint of Construction Activity in Ghana***. The aim of this study is to develop a framework for the reduction of construction activity carbon and ecological footprint for sustainable construction in Ghana.

The Delphi Survey will consist of a set of three (3) rounds of questions to be responded by the experts. This particular Round 1 instrument is divided into six parts focusing on the sustainable construction practices and sustainability issues and any general comments.

Please note that all responses will be kept ***strictly confidential and exclusively*** for academic use. The information receive will be used to develop the questionnaire for the Delphi Round 2.

Should you have any queries, please do not hesitate to contact the study promoter Professor F.A. Emuze at femuze@cut.ac.za. Kindly return the completed form to the researcher within two (2) weeks or obtain any further information relating to the study from the researcher at mosesahiabu@yahoo.com or mobile number 0203223884.

Your acceptance and contribution towards this study is highly appreciated. Please, provide your details below if you wish to receive the result of this research. ……………….............................

***The questionnaire takes about 25minutes to complete.***

Thank you.

**Moses K. Ahiabu**
**(Doctoral Candidate)**

**Professor F.A Emuze**
**(Promoter)**

## SECTION 1: DEMOGRAPHIC INFORMATION CONFIRMATION

Kindly confirm OR correct your demographic information provided in the recruitment form, please.

| | |
|---|---|
| Title | Professor |
| Gender | Male |
| City/Region | Ashanti |
| Highest level of educational qualification | Doctorate Degree |
| Professional affiliation | Ghana Institution of Construction (GIOC) |
| Where employed | Lecturer, Academic Institution (University) |
| Capacity involved in sustainable construction | Researcher |
| Years of experience | 16 - 20 Years |
| Level of knowledge of sustainable construction | High |
| Sustainable construction activity engaged in | Published in journals and attended conferences |
| Construction project worked on or know that incorporated sustainability practices | One airport square at Accra; Stanbic height building at Accra; Ridge hospital at Accra; Baby and mother unit at Okonfor Anokye teching hospital at Kumasi |

### 1.1 General sustainable construction practices

Please kindly ***tick*** (**X**) the position that correspond to your knowledge about the importance of the following elements of sustainable construction.

| **CODE** | **Elements of sustainable construction** | How important are the following in measuring sustainable construction? **(Unimportant …………… Very important)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **2.1.1** | **Key sustainability issues** | | | | | | | | | | |
| KSI 1 | Amenities and recreation | | | | | | | | | | |
| KSI 2 | Biodiversity | | | | | | | | | | |
| KSI 3 | Climate change | | | | | | | | | | |
| KSI 4 | Community | | | | | | | | | | |
| KSI 5 | Crime and security | | | | | | | | | | |
| KSI 6 | Cultural heritage | | | | | | | | | | |
| KSI 7 | Drainage and flooding | | | | | | | | | | |
| KSI 8 | Energy efficiency | | | | | | | | | | |
| KSI 9 | Geology and soils | | | | | | | | | | |
| KSI 10 | Health, safety and well-being | | | | | | | | | | |
| KSI 11 | Human rights and ethics | | | | | | | | | | |
| KSI 12 | Landscape and visual aspect | | | | | | | | | | |
| KSI 13 | Land use | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| KSI 14 | Material consumption and conservation | | | | | | | | | | |
| KSI 15 | Pollution and nuisance | | | | | | | | | | |
| KSI 16 | Shareholder and customer relations | | | | | | | | | | |
| KSI 17 | Social inclusion and accessibility | | | | | | | | | | |
| KSI 18 | Stakeholder engagement | | | | | | | | | | |
| KSI 19 | Training and development | | | | | | | | | | |
| KSI 20 | Travel and support | | | | | | | | | | |
| KSI 21 | Waste management | | | | | | | | | | |
| KSI 22 | Harmonisation with the environment | | | | | | | | | | |
| **2.1.2** | **Sustainable construction activities** | | | | | | | | | | |
| SCA1 | Regenerate used natural vegetation | | | | | | | | | | |
| SCA2 | Use renewable construction material | | | | | | | | | | |
| SCA 3 | Reduce transportation distance for raw materials | | | | | | | | | | |
| SCA 4 | Reduce material delivery distance | | | | | | | | | | |
| SCA 5 | Reduce transportation distance of people | | | | | | | | | | |
| SCA 6 | Use of forestry-authority–certified timber | | | | | | | | | | |
| SCA 7 | Minimize carbon emissions in construction | | | | | | | | | | |
| SCA 8 | Do selective construction waste disposal | | | | | | | | | | |
| SCA 9 | Recycle construction waste | | | | | | | | | | |
| SCA 10 | Ensure efficiency in energy usage for construction works | | | | | | | | | | |
| SCA 11 | Ensure efficiency in water usage during construction | | | | | | | | | | |
| SCA 12 | Minimize dust during construction | | | | | | | | | | |
| SCA13 | Optimise site planning, building orientation, and configuration | | | | | | | | | | |
| SCA14 | Reduction of resource consumption | | | | | | | | | | |
| SCA15 | Maximisation of resource reuse | | | | | | | | | | |
| SCA16 | Protect the natural environment | | | | | | | | | | |
| SCA17 | Create a healthy and non-toxic environment | | | | | | | | | | |
| SCA18 | Pursue quality in creating the built environment | | | | | | | | | | |
| SCA19 | Apply life cycle costing | | | | | | | | | | |
| **2.1.3** | **Drivers for sustainable construction** | | | | | | | | | | |
| DFSC1 | Professional knowledge in sustainable construction | | | | | | | | | | |
| DFSC2 | Sustainable design guidelines and construction standards | | | | | | | | | | |
| DFSC3 | Willingness to incorporate sustainable building practices | | | | | | | | | | |
| DFSC4 | Availability of acceptable sustainable construction roadmap | | | | | | | | | | |
| DFSC5 | Creation of public awareness | | | | | | | | | | |
| DFSC6 | Legislation | | | | | | | | | | |
| DFSC7 | Sustainable building codes and regulations | | | | | | | | | | |
| DFSC8 | Economic incentives (tax rebates, high profit margin) | | | | | | | | | | |
| DFSC9 | Sustainability practices in educational curricula | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DFSC10 | Government commitment and support | | | | | | | | | | |
| DFSC11 | Availability of measurement tool | | | | | | | | | | |
| DFSC12 | Cooperation from technical experts | | | | | | | | | | |
| DFSC13 | Client demand and requirements | | | | | | | | | | |
| DFSC14 | Stakeholder influence | | | | | | | | | | |
| DFSC15 | Cost efficiency (whole life cycle costing) | | | | | | | | | | |
| DFSC16 | Competitive advantage | | | | | | | | | | |
| DFSC17 | Top management commitment | | | | | | | | | | |
| DFSC18 | Win more contracts to remain in business | | | | | | | | | | |
| DFSC19 | Company's reputation and brand image | | | | | | | | | | |
| DFSC20 | Availability of life cycle cost analysis | | | | | | | | | | |
| DFSC21 | Moral obligation to protect the environment | | | | | | | | | | |
| **2.1.4** | **Challenges of sustainable construction** | | | | | | | | | | |
| CSC 1 | Lack of financial incentives (high taxes and low-profit margin) | | | | | | | | | | |
| CSC 2 | Lack of building code and regulation | | | | | | | | | | |
| CSC3 | Lack of investment | | | | | | | | | | |
| CSC4 | Initial investment cost | | | | | | | | | | |
| CSC5 | Lack of client demand | | | | | | | | | | |
| CSC6 | High cost of environmental services | | | | | | | | | | |
| CSC7 | Lack of research | | | | | | | | | | |
| CSC8 | Lack of public awareness | | | | | | | | | | |
| CSC9 | Competitive pressure | | | | | | | | | | |
| CSC10 | Lack of database and information | | | | | | | | | | |
| CSC11 | Lack of green products | | | | | | | | | | |
| CSC12 | Lack of professional knowledge and expertise | | | | | | | | | | |
| CSC13 | Lack of green technology | | | | | | | | | | |
| CSC14 | Tendering and contract requirements | | | | | | | | | | |
| CSC15 | High level of perceived risk | | | | | | | | | | |
| **2.1.5** | **Benefits of sustainable construction** | | | | | | | | | | |
| **A.** | ***Environmental benefits*** | | | | | | | | | | |
| BSDC 1 | Protecting air, water, land, ecosystems | | | | | | | | | | |
| BSDC 2 | Conserving natural resources (fossil fuel) | | | | | | | | | | |
| BSDC3 | Preserving animal species and genetic diversity | | | | | | | | | | |
| BSDC4 | Protecting the biosphere | | | | | | | | | | |
| BSDC5 | Using renewable natural resources | | | | | | | | | | |
| BSDC6 | Minimizing waste production or disposal | | | | | | | | | | |
| BSDC7 | Minimizing $CO_2$ emission and pollutants | | | | | | | | | | |
| BSDC8 | Maintaining essential ecological processes and life support system | | | | | | | | | | |
| BSDC9 | Pursuing active recycling | | | | | | | | | | |
| BSDC10 | Maintaining integrity of environment | | | | | | | | | | |
| BSDC11 | Preventing global warming | | | | | | | | | | |
| **B** | ***Social benefits*** | | | | | | | | | | |
| BSDC13 | Improving quality of life for all | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BSDC14 | Alleviating poverty | | | | | | | | | | |
| BSDC15 | Satisfying human needs | | | | | | | | | | |
| BSDC16 | Incorporating cultural data into development | | | | | | | | | | |
| BSDC17 | Optimising social benefits | | | | | | | | | | |
| BSDC18 | Improving health, comfort and wellbeing | | | | | | | | | | |
| BSDC19 | Having concern for inter-generational equity | | | | | | | | | | |
| BSDC20 | Minimizing cultural disruption | | | | | | | | | | |
| BSDC21 | Providing education services | | | | | | | | | | |
| BSDC22 | Promoting harmony among people and between humanity and nature | | | | | | | | | | |
| BSDC23 | Understanding the importance of social and cultural capital | | | | | | | | | | |
| BSDC24 | Understanding multidisciplinary communities | | | | | | | | | | |
| **C** | ***Economic benefits*** | | | | | | | | | | |
| BSDC24 | Improving economic growth | | | | | | | | | | |
| BSDC25 | Reducing energy consumption and costs | | | | | | | | | | |
| BSDC26 | Raising real income | | | | | | | | | | |
| BSDC27 | Improving productivity | | | | | | | | | | |
| BSDC28 | Lowering infrastructure costs | | | | | | | | | | |
| BSDC29 | Decreasing environmental damage costs | | | | | | | | | | |
| BSDC30 | Reducing water consumption and costs | | | | | | | | | | |
| BSDC31 | Decreasing health costs | | | | | | | | | | |
| BSDC32 | Decreasing absenteeism in organizations | | | | | | | | | | |
| BSDC33 | Improving return on investments (ROI) | | | | | | | | | | |
| **2.1.6** | **Environmental sustainability criteria** | | | | | | | | | | |
| ESC1 | Energy conservation | | | | | | | | | | |
| ESC2 | Water conservation | | | | | | | | | | |
| ESC3 | Land conservation | | | | | | | | | | |
| ESC4 | Materials conservation – reuse and recycling | | | | | | | | | | |
| ESC5 | Resource utilization | | | | | | | | | | |
| ESC6 | Consideration of renewable energy | | | | | | | | | | |
| ESC7 | Minimize pollution – water, land and air pollution including noise | | | | | | | | | | |
| ESC8 | Perverse and enhance bio-diversity | | | | | | | | | | |
| ESC9 | Create a healthy, non-toxic environment-including indoor air quality | | | | | | | | | | |
| ESC10 | Protect and enhance sensitive landscapes – cultural & historic sites | | | | | | | | | | |
| ESC11 | Re-use existing built assets | | | | | | | | | | |
| ESC12 | Waste minimization and management | | | | | | | | | | |
| ESC13 | Environmental impact (process and product) | | | | | | | | | | |
| ESC14 | Transport – including provision of public transport | | | | | | | | | | |
| ESC15 | Visual impact | | | | | | | | | | |
| | **Environmental sustainability criteria** | | | | | | | | | | |
| ESC1 | Conserve energy | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ESC2 | Conserve water | | | | | | | | | | |
| ESC3 | Conserve land | | | | | | | | | | |
| ESC4 | Conserve materials – reuse and recycling | | | | | | | | | | |
| ESC5 | Resource utilization | | | | | | | | | | |
| ESC6 | Consider renewable energy | | | | | | | | | | |
| ESC7 | Minimize pollution – water, land, and air pollution (including noise) at global and local levels | | | | | | | | | | |
| ESC8 | Perverse and enhance bio-diversity | | | | | | | | | | |
| ESC9 | Creating a healthy, non-toxic environment – including high indoor air quality | | | | | | | | | | |
| ESC10 | Protect and enhance sensitive landscapes including scenic, cultural, historic and architectural | | | | | | | | | | |
| ESC11 | Re-use existing built assets | | | | | | | | | | |
| ESC12 | Waste minimization and management | | | | | | | | | | |
| ESC13 | Environmental impact (process and product) | | | | | | | | | | |
| ESC14 | Transport – including provision of public transport | | | | | | | | | | |
| ESC15 | Visual impact | | | | | | | | | | |
| **2.1.7** | **Reduction of carbon and ecological footprint in construction** | | | | | | | | | | |
| RCEF1 | Use of materials from renewable sources | | | | | | | | | | |
| RCEF2 | Use biodegradable materials | | | | | | | | | | |
| RCEF3 | Reduction in air, land and water pollution | | | | | | | | | | |
| RCEF4 | Reduction in materials and water usage | | | | | | | | | | |
| RCEF5 | Aids energy efficiency | | | | | | | | | | |
| RCEF6 | Use locally available materials | | | | | | | | | | |
| RCEF7 | Waste minimisation and reuse of waste products | | | | | | | | | | |
| RCEF8 | Rethink (innovation) sustainable practices | | | | | | | | | | |
| RCEF9 | Energy conservation | | | | | | | | | | |
| RCEF10 | Reduce transportation | | | | | | | | | | |
| RCEF11 | Embodied energy | | | | | | | | | | |
| | ***Why is sustainability a focus area that cannot be ignored by construction companies in Ghana?*** | | | | | | | | | | |

