LIFECYCLE ECONOMIC FEASIBILITY ASSESSMENT MODEL FOR GREEN FINANCE IN GREEN BUILDING IN GHANA

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Lifecycle Economic Feasibility Assessment Model For Green Finance In Green Building In Ghana

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces neither material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

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Caleb DEBRAH (Name of Student)

DEDICATION

I dedicate this thesis to God, the Almighty, my family (especially my parents, Mr. Samuel and Mrs. Juliana Amoah Debrah), my church (Pentecost International Worship Centre, Hong Kong), and all my friends – home and abroad – for their most significant support in this PhD and life journey.

ABSTRACT

Green building (GB) promotes sustainability in the buildings and construction sector. However, high upfront costs and inadequate financing impede adoption and implementation. In addition, several untapped opportunities exist for green finance (GF) in GB (GF-in-GB), making it highly under-invested. Besides, it lacks the necessary research and development, particularly in developing countries.

Therefore, this study aimed to explore the dynamism of GF-in-GB projects in developing regions using Ghana to aid the development of a cost-benefit analysis (CBA) model to evaluate the economic feasibility of GF-in-GB projects. Accordingly, five objectives were established: (i) to evaluate the interactions between the critical drivers of GF-in-GB, (ii) to investigate the interrelationships between the critical barriers to GF-in-GB, (iii) to develop a risk assessment model for GF-in-GB, (iv) to assess the interdependencies of the strategies that can be adopted to promote GF-in-GB, and (v) to develop a CBA model to evaluate the economic feasibility of GF-in-GB projects. To achieve the aim and objectives, this research employed diverse methodological tools and techniques, including linguistic evaluation questionnaire surveys, the fuzzy Delphi method (FDM), the fuzzy decision-making trial and evaluation laboratory (FDEMATEL) method, the net present value method, internal

rate of return, and scenario analysis. Data were gathered from relevant literature, and experts were identified using non-probabilistic sampling techniques.

Based on the FDM and FDEMATEL results, cause-effect diagrams showing the interrelationship between the different factors of GF-in-GB in terms of the drivers, barriers, risk factors, and strategies were revealed and prioritised. The interrelationships between the factors were used to develop structural interdependence models, showing the cause-effect and influential parameters. Causal-effect frameworks can assist GF-in-GB actors and policymakers in prioritising and paying more attention to cause-group drivers, barriers, risk factors, and strategies amidst constrained resources. These cause-group factors, also known as driving and critical factors, directly impact the GF-in-GB system and demand high priority. Prioritising cause-group factors will directly impact the effect group, leading to positive results.

For the GB CBA, evolving results from emerging and developing economies demonstrate that GB requires less than 6% extra cost but offers over 37% energy and water cost savings in the lifecycle. The LCC budgets of GB and GB under renewable resource (GB-RE) considerations per square meter were 36% and 74% lower than those of non-GBs, respectively. The cost-benefit ratio of GB was 1.31, indicating that the benefits outweigh the building's costs and are expected to deliver a positive return on investment. The NPV of GB benefits over the project lifecycle was US$ 42.70/m^2. GB-

RE increased the cost-benefit ratio to 1.44 and NPV to US$ 97.21/m^2. Subsequently, the NPV results formed the basis for developing an economic feasibility assessment model for GF-in-GB. The findings reveal that lower financing risks can make the NPV of a project more profitable, thereby making the NPV positive over a shorter horizon. The results show that the optimal weight for bank loans for the GB project was approximately 42%. This means using more green bonds (58%) in GB projects is essential and profitable. Sensitivity and risk analyses proved the accuracy of the results and the robustness of the study.