## 2.2 Sustainable design

Please kindly **tick** (**X**) the position that correspond to the importance of the following sustainable design elements for construction projects.

| **CODE** | **Elements of sustainable design** | How important are the following in measuring sustainable design? **(Unimportant …………… Very important)** |
|---|---|---|

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2.2.1** | **Environmental sustainable design component** | | | | | | | | | | |
| ESDC1 | Reduction of energy consumption | | | | | | | | | | |
| ESDC2 | Reduction of raw materials consumption | | | | | | | | | | |
| ESDC3 | Reduction of dangerous materials consumption | | | | | | | | | | |
| ESDC4 | Reduction of water consumption | | | | | | | | | | |
| ESDC5 | Recycling of waste and return | | | | | | | | | | |
| ESDC6 | Land conservation | | | | | | | | | | |
| **2.2.2** | **Environmental sustainable design requirements** | | | | | | | | | | |
| ESDR1 | Resources conservation | | | | | | | | | | |
| ESDR2 | Humane adaption | | | | | | | | | | |
| ESDR3 | Life cycle design | | | | | | | | | | |
| ESDR4 | Cost efficiency | | | | | | | | | | |
| | ***How are architectural and engineering firms responding through design to sustainability requirements in Ghana?*** | | | | | | | | | | |

**2.3 Low impact building materials in construction**

Please kindly **tick** (**X**) the position that correspond to the importance of the following elements in measuring the incorporation of low impact building materials in construction projects.

| **CODE** | **Elements of low impact building materials** | How important are the following in measuring the incorporation of low impact building materials in construction? **(Unimportant …………… Very important)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **2.3.1** | **Material selection criteria** | | | | | | | | | | |
| MSC1 | Aesthetic quality of the material | | | | | | | | | | |
| MSC2 | Durability of the material | | | | | | | | | | |
| MSC3 | Ecological impact of the material | | | | | | | | | | |
| MSC4 | Embodied energy of the material | | | | | | | | | | |
| MSC5 | Performance of the material | | | | | | | | | | |
| MSC6 | Reusable/renewable potential of the material | | | | | | | | | | |
| MSC7 | Social impact of the material | | | | | | | | | | |
| MSC8 | Cost of the material | | | | | | | | | | |
| **2.3.2** | **Material Incorporation measures** | | | | | | | | | | |
| MIM1 | Choice of material to be renewable, recyclable or reusable | | | | | | | | | | |
| MIM2 | Use of materials with organic origin; e.g. use of natural materials in floors, walls, ceiling, roofs, etc. | | | | | | | | | | |
| MIM3 | Use of permeable materials for landscaping to allow dissipation of storm water into the ground | | | | | | | | | | |
| MIM4 | Use of compost and mulch in building landscaping as a water conservation measure | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MIM5 | Availability of water efficient trees, green roofs and rain gardens to provide infiltration and evapotranspiration | | | | | | | | | | |
| MIM6 | Use of materials that are long-lasting and easy to maintain | | | | | | | | | | |
| MIM7 | Materials specified in the design should have a minimum adverse impact on the environment | | | | | | | | | | |
| MIM8 | Use of local materials such as wood, thatch, laterite, gravels, sand, clay, bamboo, cement, plastic, soil blocks, etc. | | | | | | | | | | |
| **2.3.2** | **Emission reduction (Reduction of CO2 emission/pollution)** | | | | | | | | | | |
| ER1 | Restriction of energy utilization | | | | | | | | | | |
| ER2 | Impact assessment of construction process | | | | | | | | | | |
| ER3 | Construction material production and discharge | | | | | | | | | | |
| ER4 | Adopting low carbon equipment and technology | | | | | | | | | | |
| ER5 | Adhering to construction standards/policies | | | | | | | | | | |
| ER6 | Limited transportation of material and personnel | | | | | | | | | | |
| **2.3.3** | **Water efficiency/conservation measures** | | | | | | | | | | |
| WEM1 | Use of rainwater harvesting system | | | | | | | | | | |
| WEM2 | Installation of automatic plumbing fixtures and fitting such as human presence detectors to reduce | | | | | | | | | | |
| WEM3 | Recycling of grey water for irrigation and for reuse on the WCs | | | | | | | | | | |
| WEM4 | Installation of water conserving irrigation systems | | | | | | | | | | |
| WEM5 | Use of water saving appliances | | | | | | | | | | |
| WEM6 | Use of individual water metering for different tenants to conserve water | | | | | | | | | | |
| | ***How do contractors incorporate low impact building materials in the construction process in Ghana?*** | | | | | | | | | | |

Central University of Technology, Free State

## 2.4 Energy efficiency

Please kindly **tick** (**X**) the position that correspond to the importance of energy efficiency and utilization in construction projects.

| **CODE** | **Elements of energy efficiency** | How important are the following in measuring energy efficiency and utilization? **(Unimportant …………… Very important)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **2.4.1** | **Energy efficiency component** | | | | | | | | | | |
| EEC1 | Choose energy efficient materials and construction methods | | | | | | | | | | |
| EEC2 | Insulate building envelope | | | | | | | | | | |
| EEC3 | Use energy efficient deconstruction and recycling | | | | | | | | | | |
| EEC4 | Adopt low energy intensive transportation | | | | | | | | | | |
| EEC5 | Develop energy efficient technological process | | | | | | | | | | |
| EEC6 | Use of passive energy design and construction | | | | | | | | | | |
| **2.4.2** | **Energy efficiency measures** | | | | | | | | | | |
| EEM1 | Use of highly efficient light fixtures and efficient lighting controls | | | | | | | | | | |
| EEM2 | Availability of automatic presence detectors (on and off switch during the day and night) | | | | | | | | | | |
| EEM3 | Use of energy lighting | | | | | | | | | | |
| EEM4 | Adequacy of natural lighting systems | | | | | | | | | | |
| EEM5 | Adequate shading from intense heat (green roof to reduce heat from the roof) | | | | | | | | | | |
| EEM6 | Use of low emission glazing | | | | | | | | | | |
| EEM7 | Use of solar energy for external lighting | | | | | | | | | | |
| EEM8 | Use of low embodied energy materials | | | | | | | | | | |
| EEM9 | Avoiding the use of air conditioning system operating with Ozone Depleting | | | | | | | | | | |
| EEM10 | Reduce of substance (ODS) and/or Green House (GH) Gases | | | | | | | | | | |
| EEM11 | Use of renewable energy; e.g. solar, wind, geothermal, etc. | | | | | | | | | | |
| EEM12 | Use of individual metering for separate tenant to reduce energy consumption | | | | | | | | | | |
| EEM13 | Avoiding the use of sun-lit glazing to reduce AC cooling load | | | | | | | | | | |
| EEM14 | Zoning the spaces for energy-efficient air conditioning | | | | | | | | | | |
| EEM14 | Zoning the spaces for energy-efficient air conditioning | | | | | | | | | | |
| **2.4.3** | **Protection of resources for ecological sustainability** | | | | | | | | | | |
| PRES 1 | Effective land utilization | | | | | | | | | | |
| PRES 2 | Consideration in material selection | | | | | | | | | | |
| PRES 3 | Waste minimization | | | | | | | | | | |
| PRES 4 | Energy conservation | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PRES 5 | Water efficiency | | | | | | | | | | |
| PRES 6 | Pollution control | | | | | | | | | | |
| PRES 7 | Biodiversity protection | | | | | | | | | | |
| PRES 8 | Heritage and amenity protection | | | | | | | | | | |
| | ***How is energy efficient equipment utilization influencing the construction process in Ghana?*** | | | | | | | | | | |

### 2.5 Waste management practices in construction

Please kindly **tick** (**X**) the position that correspond to the importance of the following elements of waste management in construction projects.

| **CODE** | **Elements of solid waste production and discharge** | How important are the following in measuring solid waste management in construction? **(Unimportant …………… Very important)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| **2.5.1** | **Waste minimization measures** | | | | | | | | | | |
| WMM1 | Using materials before expiry dates | | | | | | | | | | |
| WMM2 | Use of more efficient equipment | | | | | | | | | | |
| WMM3 | Purchasing raw materials that are just sufficient | | | | | | | | | | |
| WMM4 | Adoption of proper site management techniques | | | | | | | | | | |
| WMM5 | Good coordination between store and construction personnel to avoid over ordering | | | | | | | | | | |
| WMM6 | Minimizing design changes | | | | | | | | | | |
| WMM7 | Training of construction personnel | | | | | | | | | | |
| WMM8 | Proper storage of materials on site | | | | | | | | | | |
| WMM9 | Employment of skills work men | | | | | | | | | | |
| WMM10 | Accurate and good specifications of materials to avoid wrong ordering | | | | | | | | | | |
| WMM11 | Checking materials supplied for right quantities and volumes | | | | | | | | | | |
| WMM12 | Change of attitudes of workers towards the handling of materials | | | | | | | | | | |
| WMM13 | Vigilance of supervisors | | | | | | | | | | |
| WMM14 | Access to latest information about types of materials on the market | | | | | | | | | | |
| WMM15 | Accurate measurement of materials during batching | | | | | | | | | | |
| WMM16 | Weekly programming of works | | | | | | | | | | |
| WMM17 | Good construction management practices | | | | | | | | | | |
| WMM18 | Mixing, transporting and placing concrete at the appropriate time | | | | | | | | | | |
| WMM19 | Adherence to standardized dimensions | | | | | | | | | | |
| WMM20 | Waste management officer or personnel employed to handle waste issues | | | | | | | | | | |
| WMM21 | Early and prompt scheduling of deliveries | | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WMM22 | Just in time operations | | | | | | | | | | |
| WMM23 | Careful handling of tools and equipment on site | | | | | | | | | | |
| WMM24 | Encourage re-use of waste materials in projects | | | | | | | | | | |
| WMM25 | Use of low waste technology | | | | | | | | | | |
| WMM26 | Recycling of some waste materials on site | | | | | | | | | | |
| | ***In your opinion what are construction companies' main barriers to reducing on-site waste generation and improving its management?*** | | | | | | | | | | |

## 2.6 General Comment

Any general comment on the factors that you consider as being critical to the successful implementation of sustainable construction in Ghana, please comment

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**Thank you for your support and time**

# APPENDIX C: DELPHI SURVEY – ROUND 2

**FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY**

## EXPERT PARTICIPATION IN DELPHI SURVEY – ROUND 2

Thank you for participating in Round 1 of the Delphi Survey. The survey required a significant time to complete thoughtfully, and we are grateful for your valuable time and effort in completing the Round 1. This Round 2 survey continues the Delphi process for this study. The purpose of Round 2 is to provide you with the opportunity to change your response, **if desired,** given the median group response for each **element** using 10-point scale. This Round 2 is intended to take approximately 25 minutes to complete. To obtain any further information relating to the study, contact the study promoter Professor F.A. Emuze at femuze@cut.ac.za or the researcher on +233(0)203223884. Kindly email your response after answering all the questions to **mosesahiabu@yahoo.com** within 2 weeks of receiving this email, please.

### SECTION 1: INSTRUCTIONS WITH GROUP MEDIAN

There are **two values** to each element/statement. The **group median** from Round 1 Survey which is indicated in the **column to the far-right** of each table and your **Round 1 survey response** indicated with a **yellow-coloured box**. Kindly take **one** of the following **three actions** for each element/statement.

1. Accept the **group median** response by leaving your statement rating completely unchanged.
2. Maintain your **original response** by placing an "**X**" in the **yellow** highlighted/coloured box which is indicating the field for your Round 1 response.
3. Indicate a **new response** by placing an "**X**" in the appropriate box if you decided to change your response in Round 1.

### NOTE

1. If you take action 3 above to choose a **new response** which is more than **one unit (10%)** above or below the **group median** of each element/statement, kindly provide reason for changing your response at the end of the table. (For instance, a **group median of 6** and your **new response** is **4** or **8**, the response is more than one unit below or above the group median respectively).
2. **New elements** identified from **Round1** are included for your response and highlighted in **green colour**

## SECTION 2: DELPHI EXPERT SURVEY- ROUND 2

INSTRUCTION: Please rate the level of importance of the following statements based on your experience and judgement on a scale of 1 to 10 using a point scale as shown in the example below.

**Scale of Importance**

| Unimportant…………………………………………………………………………………………. Very important | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0-10% | 11-20% | 21-30% | 31-40% | 41-50% | 51-60% | 61-70% | 71-80% | 81-90% | 91-100% |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | | | | | **X** | | | | |

### 2.1 General sustainable construction practices

Sustainable construction practices and why sustainability cannot be ignored by construction companies.

| **CODE** | **Elements of sustainable construction** | How important are the following in measuring sustainable construction? **(Unimportant …………… Very important)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | unimportant | | Low important | | Medium important | | High important | | Very high important | | **Median** |
| **2.1.1** | **Key sustainability issues** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| KSI 1 | Amenities and recreation | | | | | | | | | | | **8** |
| KSI 2 | Biodiversity | | | | | | | | | | | **8** |
| KSI 3 | Climate change | | | | | | | | | | | **9** |
| KSI 4 | Community | | | | | | | | | | | **7** |
| KSI 5 | Crime and security | | | | | | | | | | | **7** |
| KSI 6 | Cultural heritage | | | | | | | | | | | **7** |
| KSI 7 | Drainage and flooding | | | | | | | | | | | **9** |
| KSI 8 | Energy | | | | | | | | | | | **9** |
| KSI 9 | Geology and soils | | | | | | | | | | | **9** |
| KSI 10 | Health, safety and well-being | | | | | | | | | | | **9** |
| KSI 11 | Human rights and ethics | | | | | | | | | | | **7** |
| KSI 12 | Landscape and visual aspect | | | | | | | | | | | **8** |
| KSI 13 | Land use | | | | | | | | | | | **9** |
| KSI 14 | Material use | | | | | | | | | | | **9** |
| KSI 15 | Pollution and nuisance | | | | | | | | | | | **9** |
| KSI 16 | Shareholder and customer relations | | | | | | | | | | | **7** |
| KSI 17 | Social inclusion and accessibility | | | | | | | | | | | **8** |
| KSI 18 | Stakeholder engagement | | | | | | | | | | | **7.5** |
| KSI 19 | Training and development | | | | | | | | | | | **7** |
| KSI 20 | Travel and support | | | | | | | | | | | **6** |
| KSI 21 | Waste | | | | | | | | | | | **9** |
| KSI 22 | Water use | | | | | | | | | | | **9** |
| **2.1.2** | **Sustainable construction activities** | | | | | | | | | | | |
| SCA1 | Regenerate used natural vegetation | | | | | | | | | | | **9** |
| SCA2 | Use renewable construction material | | | | | | | | | | | **10** |
| SCA 3 | Reduce travelling distance for raw materials | | | | | | | | | | | **8** |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SCA 4 | Reduce material delivery distance | | | | | | | | | | **8** |
| SCA 5 | Reduce transportation distance of people | | | | | | | | | | **9** |
| SCA 6 | Use of forestry-authority–certified timber | | | | | | | | | | **9** |
| SCA 7 | Minimize carbon emissions in construction | | | | | | | | | | **10** |
| SCA 8 | Do selective construction waste disposal | | | | | | | | | | **9** |
| SCA 9 | Recycle construction waste | | | | | | | | | | **10** |
| SCA 10 | Ensure efficiency in energy usage for construction works | | | | | | | | | | **9** |
| SCA 11 | Ensure efficiency in water usage during construction | | | | | | | | | | **9** |
| SCA 12 | Minimize dust during construction | | | | | | | | | | **9** |
| SCA13 | Optimise site planning, building orientation, and configuration | | | | | | | | | | **7.5** |
| SCA14 | Reduction of resource consumption | | | | | | | | | | **9** |
| SCA15 | Maximisation of resource reuse | | | | | | | | | | **8** |
| SCA16 | Protect the natural environment | | | | | | | | | | **8** |
| SCA17 | Create a healthy and non-toxic environment | | | | | | | | | | **7** |
| SCA18 | Pursue quality in creating the built environment | | | | | | | | | | **9** |
| SCA19 | Apply life cycle costing | | | | | | | | | | **9** |
| **2.1.3** | **Drivers for sustainable construction** | | | | | | | | | | |
| DFSC1 | Professional knowledge in sustainable construction | | | | | | | | | | **10** |
| DFSC2 | Sustainable design guidelines and construction standards | | | | | | | | | | **9** |
| DFSC3 | Willingness to incorporate sustainable building practices | | | | | | | | | | **9** |
| DFSC4 | Availability of acceptable sustainable construction roadmap | | | | | | | | | | **9** |
| DFSC5 | Creation of public awareness | | | | | | | | | | **10** |
| DFSC6 | Legislation | | | | | | | | | | **9** |
| DFSC7 | Sustainable building codes and regulations | | | | | | | | | | **9** |
| DFSC8 | Economic incentives (tax rebates, high profit margin) | | | | | | | | | | **9** |
| DFSC9 | Sustainability in educational curricula | | | | | | | | | | **9** |
| DFSC10 | Government commitment and support | | | | | | | | | | **9** |
| DFSC11 | Availability of measurement tool | | | | | | | | | | **9** |
| DFSC12 | Cooperation from technical experts | | | | | | | | | | **9** |
| DFSC13 | Client demand and requirements | | | | | | | | | | **9** |
| DFSC14 | Stakeholder influence | | | | | | | | | | **9** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DFSC15 | Cost efficiency (whole life cycle costing) | | | | | | | | | | | **9** |
| DFSC16 | Competitive advantage | | | | | | | | | | | **9** |
| DFSC17 | Top management commitment | | | | | | | | | | | **9** |
| DFSC18 | Win more contracts to remain in business | | | | | | | | | | | **8** |
| DFSC19 | Company's reputation and brand image | | | | | | | | | | | **8** |
| DFSC20 | Availability of life cycle cost analysis | | | | | | | | | | | **9** |
| DFSC21 | Moral obligation to protect the environment | | | | | | | | | | | **9** |
| **2.1.4** | **Challenges of sustainable construction** | | | | | | | | | | | |
| CSC 1 | Lack of financial incentives (high taxes and low-profit margin) | | | | | | | | | | | **10** |
| CSC 2 | Lack of building code and regulation | | | | | | | | | | | **9** |
| CSC3 | Lack of investment | | | | | | | | | | | **9** |
| CSC4 | Initial investment cost | | | | | | | | | | | **9** |
| CSC5 | Lack of client demand | | | | | | | | | | | **9** |
| CSC6 | High cost of environmental services | | | | | | | | | | | **9** |
| CSC7 | Lack of research | | | | | | | | | | | **8** |
| CSC8 | Lack of public awareness | | | | | | | | | | | **9** |
| CSC9 | Competitive pressure | | | | | | | | | | | **8** |
| CSC10 | Lack of database and information | | | | | | | | | | | **8** |
| CSC11 | Lack of green products | | | | | | | | | | | **8** |
| CSC12 | Lack of professional knowledge and expertise | | | | | | | | | | | **9** |
| CSC13 | Lack of green technology | | | | | | | | | | | **8** |
| CSC14 | Tendering and contract requirements | | | | | | | | | | | **8** |
| CSC15 | High level of perceived risk | | | | | | | | | | | **8** |
| **2.1.5** | **Benefits of sustainable construction** | | | | | | | | | | | |
| **A.** | ***Environmental benefits*** | | | | | | | | | | | |
| BSDC 1 | Protecting air, water, land, ecosystems | | | | | | | | | | | **10** |
| BSDC 2 | Conserving natural resources (fossil fuel) | | | | | | | | | | | **10** |
| BSDC3 | Preserving animal species and genetic diversity | | | | | | | | | | | **9** |
| BSDC4 | Protecting the biosphere | | | | | | | | | | | **10** |
| BSDC5 | Using renewable natural resources | | | | | | | | | | | **9** |
| BSDC6 | Minimizing waste production or disposal | | | | | | | | | | | **9** |
| BSDC7 | Minimizing $CO_2$ emission and pollutants | | | | | | | | | | | **10** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BSDC8 | Maintaining essential ecological processes and life support system | | | | | | | | | | | **9** |
| BSDC9 | Pursuing active recycling | | | | | | | | | | | **9** |
| BSDC10 | Maintaining integrity of environment | | | | | | | | | | | **9** |
| BSDC11 | Preventing global warming | | | | | | | | | | | **10** |
| **B** | ***Social benefits*** | | | | | | | | | | | |
| BSDC13 | Improving quality of life for all | | | | | | | | | | | **9** |
| BSDC14 | Alleviating poverty | | | | | | | | | | | **9** |
| BSDC15 | Satisfying human needs | | | | | | | | | | | **9** |
| BSDC16 | Incorporating cultural data into development | | | | | | | | | | | **8** |
| BSDC17 | Optimising social benefits | | | | | | | | | | | **9** |
| BSDC18 | Improving health, comfort and wellbeing | | | | | | | | | | | **9** |
| BSDC19 | Having concern for inter-generational equity | | | | | | | | | | | **7** |
| BSDC20 | Minimizing cultural disruption | | | | | | | | | | | **8** |
| BSDC21 | Providing education services | | | | | | | | | | | **8** |
| BSDC22 | Promoting harmony among people and between humanity and nature | | | | | | | | | | | **9** |
| BSDC23 | Understanding the importance of social and cultural capital | | | | | | | | | | | **8** |
| BSDC24 | Understanding multidisciplinary communities | | | | | | | | | | | **8** |
| **C** | ***Economic benefits*** | | | | | | | | | | | |
| BSDC25 | Improving economic growth | | | | | | | | | | | **9** |
| BSDC26 | Reducing energy consumption and costs | | | | | | | | | | | **9** |
| BSDC27 | Raising real income | | | | | | | | | | | **9** |
| BSDC28 | Improving productivity | | | | | | | | | | | **9** |
| BSDC29 | Lowering infrastructure costs | | | | | | | | | | | **9** |
| BSDC30 | Decreasing environmental damage costs | | | | | | | | | | | **9** |
| BSDC30 | Reducing water consumption and costs | | | | | | | | | | | **9** |
| BSDC31 | Decreasing health costs | | | | | | | | | | | **9** |
| BSDC32 | Decreasing absenteeism in organizations | | | | | | | | | | | **8** |
| BSDC33 | Improving return on investments (ROI) | | | | | | | | | | | **9** |
| **2.1.6** | **Environmental sustainability criteria** | | | | | | | | | | | |
| ESC1 | Energy conservation | | | | | | | | | | | **9** |
| ESC2 | Water conservation | | | | | | | | | | | **9** |
| ESC3 | Land conservation | | | | | | | | | | | **8** |
| ESC4 | Materials conservation – reuse and recycling | | | | | | | | | | | **8** |
| ESC5 | Resource utilization | | | | | | | | | | | **9** |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESC6 | Consideration of renewable energy | | | | | | | | | | | **9** |
| ESC7 | Minimize pollution – water, land and air pollution including noise | | | | | | | | | | | **8** |
| ESC8 | Perverse and enhance bio-diversity | | | | | | | | | | | **8** |
| ESC9 | Create a healthy, non-toxic environment-including indoor air quality | | | | | | | | | | | **8** |
| ESC10 | Protect and enhance sensitive landscapes – cultural & historic sites | | | | | | | | | | | **8** |
| ESC11 | Re-use existing built assets | | | | | | | | | | | **8** |
| ESC12 | Waste minimization and management | | | | | | | | | | | **9** |
| ESC13 | Environmental impact (process and product) | | | | | | | | | | | **8** |
| ESC14 | Transport – including provision of public transport | | | | | | | | | | | **9** |
| ESC15 | Visual impact | | | | | | | | | | | **9** |
| **2.1.12** | **Environmental sustainability criteria** | | | | | | | | | | | |
| ESC1 | Conserve energy | | | | | | | | | | | **9** |
| ESC2 | Conserve water | | | | | | | | | | | **9** |
| ESC3 | Conserve land | | | | | | | | | | | **10** |
| ESC4 | Conserve materials – reuse and recycling | | | | | | | | | | | **10** |
| ESC5 | Resource utilization | | | | | | | | | | | **10** |
| ESC6 | Consider renewable energy | | | | | | | | | | | **10** |
| ESC7 | Minimize pollution – water, land, and air pollution (including noise) at global and local levels | | | | | | | | | | | **10** |
| ESC8 | Perverse and enhance bio-diversity | | | | | | | | | | | **9** |
| ESC9 | Creating a healthy, non-toxic environment – including high indoor air quality | | | | | | | | | | | **10** |
| ESC10 | Protect and enhance sensitive landscapes including scenic, cultural, historic and architectural | | | | | | | | | | | **9** |
| ESC11 | Re-use existing built assets | | | | | | | | | | | **9** |
| ESC12 | Waste minimization and management | | | | | | | | | | | **10** |
| ESC13 | Environmental impact (process and product) | | | | | | | | | | | **9** |
| ESC14 | Transport – including provision of public transport | | | | | | | | | | | **9** |
| ESC15 | Visual impact | | | | | | | | | | | **9** |
| **2.1.7** | **Reduction of carbon and ecological footprint in construction** | | | | | | | | | | | |
| RCEF1 | Use of materials from renewable sources | | | | | | | | | | | **9** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RCEF2 | Use biodegradable materials | | | | | | | | | | | **9** |
| RCEF3 | Reduction in air, land and water pollution | | | | | | | | | | | **9** |
| RCEF4 | Reduction in materials and water usage | | | | | | | | | | | **9** |
| RCEF5 | Aids energy efficiency | | | | | | | | | | | **9** |
| RCEF6 | Use locally available materials | | | | | | | | | | | **9** |
| RCEF7 | Waste minimisation and reuse of waste products | | | | | | | | | | | **9** |
| RCEF8 | Rethink (innovation) sustainable practices | | | | | | | | | | | **9** |
| RCEF9 | Energy conservation | | | | | | | | | | | **9** |
| RCEF10 | Reduce transportation | | | | | | | | | | | **9** |
| RCEF11 | Embodied energy | | | | | | | | | | | **9** |
| **Comment** | | | | | | | | | | | | |