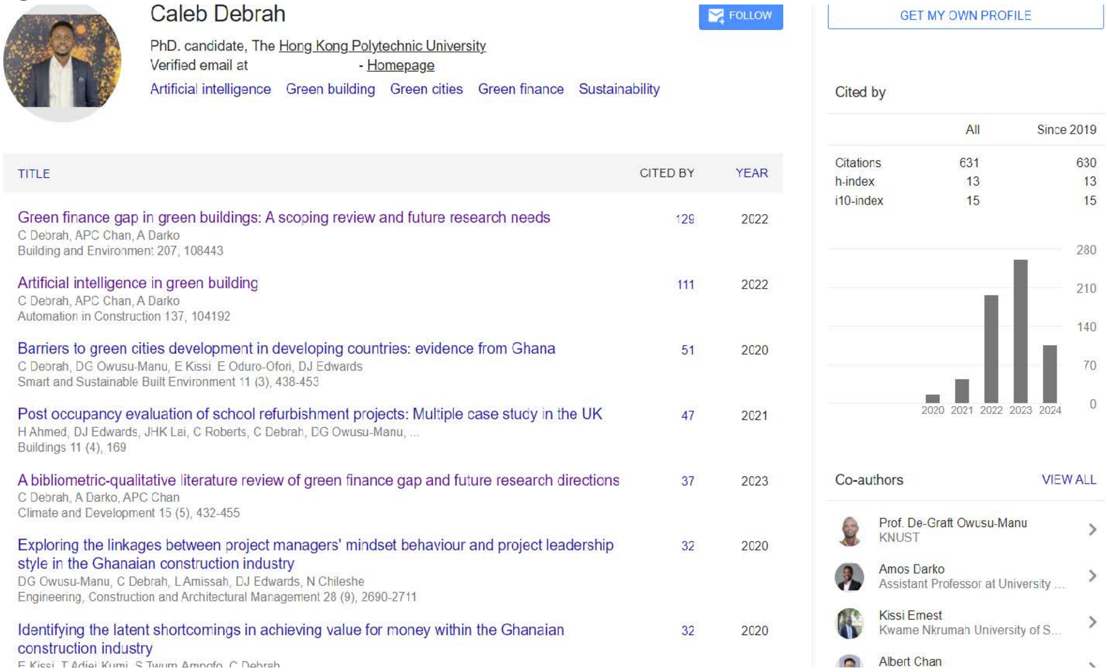
This study makes valuable contributions to the GB and GF literature, especially for developing countries, but also helps policymakers, practitioners, advocates, academics, and other stakeholders promote GF-in-GB in the buildings and construction sector.

Keywords: Cost Benefit Analysis; Developing Countries; Fuzzy Delphi Method; Fuzzy DEMATEL; Ghana; Green Building; Green Finance; Sustainable Finance.

LIST OF RESEARCH PUBLICATIONS

Citation Metrics (May 2024)

<u>Google Scholar</u> citations = 640; h-index = 13



<u>Scopus</u> citations = 408+; h-index = 11

<u>Web of Science</u> citations = 339+; h-index = 10

The following provides a list of research publications by the author of this thesis during his PhD study, as shown in the text. Some chapters of this thesis are based on fully published works by the author or those currently under consideration for publication and are directly relevant to this thesis:

A. Refereed Journal Papers (Published/Accepted: 2021 – 2024)

Those Directly Relevant to This Thesis

1. <u>Debrah, C.,</u> Chan, A.P.C., Darko, A., Ries R.J., Ohene, E. and Tetteh, M.O. (2024). Driving factors for the adoption of green finance in green building for sustainable development in developing countries: The case of Ghana. *Sustainable Development* (**IF = 12.5**), <u>https://doi.org/10.1002/SD.3022</u> - Q1

2. <u>Debrah, C.</u>, Darko, A., and Chan, A.P.C. (2023). A bibliometric-qualitative literature review of green finance gap and future research directions, *Climate and Development* (**IF = 4.3**), 1-24. <u>https://doi.org/10.1080/17565529.2022.2095331</u> - Q1

3. <u>Debrah, C.,</u> Chan, A.P.C., and Darko, A. (2022). Artificial intelligence in green building. *Automation in Construction* (**IF = 10.3**), 137, 104192.

https://doi.org/10.1016/j.autcon.2022.104192 - Q1. **(“Highly Cited Paper” in the field of Engineering – Web of Science Core Collection, 2023)**

4. Debrah, C., Chan, A.P.C., and Darko, A. (2022). Green finance gap in green buildings: A scoping review and future research needs, *Building and Environment* (**IF = 7.4**), 207, 108443. https://doi.org/10.1016/j.buildenv.2021.108443 - Q1.