**2.2 Sustainable design**

Respond to sustainability through sustainable building design

| **CODE** | **Elements of sustainable design** | What is the **influence** of the following elements in measuring sustainable design? **(Low Influence ……………………..… High Influence)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No influence | | Low influence | | Medium influence | | High influence | | Very high influence | | **Median** |
| **2.2.1** | **Environmental sustainable design component** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| ESDC1 | Reduction of energy consumption | | | | | | | | | | | **9** |
| ESDC2 | Reduction of raw materials consumption | | | | | | | | | | | **10** |
| ESDC3 | Reduction of dangerous materials consumption | | | | | | | | | | | **8.5** |
| ESDC4 | Reduction of water consumption | | | | | | | | | | | **9** |
| ESDC5 | Recycling of waste and return | | | | | | | | | | | **9** |
| ESDC6 | Land conservation | | | | | | | | | | | **9** |
| **2.2.2** | **Environmental sustainable design requirements** | | | | | | | | | | | |
| ESDR1 | Resources conservation | | | | | | | | | | | **9** |
| ESDR2 | Humane adaption | | | | | | | | | | | **9** |
| ESDR3 | Life cycle design | | | | | | | | | | | **9** |
| ESDR4 | Cost efficiency | | | | | | | | | | | **9** |
| **Comment** | | | | | | | | | | | | |

## 2.3 Low impact building materials in construction

Low impact building materials selection and incorporation in construction projects.

| CODE | Elements of low impact building materials | How important are the following in measuring the incorporation of low impact building materials in construction? **(Unimportant ………..………… Very important)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | unimportant | | Low important | | Medium important | | High important | | Very high important | | **Median** |
| **2.3.1** | **Material selection criteria** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| MSC1 | Aesthetic quality of the material | | | | | | | | | | | **9** |
| MSC2 | Durability of the material | | | | | | | | | | | **9** |
| MSC3 | Ecological impact of the material | | | | | | | | | | | **9** |
| MSC4 | Embodied energy of the material | | | | | | | | | | | **8** |
| MSC5 | Performance of the material | | | | | | | | | | | **9** |
| MSC6 | Reusable/renewable potential of the material | | | | | | | | | | | **9** |
| MSC7 | Social impact of the material | | | | | | | | | | | **8** |
| MSC8 | Cost of the material | | | | | | | | | | | **9** |
| **2.3.2** | **Material Incorporation measures** | | | | | | | | | | | |
| MCM1 | Choice of material to be renewable, recyclable or reusable | | | | | | | | | | | **9** |
| MCM2 | Use of materials with organic origin; e.g. use of natural materials in floors, walls, ceiling, roofs, etc. | | | | | | | | | | | **9** |
| MCM3 | Use of permeable materials for landscaping to allow dissipation of storm water into the ground | | | | | | | | | | | **9** |
| MCM4 | Use of compost and mulch in building landscaping as a water conservation measure | | | | | | | | | | | **8** |
| MCM5 | Availability of water efficient trees, green roofs and rain gardens to provide infiltration and evapotranspiration | | | | | | | | | | | **9** |
| MCM6 | Use of materials that are long-lasting and easy to maintain | | | | | | | | | | | **9** |
| MCM7 | Materials specified in the design should have a minimum adverse impact on the environment | | | | | | | | | | | **9** |
| MCM8 | Use of local materials such as wood, thatch, laterite, gravels, sand, clay, bamboo, cement, plastic, soil blocks, etc. | | | | | | | | | | | **9** |
| **2.3.2** | **Emission reduction (Reduction of CO2 emission/pollution)** | | | | | | | | | | | |
| ER1 | Restriction of energy utilization | | | | | | | | | | | **9** |
| ER2 | Impact assessment of construction process | | | | | | | | | | | **10** |
| ER3 | Construction material production and discharge | | | | | | | | | | | **9** |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ER4 | Adopting low carbon equipment and technology | | | | | | | | | | | **9** |
| ER5 | Adhering to construction standards/policies | | | | | | | | | | | **9** |
| ER6 | Limited transportation of material and personnel | | | | | | | | | | | **10** |
| **2.3.3** | **Water efficiency/conservation measures** | | | | | | | | | | | |
| WEM1 | Use of rainwater harvesting system | | | | | | | | | | | **10** |
| WEM2 | Installation of automatic plumbing fixtures and fitting such as human presence detectors to reduce | | | | | | | | | | | **9** |
| WEM3 | Recycling of grey water for irrigation and for reuse on the WCs | | | | | | | | | | | **9** |
| WEM4 | Installation of water conserving irrigation systems | | | | | | | | | | | **9** |
| WEM5 | Use of water saving appliances | | | | | | | | | | | **9** |
| WEM6 | Use of individual water metering for different tenants to conserve water | | | | | | | | | | | **9** |
| **Comment /input** | | | | | | | | | | | | |

**2.4 Energy efficiency**

To explore energy efficiency in construction and determine how energy efficiency equipment utilization is influencing construction process.

| **CODE** | **Elements of energy efficiency** | How important are the following in measuring energy efficiency and utilization? **(Unimportant …………… Very important)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | unimportant | | Low important | | Medium important | | High important | | Very high important | | **Median** |
| **2.4.1** | **Energy efficiency component** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| EEC1 | Choose energy efficient materials and construction methods | | | | | | | | | | | **9** |
| EEC2 | Insulate building envelope | | | | | | | | | | | **9** |
| EEC3 | Use energy efficient deconstruction and recycling | | | | | | | | | | | **9** |
| EEC4 | Adopt low energy intensive transportation | | | | | | | | | | | **9** |
| EEC5 | Develop energy efficient technological process | | | | | | | | | | | **9** |
| EEC6 | Use of passive energy design and construction | | | | | | | | | | | **9** |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2.4.2** | **Energy efficiency measures** | | | | | | | | | | | |
| EEM1 | Use of highly efficient light fixtures and efficient lighting controls | | | | | | | | | | | **9** |
| EEM2 | Availability of automatic presence detectors (on and off switch during the day and night) | | | | | | | | | | | **9** |
| EEM3 | Use of energy lighting | | | | | | | | | | | **9** |
| EEM4 | Adequacy of natural lighting systems | | | | | | | | | | | **9** |
| EEM5 | Adequate shading from intense heat (green roof to reduce heat from the roof) | | | | | | | | | | | **10** |
| EEM6 | Use of low emission glazing | | | | | | | | | | | **9** |
| EEM7 | Use of solar energy for external lighting | | | | | | | | | | | **9** |
| EEM8 | Use of low embodied energy materials | | | | | | | | | | | **9** |
| EEM9 | Avoiding the use of air conditioning system operating with Ozone Depleting | | | | | | | | | | | **9** |
| EEM10 | Reduce of substance (ODS) and/or Green House (GH) Gases | | | | | | | | | | | **9** |
| EEM11 | Use of renewable energy; e.g. solar, wind, geothermal, etc. | | | | | | | | | | | **10** |
| EEM12 | Use of individual metering for separate tenant to reduce energy consumption | | | | | | | | | | | **9** |
| EEM13 | Avoiding the use of sun-lit glazing to reduce AC cooling load | | | | | | | | | | | **9** |
| EEM14 | Zoning the spaces for energy-efficient air conditioning | | | | | | | | | | | **9** |
| **2.4.3** | **Energy efficient equipment** | | | | | | | | | | | |
| EEE 1 | Reduce fuel usage | | | | | | | | | | | |
| EEE 2 | Reduce emission levels and protect the environment | | | | | | | | | | | |
| EEE 3 | Minimize energy consumption | | | | | | | | | | | |
| EEE 4 | Upgrade/replace equipment with energy serving devices | | | | | | | | | | | |
| EEE 5 | Improve productivity & increase value | | | | | | | | | | | |
| EEE 6 | Reduction in energy cost | | | | | | | | | | | |
| **2.4.4** | **Protection of resources for ecological sustainability** | | | | | | | | | | | |
| PRES 1 | Effective land utilization | | | | | | | | | | | |
| PRES 2 | Consideration in material selection | | | | | | | | | | | |
| PRES 3 | Waste minimization | | | | | | | | | | | |
| PRES 4 | Energy conservation | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PRES 5 | Water efficiency | | | | | | | | | | | |
| PRES 6 | Pollution control | | | | | | | | | | | |
| PRES 7 | Biodiversity protection | | | | | | | | | | | |
| PRES 8 | Heritage and amenity protection | | | | | | | | | | | |
| **Comment** | | | | | | | | | | | | |

**2.5 Waste management practices in construction**

To evaluate the modalities employed by contractors to reduce construction site solid waste production and discharge.

| **CODE** | **Elements of solid waste production and discharge** | How important are the following in measuring solid waste management in construction? **(Unimportant …………… Very important)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | unimportant | | Low important | | Medium important | | High important | | Very high important | | **Median** |
| **2.5.1** | **Waste minimization measures** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | |
| WMM1 | Using materials before expiry dates | | | | | | | | | | | **9** |
| WMM2 | Use of more efficient equipment | | | | | | | | | | | **9** |
| WMM3 | Purchasing raw materials that are just sufficient | | | | | | | | | | | **9** |
| WMM4 | Adoption of proper site management techniques | | | | | | | | | | | **9** |
| WMM5 | Good coordination between store and construction personnel to avoid over ordering | | | | | | | | | | | **9** |
| WMM6 | Minimizing design changes | | | | | | | | | | | **9** |
| WMM7 | Training of construction personnel | | | | | | | | | | | **9** |
| WMM8 | Proper storage of materials on site | | | | | | | | | | | **9** |
| WMM9 | Employment of skills work men | | | | | | | | | | | **9** |
| WMM10 | Accurate and good specifications of materials to avoid wrong ordering | | | | | | | | | | | **9** |
| WMM11 | Checking materials supplied for right quantities and volumes | | | | | | | | | | | **9** |
| WMM12 | Change of attitudes of workers towards the handling of materials | | | | | | | | | | | **9** |
| WMM13 | Vigilance of supervisors | | | | | | | | | | | **9** |
| WMM14 | Access to latest information about types of materials on the market | | | | | | | | | | | **9** |
| WMM15 | Accurate measurement of materials during batching | | | | | | | | | | | **9** |
| WMM16 | Weekly programming of works | | | | | | | | | | | **9** |
| WMM17 | Good construction management practices | | | | | | | | | | | **9** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WMM18 | Mixing, transporting and placing concrete at the appropriate time | | | | | | | | | | | **9** |
| WMM19 | Adherence to standardized dimensions | | | | | | | | | | | **9** |
| WMM20 | Waste management officer or personnel employed to handle waste issues | | | | | | | | | | | **9** |
| WMM21 | Early and prompt scheduling of deliveries | | | | | | | | | | | **9** |
| WMM22 | Just in time operations | | | | | | | | | | | **9** |
| WMM23 | Careful handling of tools and equipment on site | | | | | | | | | | | **9** |
| WMM24 | Encourage re-use of waste materials in projects | | | | | | | | | | | **9** |
| WMM25 | Use of low waste technology | | | | | | | | | | | **9** |
| WMM26 | Recycling of some waste materials on site | | | | | | | | | | | **9** |
| **Comment** | | | | | | | | | | | | |

**THANK YOU**

# APPENDIX D: DELPHI STUDY – ROUND 3

**FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY**

## INSTRUCTIONS TO EXPERT ON DELPHI STUDY – ROUND 3 WITH GROUP MEDIAN

DELPHI SURVEY – ROUND 3

Thank you for participating in Round 2 of the Delphi Survey. We are grateful for your valuable time and effort in completing the Round 2 of the Delphi Survey. This Round 3 survey concludes the Delphi process for this study. The purpose of Round 3 is to provide you with **a final opportunity** to change your response, **if desired,** given the group median response for each **element** using 10-point scale.

This Round 3 is intended to take approximately 20 minutes to complete. To obtain any further information relating to the study, contact the study promoter Professor F.A. Emuze at femuze@cut.ac.za or the researcher on +233(0)203223884. Kindly email your response after answering all the questions to **mosesahiabu@yahoo.com** within 2 weeks of receiving this email, please.

**INSTRUCTIONS**

The instructions for this Round 3 survey are nearly identical to that of Round 2 survey. The only difference between this Round 3 survey and Round 2 survey is that you are given an opportunity to provide an additional statement that will improve sustainability practices of construction companies in reducing the carbon and ecological footprint of their activity. In Round 2, all participants were asked to provide reasons if their responses were more than one unit above or below the group median of each statement. You are encourage to review and consider the median and the responses provided by the other expert participants when considering your final response.

There are **two values** to each element/statement; the **group median** from Round 2 Survey which is indicated in the **column to the far-right** of each table and your **Round 2 survey response** indicated with a **yellow-coloured box**. Kindly take **one** of the following **three actions** for each element/statement please.

1. Accept the **group median** response by leaving your statement rating completely unchanged.
2. Maintain your **original response** by placing an “**X**” in the **yellow** highlighted/coloured box which is indicating the field for your Round 2 response.
3. Indicate a **new response** by placing an “**X**” in the appropriate box if you decided to change your response in Round 2.

**NOTE:**
Kindly review the questions without an initial response from the Round 2 survey (indicated with a yellow highlighted colour). If you take action 3 above to choose a **new response** which is more than **two units (20%)** above or below the **group median** of each element/statement, kindly provide reason(s) for changing your response at the end of the table. (For instance, a **group median of 6** and your **new response** is **3** or **9**, the response is more than two units below or above the group median respectively).

**INSTRUCTION**

Please rate the level of importance of the following statements based on your experience and judgement on a scale of 1 to 10 using a point scale as shown in the example below.

**Scale of Importance**

| Unimportant…………………………………………………………………………………. Very important | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0-10% | 11-20% | 21-30% | 31-40% | 41-50% | 51-60% | 61-70% | 71-80% | 81-90% | 91-100% |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | | | | | **X** | | | | |

**2.1 General sustainable construction practices**

Sustainable construction practices and why sustainability cannot be ignored by construction companies.

| **CODE** | **Elements of sustainable construction** | How important are the following in measuring sustainable construction? **(Unimportant …………… Very important)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Unimportant | | Low important | | Medium important | | High important | | Very high important | | **Median** |
| **2.1.1** | **Key sustainability issues** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| KSI 1 | Amenities and recreation | | | | | | | | | | | **8** |
| KSI 2 | Biodiversity | | | | | | | | | | | **9** |
| KSI 3 | Climate change | | | | | | | | | | | **9** |
| KSI 4 | Community | | | | | | | | | | | **7** |
| KSI 5 | Crime and security | | | | | | | | | | | **7** |
| KSI 6 | Cultural heritage | | | | | | | | | | | **7** |
| KSI 7 | Drainage and flooding | | | | | | | | | | | **9** |
| KSI 8 | Energy efficiency | | | | | | | | | | | **10** |
| KSI 9 | Geology and soils | | | | | | | | | | | **8** |
| KSI 10 | Health, safety and well-being | | | | | | | | | | | **9** |
| KSI 11 | Human rights and ethics | | | | | | | | | | | **7** |
| KSI 12 | Landscape and visual aspect | | | | | | | | | | | **8** |
| KSI 13 | Land use | | | | | | | | | | | **9** |
| KSI 14 | Material consumption and conservation | | | | | | | | | | | **9** |
| KSI 15 | Pollution and nuisance | | | | | | | | | | | **9** |
| KSI 16 | Shareholder and customer relations | | | | | | | | | | | **7** |
| KSI 17 | Social inclusion and accessibility | | | | | | | | | | | **8** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KSI 18 | Stakeholder engagement | | | | | | | | | | | **7** |
| KSI 19 | Training and development | | | | | | | | | | | **7** |
| KSI 20 | Travel and support | | | | | | | | | | | **6** |
| KSI 21 | Waste management | | | | | | | | | | | **9** |
| KSI 22 | Harmonisation with the environment | | | | | | | | | | | **9** |
| **2.1.2** | **Sustainable construction activities** | | | | | | | | | | | |
| SCA1 | Regenerate used natural vegetation | | | | | | | | | | | **9** |
| SCA2 | Use renewable construction material | | | | | | | | | | | **9** |
| SCA 3 | Reduce transportation distance for raw materials | | | | | | | | | | | **8** |
| SCA 4 | Reduce material delivery distance | | | | | | | | | | | **8** |
| SCA 5 | Reduce transportation distance of people | | | | | | | | | | | **9** |
| SCA 6 | Use of forestry-authority–certified timber | | | | | | | | | | | **9** |
| SCA 7 | Minimize carbon emissions in construction | | | | | | | | | | | **10** |
| SCA 8 | Do selective construction waste disposal | | | | | | | | | | | **9** |
| SCA 9 | Recycle construction waste | | | | | | | | | | | **10** |
| SCA 10 | Ensure efficiency in energy usage for construction works | | | | | | | | | | | **9** |
| SCA 11 | Ensure efficiency in water usage during construction | | | | | | | | | | | **9** |
| SCA 12 | Minimize dust during construction | | | | | | | | | | | **9** |
| SCA13 | Optimise site planning, building orientation, and configuration | | | | | | | | **X** | | | **9** |
| SCA14 | Reduction of resource consumption | | | | | | | | | | | **9** |
| SCA15 | Maximisation of resource reuse | | | | | | | | | | | **9** |
| SCA16 | Protect the natural environment | | | | | | | | | | | **9** |
| SCA17 | Create a healthy and non-toxic environment | | | | | | | | | | | **9** |
| SCA18 | Pursue quality in creating the built environment | | | | | | | | | | | **9** |
| SCA19 | Apply life cycle costing | | | | | | | | | | | **9** |
| **2.1.3** | **Drivers for sustainable construction** | | | | | | | | | | | |
| DFSC1 | Professional knowledge in sustainable construction | | | | | | | | | | | **10** |
| DFSC2 | Sustainable design guidelines and construction standards | | | | | | | | | | | **9** |
| DFSC3 | Willingness to incorporate sustainable building practices | | | | | | | | | | | **9** |
| DFSC4 | Availability of acceptable sustainable construction roadmap | | | | | | | | | | | **9** |
| DFSC5 | Creation of public awareness | | | | | | | | | | | **10** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DFSC6 | Legislation | | | | | | | | | | | **9** |
| DFSC7 | Sustainable building codes and regulations | | | | | | | | | | | **9** |
| DFSC8 | Economic incentives (tax rebates, high profit margin) | | | | | | | | | | | **9** |
| DFSC9 | Sustainability practices in educational curricula | | | | | | | | | | | **9** |
| DFSC10 | Government commitment and support | | | | | | | | | | | **10** |
| DFSC11 | Availability of measurement tool | | | | | | | | | | | **9** |
| DFSC12 | Cooperation from technical experts | | | | | | | | | | | **9** |
| DFSC13 | Client demand and requirements | | | | | | | | | | | **9** |
| DFSC14 | Stakeholder influence | | | | | | | | | | | **9** |
| DFSC15 | Cost efficiency (whole life cycle costing) | | | | | | | | | | | **9** |
| DFSC16 | Competitive advantage | | | | | | | | | | | **9** |
| DFSC17 | Top management commitment | | | | | | | | | | | **9** |
| DFSC18 | Win more contracts to remain in business | | | | | | | | | | | **8** |
| DFSC19 | Company's reputation and brand image | | | | | | | | | | | **8** |
| DFSC20 | Availability of life cycle cost analysis | | | | | | | | | | | **9** |
| DFSC21 | Moral obligation to protect the environment | | | | | | | | | | | **9** |
| **2.1.4** | **Challenges of sustainable construction** | | | | | | | | | | | |
| CSC 1 | Lack of financial incentives (high taxes and low-profit margin) | | | | | | | | | | | **10** |
| CSC 2 | Lack of building code and regulation | | | | | | | | | | | **9** |
| CSC3 | Lack of investment | | | | | | | | | | | **9** |
| CSC4 | Initial investment cost | | | | | | | | | | | **9** |
| CSC5 | Lack of client demand | | | | | | | | | | | **9** |
| CSC6 | High cost of environmental services | | | | | | | | | | | **9** |
| CSC7 | Lack of research | | | | | | | | **X** | | | **8** |
| CSC8 | Lack of public awareness | | | | | | | | | | | **9** |
| CSC9 | Competitive pressure | | | | | | | | | | | **9** |
| CSC10 | Lack of database and information | | | | | | | | | | | **8** |
| CSC11 | Lack of green products | | | | | | | | | **X** | | **9** |
| CSC12 | Lack of professional knowledge and expertise | | | | | | | | | **X** | | **9** |
| CSC13 | Lack of green technology | | | | | | | | | **X** | | **9** |
| CSC14 | Tendering and contract requirements | | | | | | | | **X** | | | **8** |
| CSC15 | High level of perceived risk | | | | | | | | **X** | | | **8** |
| **2.1.5** | **Benefits of sustainable construction** | | | | | | | | | | | |
| **A.** | ***Environmental benefits*** | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BSDC 1 | Protecting air, water, land, ecosystems | | | | | | | | | | | **10** |
| BSDC 2 | Conserving natural resources (fossil fuel) | | | | | | | | | | | **10** |
| BSDC3 | Preserving animal species and genetic diversity | | | | | | | | | | | **9** |
| BSDC4 | Protecting the biosphere | | | | | | | | | | | **10** |
| BSDC5 | Using renewable natural resources | | | | | | | | | | | **9** |
| BSDC6 | Minimizing waste production or disposal | | | | | | | | | | | **9** |
| BSDC7 | Minimizing $CO_2$ emission and pollutants | | | | | | | | | | | **10** |
| BSDC8 | Maintaining essential ecological processes and life support system | | | | | | | | | | | **9** |
| BSDC9 | Pursuing active recycling | | | | | | | | | | | **9** |
| BSDC10 | Maintaining integrity of environment | | | | | | | | | | | **9** |
| BSDC11 | Preventing global warming | | | | | | | | | | | **10** |
| **B** | ***Social benefits*** | | | | | | | | | | | |
| BSDC13 | Improving quality of life for all | | | | | | | | **X** | | | **9** |
| BSDC14 | Alleviating poverty | | | | | | | | | | | **9** |
| BSDC15 | Satisfying human needs | | | | | | | | | | | **9** |
| BSDC16 | Incorporating cultural data into development | | | | | | | | | | | **8** |
| BSDC17 | Optimising social benefits | | | | | | | | | | | **9** |
| BSDC18 | Improving health, comfort and wellbeing | | | | | | | | | | | **9** |
| BSDC19 | Having concern for inter-generational equity | | | | | | | | | | | **7** |
| BSDC20 | Minimizing cultural disruption | | | | | | | | | | | **8** |
| BSDC21 | Providing education services | | | | | | | | | | | **8** |
| BSDC22 | Promoting harmony among people and between humanity and nature | | | | | | | | | | | **9** |
| BSDC23 | Understanding the importance of social and cultural capital | | | | | | | | | | | **8** |
| BSDC24 | Understanding multidisciplinary communities | | | | | | | | | | | **8** |
| **C** | ***Economic benefits*** | | | | | | | | | | | |
| BSDC24 | Improving economic growth | | | | | | | | | | | **9** |
| BSDC25 | Reducing energy consumption and costs | | | | | | | | | | | **9** |
| BSDC26 | Raising real income | | | | | | | | | | | **9** |
| BSDC27 | Improving productivity | | | | | | | | | | | **9** |
| BSDC28 | Lowering infrastructure costs | | | | | | | | | | | **9** |
| BSDC29 | Decreasing environmental damage costs | | | | | | | | | | | **9** |
| BSDC30 | Reducing water consumption and costs | | | | | | | | | | | **9** |
| BSDC31 | Decreasing health costs | | | | | | | | | | | **9** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BSDC32 | Decreasing absenteeism in organizations | | | | | | | | | | | **7** |
| BSDC33 | Improving return on investments (ROI) | | | | | | | | | | | **9** |
| **2.1.6** | **Environmental sustainability criteria** | | | | | | | | | | | |
| ESC1 | Energy conservation | | | | | | | | | | | **10** |
| ESC2 | Water conservation | | | | | | | | | | | **10** |
| ESC3 | Land conservation | | | | | | | | | | | **10** |
| ESC4 | Materials conservation – reuse and recycling | | | | | | | | | | | **10** |
| ESC5 | Resource utilization | | | | | | | | | | | **10** |
| ESC6 | Consideration of renewable energy | | | | | | | | | | | **10** |
| ESC7 | Minimize pollution – water, land and air pollution including noise | | | | | | | | | | | **10** |
| ESC8 | Perverse and enhance bio-diversity | | | | | | | | | | | **9** |
| ESC9 | Create a healthy, non-toxic environment-including indoor air quality | | | | | | | | | | | **10** |
| ESC10 | Protect and enhance sensitive landscapes – cultural & historic sites | | | | | | | | | | | **9** |
| ESC11 | Re-use existing built assets | | | | | | | | | | | **9** |
| ESC12 | Waste minimization and management | | | | | | | | | | | **10** |
| ESC13 | Environmental impact (process and product) | | | | | | | | | | | **9** |
| ESC14 | Transport – including provision of public transport | | | | | | | | | | | **9** |
| ESC15 | Visual impact | | | | | | | | | | | **9** |
| **2.1.7** | **Reduction of carbon and ecological footprint in construction** | | | | | | | | | | | |
| RCEF1 | Use of materials from renewable sources | | | | | | | | | | | **9** |
| RCEF2 | Use biodegradable materials | | | | | | | | | | | **9** |
| RCEF3 | Reduction in air, land and water pollution | | | | | | | | | | | **9** |
| RCEF4 | Reduction in materials and water usage | | | | | | | | | | | **9** |
| RCEF5 | Aids energy efficiency | | | | | | | | | | | **9** |
| RCEF6 | Use locally available materials | | | | | | | | | | | **9** |
| RCEF7 | Waste minimisation and reuse of waste products | | | | | | | | | | | **9** |
| RCEF8 | Rethink (innovation) sustainable practices | | | | | | | | | | | **9** |
| RCEF9 | Energy conservation | | | | | | | | | | | **10** |
| RCEF10 | Reduce transportation | | | | | | | | | | | **9** |
| RCEF11 | Embodied energy | | | | | | | | | | | **9** |