The Candidate’s level of contribution to the above papers

The candidate, Mr. Caleb Debrah, under the direct guidance of his Chief Supervisor, Ir. Prof. Albert P. C. Chan, and Co-Supervisor, Dr. Amos Darko, was responsible for the exploration, development, and initial drafting of all papers listed above. Afterward, Caleb diligently revised and enhanced the quality of the papers, considering the constructive input provided by his supervisors on the initial drafts. It is worth noting that all papers were initially written in English, and no professional English language editing services were used during the publication process. Furthermore, Mr. Debrah assumed the corresponding author role in all these papers. He oversaw all revisions, addressed feedback for journal reviewers, and made necessary adjustments to address their comments effectively.

Others

1. Owusu-Boadi, J., Kissi, E., Abu, I. M., Owusu, C. D., Baiden, B., & Debrah, C. (2024). A bibliometric and scientometric analysis-based review of environmental health and safety research in the construction industry. *Journal of Engineering, Design and Technology* (**IF = 2.8**), https://doi.org/10.1108/JEDT-09-2023-0423 - Q1
2. Debrah, C., Owusu-Manu, D., Darko, A., Oduro-Ofori E., Acquah, P. C. and Asamoah, E (2023). Drivers for green cities development in developing countries: Ghanaian perspective. *International Journal of Construction Management* (**IF = 3.9**), 23 (6), 1086-1096. https://doi.org/10.1080/15623599.2021.1955321 - Q2
3. Debrah, C., Owusu-Manu, D., Amonoo-Parker, L., Baiden, B. K., Oduro-Ofori, E., and Edwards, D. J. (2023). A factor analysis of the key sustainability content underpinning green cities development in Ghana. *International Journal of Construction Management* (**IF = 3.9**), 23 (4). http://doi.org/1080/15623599.2022.2068786 - Q2
4. Kuoribo E., Owusu-Manu, D., Yomoah, R., Debrah, C., Acheampong, A. and Edwards, D. J. (2023). “Ethical and Unethical Behaviour of Built Environment Professionals in the Ghanaian Construction Industry”, *Journal of Engineering, Design and Technology* (**IF = 2.8**), 21 (3) 840-861. https://doi.org/10.1108/JEDT-02-2021-0108 - Q1
5. Debrah, C. and Owusu-Manu, D.G., (2022). An apposite framework for green cities development in developing countries: the case of Ghana. *Construction Innovation* (**IF = 3.3**), 22(4), 789-808. https://doi.org/10.1108/CI-08-2020-0132 - Q2
6. Kuoribo, E., Yomoah, R., Owusu-Manu, D., Edwards, D. J., Acheampong, A. Debrah, C. and Ghansah, F. A (2022). Assessing the Interactive Effects of the Ethics of Construction Professionals on Project Performance in the Ghanaian Construction Industry. *Engineering,*

Construction and Architectural Management (**IF = 4.1**). https://doi.org/10.1108/ECAM-10-2021-0865 - Q2

7. Ahmed, H., Edwards, D.J., Lai, J.H.K., Roberts, C., Debrah, C., Owusu-Manu, D.-G., and Thwala, W.D. (2021). Post Occupancy Evaluation of School Refurbishment Projects: Multiple Case Study in the UK. *Buildings* (**IF = 3.8**), *11(4)*, 169. https://doi.org/10.3390/buildings11040169 - Q2 **("Highly Cited Paper" in Buildings, 2023)**

8. Owusu-Manu, D., Mankata, L., Debrah, C., Edwards, D. J., and Martek, I. (2021). "Mechanisms and Challenges in Financing Renewable Energy Projects in Sub-Saharan Africa: A Ghanaian Perspective", *Journal of Financial Management of Property and Construction* (**IF = 1.9**), 26(3), 319-336. https://doi.org/10.1108/JFMPC-03-2020-0014 - Q2

9. Antwi-Afari, P., Owusu-Manu, D., Simons, B., Debrah, C. and Ghansah, F. A. (2021). "Sustainability Guidelines to Attaining Smart Sustainable Cities in Developing Countries: A Ghanaian Context", *Sustainable Futures* (**IF = 5.5**), *3, 100044.* https://doi.org/10.1016/j.sftr.2021.100044 - Q2