## 2.2 Sustainable design

Respond to sustainability through sustainable building design

| CODE | Elements of sustainable design | What is the **influence** of the following elements in measuring sustainable design? **(Low Influence ……………………..… High Influence)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No influence | | Low influence | | Medium influence | | High influence | | Very high influence | | **Median** |
| **2.2.1** | **Environmental sustainable design component** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| ESDC1 | Reduction of energy consumption | | | | | | | | | | | **9** |
| ESDC2 | Reduction of raw materials consumption | | | | | | | | | | | **9** |
| ESDC3 | Reduction of dangerous materials consumption | | | | | | | | | | | **9** |
| ESDC4 | Reduction of water consumption | | | | | | | | | | | **10** |
| ESDC5 | Recycling of waste and return | | | | | | | | | | | **9** |
| ESDC6 | Land conservation | | | | | | | | | | | **9** |
| **2.2.2** | **Environmental sustainable design requirements** | | | | | | | | | | | |
| ESDR1 | Resources conservation | | | | | | | | | | | **9** |
| ESDR2 | Humane adaption | | | | | | | | | | | **9** |
| ESDR3 | Life cycle design | | | | | | | | | | | **9** |
| ESDR4 | Cost efficiency | | | | | | | | | | | **9** |

## 2.3 Low impact building materials in construction

Low impact building materials selection and incorporation in construction projects.

| CODE | Elements of low impact building materials | How important are the following in measuring the incorporation of low impact building materials in construction? **(Unimportant ………..………… Very important)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | unimportant | | Low important | | Medium important | | High important | | Very high important | | **Median** |
| **2.3.1** | **Material selection criteria** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| MSC1 | Aesthetic quality of the material | | | | | | | | | | | **9** |
| MSC2 | Durability of the material | | | | | | | | | | | **9** |
| MSC3 | Ecological impact of the material | | | | | | | | | | | **9** |
| MSC4 | Embodied energy of the material | | | | | | | | | | | **9** |
| MSC5 | Performance of the material | | | | | | | | | | | **9** |
| MSC6 | Reusable/renewable potential of the material | | | | | | | | | | | **9** |
| MSC7 | Social impact of the material | | | | | | | | | | | **8** |
| MSC8 | Cost of the material | | | | | | | | **X** | | | **9** |
| **2.3.2** | **Material Incorporation measures** | | | | | | | | | | | |
| MIM1 | Choice of material to be renewable, recyclable or reusable | | | | | | | | | | | **9** |
| MIM2 | Use of materials with organic origin; e.g. use of natural materials in floors, walls, ceiling, roofs, etc. | | | | | | | | | | | **9** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIM3 | Use of permeable materials for landscaping to allow dissipation of storm water into the ground | | | | | | | | | | | **9** |
| MIM4 | Use of compost and mulch in building landscaping as a water conservation measure | | | | | | | | | | | **8** |
| MIM5 | Availability of water efficient trees, green roofs and rain gardens to provide infiltration and evapotranspiration | | | | | | | | | | | **9** |
| MIM6 | Use of materials that are long-lasting and easy to maintain | | | | | | | | | | | **9** |
| MIM7 | Materials specified in the design should have a minimum adverse impact on the environment | | | | | | | | | | | **9** |
| MIM8 | Use of local materials such as wood, thatch, laterite, gravels, sand, clay, bamboo, cement, plastic, soil blocks, etc. | | | | | | | | | | | **9** |
| **2.3.2** | **Emission reduction (Reduction of CO2 emission/pollution)** | | | | | | | | | | | |
| ER1 | Restriction of energy utilization | | | | | | | | | | | **10** |
| ER2 | Impact assessment of construction process | | | | | | | | | | | **10** |
| ER3 | Construction material production and discharge | | | | | | | | | | | **9** |
| ER4 | Adopting low carbon equipment and technology | | | | | | | | | | | **9** |
| ER5 | Adhering to construction standards/policies | | | | | | | | | | | **9** |
| ER6 | Limited transportation of material and personnel | | | | | | | | | | | **10** |
| **2.3.3** | **Water efficiency/conservation measures** | | | | | | | | | | | |
| WEM1 | Use of rainwater harvesting system | | | | | | | | | | | **10** |
| WEM2 | Installation of automatic plumbing fixtures and fitting such as human presence detectors to reduce | | | | | | | | | | | **9** |
| WEM3 | Recycling of grey water for irrigation and for reuse on the WCs | | | | | | | | | | | **9** |
| WEM4 | Installation of water conserving irrigation systems | | | | | | | | | | | **9** |
| WEM5 | Use of water saving appliances | | | | | | | | | | | **9** |
| WEM6 | Use of individual water metering for different tenants to conserve water | | | | | | | | | | | **9** |

## 2.4 Energy efficiency

To explore energy efficiency in construction and determine how energy efficiency equipment utilization is influencing construction process.

| CODE | Elements of energy efficiency | How important are the following in measuring energy efficiency and utilization? **(Unimportant …………… Very important)** | | | | | | | | | | Median |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | unimportant | | Low important | | Medium important | | High important | | Very high important | | |
| **2.4.1** | **Energy efficiency component** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| EEC1 | Choose energy efficient materials and construction methods | | | | | | | | | | | **9** |
| EEC2 | Insulate building envelope | | | | | | | | | | | **9** |
| EEC3 | Use energy efficient deconstruction and recycling | | | | | | | | | | | **9** |
| EEC4 | Adopt low energy intensive transportation | | | | | | | | | | | **9** |
| EEC5 | Develop energy efficient technological process | | | | | | | | | | | **9** |
| EEC6 | Use of passive energy design and construction | | | | | | | | | | | **9** |
| **2.4.2** | **Energy efficiency measures** | | | | | | | | | | | |
| EEM1 | Use of highly efficient light fixtures and efficient lighting controls | | | | | | | | | | | **9** |
| EEM2 | Availability of automatic presence detectors (on and off switch during the day and night) | | | | | | | | | | | **9** |
| EEM3 | Use of energy lighting | | | | | | | | | | | **9** |
| EEM4 | Adequacy of natural lighting systems | | | | | | | | | | | **9** |
| EEM5 | Adequate shading from intense heat (green roof to reduce heat from the roof) | | | | | | | | | | | **10** |
| EEM6 | Use of low emission glazing | | | | | | | | | | | **9** |
| EEM7 | Use of solar energy for external lighting | | | | | | | | | | | **10** |
| EEM8 | Use of low embodied energy materials | | | | | | | | | | | **9** |
| EEM9 | Avoiding the use of air conditioning system operating with Ozone Depleting | | | | | | | | | | | **9** |
| EEM10 | Reduce of substance (ODS) and/or Green House (GH) Gases | | | | | | | | | | | **9** |
| EEM11 | Use of renewable energy; e.g. solar, wind, geothermal, etc. | | | | | | | | | | | **10** |
| EEM12 | Use of individual metering for separate tenant to reduce energy consumption | | | | | | | | | | | **10** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EEM13 | Avoiding the use of sun-lit glazing to reduce AC cooling load | | | | | | | | | | | **9** |
| EEM14 | Zoning the spaces for energy-efficient air conditioning | | | | | | | | | | | **9** |
| **2.4.3** | **Energy efficient equipment use** | | | | | | | | | | | |
| EEE 1 | Reduce fuel usage | | | | | | | | | | | **10** |
| EEE 2 | Reduce emission levels and protect the environment | | | | | | | | | | | **9** |
| EEE 3 | Minimize energy consumption | | | | | | | | | | | **9** |
| EEE 4 | Upgrade/replace equipment with energy serving devices | | | | | | | | | | | **8** |
| EEE 5 | Improve productivity & increase value | | | | | | | | | | | **9** |
| EEE 6 | Reduction in energy cost | | | | | | | | | | | **9** |
| **2.4.4** | **Protection of resources for ecological sustainability** | | | | | | | | | | | |
| PRES 1 | Effective land utilization | | | | | | | | | | | **9** |
| PRES 2 | Consideration in material selection | | | | | | | | | | | **9** |
| PRES 3 | Waste minimization | | | | | | | | | | | **9** |
| PRES 4 | Energy conservation | | | | | | | | | | | **9** |
| PRES 5 | Water efficiency | | | | | | | | | | | **9** |
| PRES 6 | Pollution control | | | | | | | | | | | **9** |
| PRES 7 | Biodiversity protection | | | | | | | | | | | **9** |
| PRES 8 | Heritage and amenity protection | | | | | | | | | | | |

**2.5 Waste management practices in construction**

To evaluate the modalities employed by contractors to reduce construction site solid waste production and discharge.

| **CODE** | **Elements of solid waste production and discharge** | How important are the following in measuring solid waste management in construction? **(Unimportant …………… Very important)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | unimportant | | Low important | | Medium important | | High important | | Very high important | | **Median** |
| **2.5.1** | **Waste minimization measures** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | |
| WMM1 | Using materials before expiry dates | | | | | | | | | | | **9** |
| WMM2 | Use of more efficient equipment | | | | | | | | | | | **9** |
| WMM3 | Purchasing raw materials that are just sufficient | | | | | | | | | | | **9** |
| WMM4 | Adoption of proper site management techniques | | | | | | | | | | | **9** |
| WMM5 | Good coordination between store and construction personnel to avoid over ordering | | | | | | | | | | | **9** |
| WMM6 | Minimizing design changes | | | | | | | | | | | **9** |
| WMM7 | Training of construction personnel | | | | | | | | | | | **9** |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WMM8 | Proper storage of materials on site | | | | | | | | | | | **9** |
| WMM9 | Employment of skills work men | | | | | | | | | | | **9** |
| WMM10 | Accurate and good specifications of materials to avoid wrong ordering | | | | | | | | | | | **10** |
| WMM11 | Checking materials supplied for right quantities and volumes | | | | | | | | | | | **9** |
| WMM12 | Change of attitudes of workers towards the handling of materials | | | | | | | | | | | **9** |
| WMM13 | Vigilance of supervisors | | | | | | | | | | | **9** |
| WMM14 | Access to latest information about types of materials on the market | | | | | | | | | | | **9** |
| WMM15 | Accurate measurement of materials during batching | | | | | | | | | | | **9** |
| WMM16 | Weekly programming of works | | | | | | | | | | | **9** |
| WMM17 | Good construction management practices | | | | | | | | | | | **9** |
| WMM18 | Mixing, transporting and placing concrete at the appropriate time | | | | | | | | | | | **9** |
| WMM19 | Adherence to standardized dimensions | | | | | | | | | | | **9** |
| WMM20 | Waste management officer or personnel employed to handle waste issues | | | | | | | | | | | **9** |
| WMM21 | Early and prompt scheduling of deliveries | | | | | | | | | | | **9** |
| WMM22 | Just in time operations | | | | | | | | | | | **9** |
| WMM23 | Careful handling of tools and equipment on site | | | | | | | | | | | **9** |
| WMM24 | Encourage re-use of waste materials in projects | | | | | | | | | | | **9** |
| WMM25 | Use of low waste technology | | | | | | | | | | | **9** |
| WMM26 | Recycling of some waste materials on site | | | | | | | | | | | **9** |

**Reason(s) for the difference between the group median and your response:**

- Some statements were not clear to me earlier and I have understood them now, hence the variation in my response.
- The variation in my response to the group mean is due to the level of importance each respondent attached to the elements and individual's professional experience in sustainable construction.

1. Kindly provide additional statement(s), if any, which will improve sustainable construction practices of construction companies:

___

___

2. Kindly provide reason(s) for changing your responses:

**THANK YOU**

Central University of Technology, Free State

## APPENDIX E: SURVEY QUESTIONNAIRE

Central University of Technology, Free State

**Faculty of Engineering, Built Environment and Information Technology**

**SURVEY QUESTIONNAIRE**

16th December, 2021

## TO WHOM IT MAY CONCERN

Dear Sir/Madam,

**Re: Request to participate in a study entitled: 'A Roadmap for the Reduction of Carbon and Ecological Footprint of Construction Activity in Ghana'**

The lack of roadmap for reduction of construction activity carbon and ecological footprint hinders continuous improvement within the public sector construction in Ghana. Therefore, the purpose of this study is to develop a roadmap of sustainability practices for construction companies in reducing the carbon and ecological footprint of their activity to achieve environmental sustainability of the construction industry in Ghana.

You are kindly requested to participate in completing a Questionnaire designed from Delphi technique to collect data for an ongoing doctoral study by Moses K. Ahiabu on the above topic at Central University of Technology, Free State, South Africa.

Your participation in this study is highly solicited and appreciated. You are assured that any information given would be treated highly confidential and shall be used for academic purposes only. To obtain any further information relating to the study, contact the study promoter Professor F.A. Emuze at femuze@cut.ac.za or the researcher on +233(0)203223884.

The questionnaire takes approximately 20 minutes to complete. Kindly return the completed questionnaire via email to the researcher on **mosesahiabu@yahoo.com** within 2 weeks of receiving this email, please. The result of the study will be made available to you on request. We look forward to receiving a favourable contribution from you. Thank you for your time.

Yours sincerely,

**MR. MOSES K. AHIABU**
**(Doctoral Candidate)**

**PROF. FIDELIS A. EMUZE**
**(Study Promoter)**

**INSTRUCTIONS**

The questionnaire is divided into six (6) sections. Section A is on the demographic information of the respondent for statistical purpose only. The section B is on the components of sustainable construction practices whilst section C is on the sustainable building design. Sections D and E are on the protection of resources & low impact building materials, and reduction of carbon emission/pollution & energy efficiency respectively. Section F on the other hand is on dimensions of waste management.

**SECTION A: Demographic information**

Kindly tick the appropriate box that correspond to your answer or fill in the blank spaces.

1. What is your highest academic qualification?

Doctorate Degree ☐ Master's Degree ☐ BSc Degree ☐ HND/Diploma/CTC ☐

SSCE/WASSCE ☐ BECE ☐ Other ☐ If other, specify …………………...

2. Which professional body are you affiliated?

Ghana Institution of Surveyors (GhIS) ☐ Ghana Institution of Engineers (GIE) ☐

Ghana Institute of Architects (GIA) ☐ Ghana Institution of Construction (GIOC) ☐

Ghana Institution of Engineers (GhIE) ☐ Other ☐ If other, specify …………………

3. What is your position in the company?

Owner ☐ Managing Director ☐ Project Manager ☐ Quantity Surveyor ☐

Engineer ☐ Architect ☐ Site Foreman ☐ Other ☐ If other, specify ………..

4. How many years of experience do you have in the construction industry?

0-5 years ☐ 6-10 years ☐ 11-15 years ☐ 16-20 years ☐ Above 20 years ☐

5. How many years have you been working in this particular company?

0-5 years ☐ 6-10 years ☐ 11-15 years ☐ 16-20 years ☐ Above 20 years ☐

6. Which category is the company registered with Registrar General Department?

Limited liability ☐ Partnership ☐ Enterprise ☐

7. What is the classification of the company?

D1K1 ☐ D2K2 ☐ D3K3 ☐ D4K4 ☐ If other, specify …………………

8. What is the nature of business activity of the company?

General contractor ☐ Sub-contractor ☐ Specialist contractor ☐ Other ☐

If other, specify ……………………………………………………………………………

9. Which project are you currently working on? Please state ……………………………………

10. Does your company adopt sustainable practices in its construction activities?

Yes ☐ No ☐ If yes, state ……………………………………………………

11. Are you aware of the existence of sustainable construction roadmap for Ghana that guides the construction activity of your company?

Yes ☐ No ☐

12. If yes, state …………………………………………………………………………

13. What is the following stakeholder's extent of influence on reduction of carbon and ecological footprints of construction activity in your organization?

Kindly rate the level of influence using a 5 – point Likert scale where 1 = very low; 2 = low; 3 = somewhat high; 4 = high; and 5 = very high.

| **CODE** | **Stakeholders** | **Very low** | **Low** | **Somewhat high** | **High** | **Very high** |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** |
| SEI 1 | Academia | | | | | |
| SEI 2 | Client/Developer | | | | | |
| SEI 3 | Contractor | | | | | |
| SEI 4 | Consultant | | | | | |
| SEI 5 | Government | | | | | |
| SEI 6 | Green Building Council | | | | | |
| SEI 7 | Environmental Protection Agency | | | | | |
| SEI 8 | Media | | | | | |

**SECTION B: General knowledge and importance of sustainable construction practices**

14. Kindly rate your level of agreement with the variables of the following sustainable construction practices to reduce carbon and ecological footprints in your company using a 5 – point Likert scale where 1 = strongly disagree; 2 = disagree; 3 = somewhat agree; 4 = agree; and 5 = strongly agree.

| **CODE** | **Variables** | **Strongly disagree** | **Disagree** | **Somewhat agree** | **Agree** | **Strongly agree** |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** |
| **14.1** | **What are the key sustainability issues** | | | | | |
| KSI 1 | Biodiversity | | | | | |
| KSI 2 | Climate change | | | | | |
| KSI 3 | Carrying capacity | | | | | |
| KSI 4 | Energy efficiency | | | | | |
| KSI 5 | Health, safety and well-being | | | | | |
| KSI 6 | Resources efficiency | | | | | |
| KSI 7 | Material consumption and conservation | | | | | |
| KSI 8 | Pollution and nuisance | | | | | |
| KSI 9 | Waste management | | | | | |
| KSI 10 | Harmonisation with environment | | | | | |
| **14.2** | **How do you understand sustainable construction activities/practices** | | | | | |
| SCA 1 | Regenerate used natural vegetation | | | | | |
| SCA 2 | Use renewable construction material | | | | | |
| SCA 3 | Reduce transportation distance of people | | | | | |
| SCA 4 | Use of forestry-authority–certified timber | | | | | |
| SCA 5 | Minimize carbon emissions in construction | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| SCA 6 | Do selective construction waste disposal | | | | | |
| SCA 7 | Recycle construction waste | | | | | |
| SCA 8 | Ensure efficiency in energy usage for construction works | | | | | |
| SCA 9 | Ensure efficiency in water usage during construction | | | | | |
| SCA 10 | Minimize dust during construction | | | | | |
| SCA 11 | Optimise site planning, building orientation, and configuration | | | | | |
| SCA 12 | Reduction of resource consumption | | | | | |
| SCA 13 | Maximisation of resource reuse | | | | | |
| SCA 14 | Protect the natural environment | | | | | |
| SCA 15 | Create a healthy and non-toxic environment | | | | | |
| SCA 16 | Pursue quality in creating the built environment | | | | | |
| SCA 17 | Apply life cycle costing | | | | | |
| **14.3** | **Drivers of sustainable construction** | | | | | |
| DSC1 | Professional knowledge in sustainable construction | | | | | |
| DSC2 | Sustainable design guidelines and construction standards | | | | | |
| DSC3 | Willingness to incorporate sustainable building practices | | | | | |
| DSC4 | Availability of acceptable sustainable construction roadmap | | | | | |
| DSC5 | Creation of public awareness | | | | | |
| DSC6 | Legislation | | | | | |
| DSC7 | Sustainable building codes and regulations | | | | | |
| DSC8 | Economic incentives (tax rebates, high profit margin) | | | | | |
| DSC9 | Sustainability practices in educational curricula | | | | | |
| DSC10 | Government commitment and support | | | | | |
| DSC11 | Availability of measurement tool | | | | | |
| DSC12 | Cooperation from technical experts | | | | | |
| DSC13 | Client demand and requirements | | | | | |
| DSC14 | Stakeholder influence | | | | | |
| DSC15 | Cost efficiency | | | | | |
| DSC16 | Competitive advantage | | | | | |
| DSC17 | Top management commitment | | | | | |
| DSC18 | Availability of life cycle cost analysis | | | | | |
| DSC19 | Moral obligation to protect the environment | | | | | |
| **14.4** | **Challenges of sustainable construction** | | | | | |
| CSC 1 | Lack of financial incentives (high taxes and low-profit margin) | | | | | |
| CSC 2 | Lack of building code and regulation | | | | | |
| CSC3 | Lack of investment | | | | | |
| CSC4 | Initial investment cost | | | | | |
| CSC5 | Lack of client demand | | | | | |
| CSC6 | High cost of environmental services | | | | | |
| CSC7 | Lack of research | | | | | |
| CSC8 | Lack of public awareness | | | | | |
| CSC9 | Competitive pressure | | | | | |
| CSC10 | Lack of green products | | | | | |
| CSC11 | Lack of professional knowledge and expertise | | | | | |
| CSC12 | Lack of green technology | | | | | |
| **14.5** | **Environmental sustainability criteria** | | | | | |
| ESC1 | Energy conservation | | | | | |
| ESC2 | Water conservation | | | | | |
| ESC3 | Land conservation | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| ESC4 | Materials conservation – reuse and recycling | | | | | |
| ESC5 | Resource utilization | | | | | |
| ESC6 | Consideration of renewable energy | | | | | |
| ESC7 | Minimize pollution – water, land and air pollution including noise | | | | | |
| ESC8 | Perverse and enhance bio-diversity | | | | | |
| ESC9 | Create a healthy, non-toxic environment-including indoor air quality | | | | | |
| ESC10 | Protect and enhance sensitive landscapes – cultural & historic sites | | | | | |
| ESC11 | Re-use existing built assets | | | | | |
| ESC12 | Waste minimization and management | | | | | |
| ESC13 | Environmental impact (process and product) | | | | | |
| ESC14 | Transport – including provision of public transport | | | | | |
| ESC15 | Visual impact | | | | | |
| **14.6a** | **Benefits/ importance of sustainable construction - environmental** | | | | | |
| BSC 1 | Protect air, water, land and ecosystems | | | | | |
| BSC 2 | Conserve natural resources ( e.g. fossil fuel) | | | | | |
| BSC3 | Preserve animal species and genetic diversity | | | | | |
| BSC4 | Protect the biosphere | | | | | |
| BSC5 | Use renewable natural resources | | | | | |
| BSC6 | Minimize waste production or disposal | | | | | |
| BSC7 | Minimize $CO_2$ emission and pollutants | | | | | |
| BSC8 | Maintain essential ecological processes and life support system | | | | | |
| BSC9 | Pursue active recycling | | | | | |
| BSC10 | Maintain integrity of environment | | | | | |
| BSC11 | Prevent global warming | | | | | |
| **14.6b** | **Benefits/ importance of sustainable construction - social** | | | | | |
| BSC12 | Improve quality of life for all | | | | | |
| BSC13 | Alleviate poverty | | | | | |
| BSC14 | Satisfy human needs | | | | | |
| BSC15 | Optimise social benefits | | | | | |
| BSC16 | Improve health, comfort and wellbeing | | | | | |
| BSC17 | Promote harmony among people and between humanity and nature | | | | | |
| **14.6c** | **Benefits/ importance of sustainable construction - economics** | | | | | |
| BSC18 | Improve economic growth | | | | | |
| BSC19 | Reduce energy consumption and costs | | | | | |
| BSC20 | Raise real income | | | | | |
| BSC21 | Improve productivity | | | | | |
| BSC22 | Lower infrastructure costs | | | | | |
| BSC23 | Decrease environmental damage costs | | | | | |
| BSC24 | Reduce water consumption and costs | | | | | |
| BSC25 | Decrease in health costs | | | | | |
| BSC26 | Improve return on investments (ROI) | | | | | |
| **14.7** | **Reduction of carbon and ecological footprint in construction** | | | | | |
| RCEF1 | Use of materials from renewable sources | | | | | |
| RCEF2 | Use biodegradable materials | | | | | |
| RCEF3 | Reduction in air, land and water pollution | | | | | |
| RCEF4 | Reduction in materials and water usage | | | | | |
| RCEF5 | Aids energy efficiency | | | | | |
| RCEF6 | Use locally available materials | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| RCEF7 | Waste minimisation and reuse of waste products | | | | | |
| RCEF8 | Rethink (innovation) sustainable practices | | | | | |
| RCEF9 | Energy conservation | | | | | |
| RCEF10 | Reduce transportation | | | | | |
| RCEF11 | Embodied energy | | | | | |

**SECTION C: Sustainable building design**

15. Kindly rate your level of agreement with the following variables to determine how architectural and engineering firms contribute to sustainability of construction activities through design of buildings to reduce carbon and ecological footprint using a 5 – point Likert scale, where 1 = strongly disagree; 2 = disagree; 3 = somewhat agree; 4 = agree; and 5 = strongly agree.

| CODE | VARIABLES | Strongly disagree | Disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** |
| **15.1** | **Environmental sustainable design component** | | | | | |
| ESDC1 | Reduction of energy consumption | | | | | |
| ESDC2 | Reduction of raw materials consumption | | | | | |
| ESDC3 | Reduction of dangerous materials consumption | | | | | |
| ESDC4 | Reduction of water consumption | | | | | |
| ESDC5 | Recycling of waste and return | | | | | |
| ESDC6 | Land conservation | | | | | |
| **15.2** | **Environmental sustainable design requirements** | | | | | |
| ESDR1 | Resources conservation | | | | | |
| ESDR2 | Humane adaption | | | | | |
| ESDR3 | Life cycle design | | | | | |
| ESDR4 | Cost efficiency | | | | | |

**SECTION D: Protection of resources and Low impact building materials**

16. Kindly rate your level of agreement with the following variables on how you incorporate low impact building materials in your construction activities and protect the natural resources to reduce carbon and ecological footprints in your company using a 5 – point Likert scale where 1 = strongly disagree; 2 = disagree; 3 = somewhat agree; 4 = agree; and 5 = strongly agree.

| CODE | VARIABLES | Strongly disagree | Disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** |
| **16.1** | **Low impact material selection criteria** | | | | | |
| MSC1 | Aesthetic quality of the material | | | | | |
| MSC2 | Durability of the material | | | | | |
| MSC3 | Ecological impact of the material | | | | | |
| MSC4 | Embodied energy of the material | | | | | |
| MSC5 | Performance of the material | | | | | |
| MSC6 | Reusable/renewable potential of the material | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| MSC7 | Social impact of the material | | | | | |
| MSC8 | Cost of the material | | | | | |
| **16.2** | **Low impact material incorporation measures** | | | | | |
| MIM1 | Materials use are renewable, recyclable or reusable | | | | | |
| MIM2 | Use of materials with organic origin/natural materials | | | | | |
| MIM3 | Use of permeable materials for landscaping to allow dissipation of storm water into the ground | | | | | |
| MIM4 | Use water efficient trees, green roofs and rain gardens | | | | | |
| MIM5 | Use of materials that are long-lasting and easy to maintain | | | | | |
| MIM6 | Materials of minimum adverse impact on the environment | | | | | |
| MIM7 | Use of local materials (wood, thatch, laterite, bamboo, etc.) | | | | | |
| **16.3** | **Protection of resources for ecological sustainability** | | | | | |
| PRES 1 | Effective land utilization | | | | | |
| PRES 2 | Consideration in material selection | | | | | |
| PRES 3 | Waste minimization | | | | | |
| PRES 4 | Energy conservation | | | | | |
| PRES 5 | Water efficiency | | | | | |
| PRES 6 | Pollution control | | | | | |
| PRES 7 | Biodiversity protection | | | | | |
| PRES 8 | Heritage and amenity protection | | | | | |
| **16.4** | **Water efficiency measures** | | | | | |
| WEM1 | Use rainwater harvesting system | | | | | |
| WEM2 | Install automatic plumbing fixtures and fittings | | | | | |
| WEM3 | Recycle grey water for irrigation and reuse in WCs | | | | | |
| WEM4 | Install water conserving irrigation systems | | | | | |
| WEM5 | Use water saving appliances | | | | | |
| WEM6 | Use individual water metering for different tenants | | | | | |

**SECTION E: Reduction of CO2 emission/pollution and energy efficiency**

17. Kindly rate your level of agreement with the following variables on how you reduce carbon emission/pollution in your construction activities, and energy efficiency using a 5 – point Likert scale where 1 = strongly disagree; 2 = disagree; 3 = somewhat agree; 4 = agree; and 5 = strongly agree.

| **CODE** | **VARIABLES** | **Strongly disagree** 1 | **Disagree** 2 | **Somewhat agree** 3 | **Agree** 4 | **Strongly agree** 5 |
|---|---|---|---|---|---|---|
| **17.1** | **Emission reduction (Reduction of CO2 emission/pollution)** | | | | | |
| ER1 | Restriction of energy utilization | | | | | |
| ER2 | Impact assessment of construction process | | | | | |
| ER3 | Construction material production and discharge | | | | | |
| ER4 | Adopting low carbon equipment and technology | | | | | |
| ER5 | Adhering to construction standards/policies | | | | | |
| ER6 | Limited transportation of material and personnel | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **17.2** | **Energy efficiency component** | | | | | |
| EEC1 | Choose energy efficient materials and construction methods | | | | | |
| EEC2 | Insulate building envelope | | | | | |
| EEC3 | Use energy efficient deconstruction and recycling | | | | | |
| EEC4 | Adopt low energy intensive transportation | | | | | |
| EEC5 | Develop energy efficient technological process | | | | | |
| EEC6 | Use of passive energy design and construction | | | | | |
| **17.3** | **Energy efficiency measures** | | | | | |
| EEM1 | Use of highly efficient lighting fixtures and controls | | | | | |
| EEM2 | Use automatic presence detectors and photocell | | | | | |
| EEM3 | Use of energy efficient lighting systems | | | | | |
| EEM4 | Adequate provision of natural day lighting systems | | | | | |
| EEM5 | Adequate shading from intense heat (e.g. green roof) | | | | | |
| EEM6 | Use of low emission glazing | | | | | |
| EEM7 | Use of solar energy for external lighting | | | | | |
| EEM8 | Use of low embodied energy materials | | | | | |
| EEM9 | Avoid using air conditioning system operating with Ozone Depleting | | | | | |
| EEM10 | Reduce substances or Green House (GH) Gases | | | | | |
| EEM11 | Use renewable energy; e.g. solar, wind, geothermal, etc. | | | | | |
| EEM12 | Use individual metering for separate tenant | | | | | |
| EEM13 | Avoid the use of sun-lit glazing to reduce AC cooling load | | | | | |
| EEM14 | Zoning the spaces for energy-efficient air conditioning | | | | | |
| **17.4** | **Energy efficient equipment utilization** | | | | | |
| EEEU 1 | Reduce fuel usage | | | | | |
| EEEU 2 | Reduce emission levels and protect the environment | | | | | |
| EEEU 3 | Minimize energy consumption | | | | | |
| EEEU 4 | Upgrade/replace equipment with energy serving devices | | | | | |
| EEEU 5 | Improve productivity & increase value | | | | | |
| EEEU 6 | Reduction in energy cost | | | | | |

**SECTION F: Waste management**

18. Kindly rate your level of agreement with the following variables on how you manage the construction waste to reduce carbon and ecological footprint in your company using a 5 – point Likert scale where 1 = strongly disagree; 2 = disagree; 3 = somewhat agree; 4 = agree; and 5 = strongly agree.

| **CODE** | **VARIABLES** | **Strongly disagree** | **Disagree** | **Somewhat agree** | **Agree** | **Strongly agree** |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | **5** |
| **18.1** | **Waste management measures** | | | | | |
| WMM1 | Use materials before expiry dates | | | | | |
| WMM2 | Use of more efficient equipment | | | | | |
| WMM3 | Purchase raw materials that are just sufficient | | | | | |
| WMM4 | Adopt proper site management techniques | | | | | |
| WMM5 | Ensure good coordination between store and construction personnel to avoid over ordering | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| WMM6 | Minimize design changes | | | | | |
| WMM7 | Training of construction personnel and staff | | | | | |
| WMM8 | Proper storage of materials on site | | | | | |
| WMM9 | Employ skills work men | | | | | |
| WMM10 | Ensure accurate specifications of materials to avoid wrong ordering | | | | | |
| WMM11 | Check materials supplied for right quantities and volumes | | | | | |
| WMM12 | Change attitudes of workers towards handling of materials | | | | | |
| WMM13 | Supervisors should be vigilant | | | | | |
| WMM14 | Access to information on types of materials in the market | | | | | |
| WMM15 | Accurate measurement of materials during batching | | | | | |
| WMM16 | Weekly programming of works | | | | | |
| WMM17 | Good construction management practices | | | | | |
| WMM18 | Right mixing, transportation and placing of concrete | | | | | |
| WMM19 | Adherence to standardized dimensions | | | | | |
| WMM20 | Waste management officer employed to handle waste issues | | | | | |
| WMM21 | Early and prompt scheduling of deliveries | | | | | |
| WMM22 | Just in time operations | | | | | |
| WMM23 | Careful handling of tools and equipment on site | | | | | |
| WMM24 | Encourage re-use of waste materials in projects | | | | | |
| WMM25 | Use low waste technology | | | | | |
| WMM26 | Recycle some waste materials on site | | | | | |

**THANK YOU**

**APPENDIX F: INTERVIEW GUIDE**

**FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY**

**INTERVIEW GUIDE**

Date: 19th July, 2022

The lack of roadmap for reduction of construction activity carbon and ecological footprint hinders continuous improvement within the public sector construction in Ghana. Therefore, the purpose of this interview seeks to validate the roadmap developed to reduce carbon and ecological footprint of construction activity to implement sustainable construction in Ghana. This interview is intended to take approximately 15 minutes to complete.

**Demographic information**

1. Highest academic qualification: ………………………………………………………….
2. Profession/area of expertise: ..…………………………………………………………
3. Type of organisation: ……………………………………………..……………………
4. Institution (Academia/industry): ..……………………………………………………..
5. Years of experience: ..…………………………………………………………………

**Roadmap validation**

Kindly rate your level of agreement with the variables to validate the proposed roadmap using a 5 – point Likert scale where 1 = strongly disagree; 2 = disagree; 3 = somewhat agree; 4 = agree; and 5 = strongly agree.

| S/N | Variables | Strongly disagree | Disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 1. | Level of coverage of the roadmap for overall contents and main sections including issues on knowledge and awareness, drivers, challenges and benefits reflect the situation of sustainable construction in the Ghanaian construction industry currently | | | | | |
| 2. | Level of coverage of the roadmap for logical flow are appropriate and can easily be used in the Ghanaian construction industry | | | | | |
| 3. | Level of understanding of the roadmap is easy to understand and can easily be used in the construction industry in Ghana | | | | | |
| 4. | The carbon and ecological footprint reduction roadmap is inclusive and proper application of the roadmap would enhance the implementation of sustainable in Ghana | | | | | |
| 5. | Would you recommend the roadmap for use by the construction stakeholders in Ghana to reduce carbon and ecological footprints of construction activity? | | | | | |
| 6. | Suggestion/comment on areas of the roadmap that need improvement/deletion. | | | | | |

To obtain any further information relating to the study, please contact the researcher Moses K. Ahiabu at mosesahiabu@yahoo.com and on telephone number +233(0)203223884 or the study promoter Professor F.A. Emuze at femuze@cut.ac.za.

**Thank you for your time**