The Candidate's level of contribution to the above papers

This candidate made substantial contributions to the papers listed above. These contributions encompassed various activities, including developing ideas for some papers, comprehensive English language editing, meticulous review, data analysis, and thorough proofreading. Moreover, the candidate offered valuable feedback and suggestions to enhance initial drafts. These efforts were geared towards improving the quality of the papers before their submission to journals. Furthermore, Caleb played a crucial role in the revision process based on journal reviewers' comments, effectively addressing their comments and making the necessary adjustments. It should be noted that three of the papers listed above were from a previous study conducted by a candidate for an earlier degree. However, these papers, in which the author assumed both the first and corresponding author roles, were published during his PhD studies.

B. Refereed Journal papers (Under review for the first or second time)

1. Adabre, M.A., Chan, A.P.C., Darko, A., Yang, Y. and Debrah, C. (**R2**). Institutional Drivers to Circular Economy Implementation in Transitional Housing: The Case of Hong Kong. *Cities*. JCIT-D-22-03019

C. Refereed Conference Papers (Published)

1. Ohene, E. Chan, A.P.C, Krarti, M. and Debrah, C. (2023, July). Driving sustainable building solutions: Exploring Business Model innovations for delivering net-zero carbon buildings. *In the 2nd Green building research conference, 27-28 July 2023, Accra, Ghana.*

2. Debrah, C.*, Darko, A., and Chan, A.P.C., Owusu-Manu, D.-G. and Edwards, D.J. (2022, October). Green finance in green building needs under the Paris Agreement, *IOP*

Conference Series: Earth and Environmental Science, 1085, 012033. In SBE22Delft - Innovations for the Urban Energy Transition: Preparing for the European Renovation Wave 11-13 October 2022, Delft, Netherlands. https://doi.org/10.1088/1755-1315/1085/1/012033

3. Seidu, S., Owusu-Manu, D. G., Debrah, C., and Edwards, D. J. (2021). Graduate Employability Development Schemes: The Case of Quantity Surveying Graduates in Ghana. *In the IDoBE International Conference 2021, London South Bank University, UK.*

D. Book Chapters (Accepted/under review)

1. Debrah, C.*, Chan, A.P.C., Darko, A. Owusu-Manu, D.-G., and Ohene, E. (**accepted**). "Green finance: A tool for financing green building projects." In *Rethinking Pathways to Sustainable Built Environment*. (Eds) Goh, C.S and Chong, H-Y. Taylor and Francis.
2. Darko, A., Debrah, C.*, and Chan, A.P.C. (**accepted**). Introduction to Green Construction Projects. In *Developing a Body of Knowledge for Green Construction Project Book Management*. (Eds). Darko, A., and Chan, A.P.C.
3. Debrah, C., Ohene, E., Weeransighe, L.N.K., Darko, A. and Chan, A.P.C. (**R2**). Green Building Practices: Integrating Sustainability into Construction Projects. In *Digital Transformation in the Construction Industry: Sustainability, Resilience, and Data-Centric Engineering*. Elsevier.

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CHAPTER 1 - INTRODUCTION[1]

1.1 Introduction

This chapter introduces the thesis by providing an overview of the study and setting the stage for the subsequent chapters. First, it describes the context of the study by defining the research background and the specific research problem that this thesis aims to address. The existing knowledge gap addressed in this study is then explained. This justifies the rationale for this study. To do this, a clear and concise problem statement that this thesis investigated and resolved was provided. To this end, the research questions considered in this study are outlined. Subsequently, the aim of the study and specific study objectives are presented, followed by an overview of the methodology adopted. The research scope, which specifies the research focus and boundaries of the study, is presented in this chapter. The potential significance and

[1] This chapter is largely based upon:

Debrah, C., Chan, A.P.C., Darko, A., Ries R.J., Ohene, E. and Tetteh, M.O. (2024) Driving factors for the adoption of green finance in green building for sustainable development in developing countries: The case of Ghana. *Sustainable Development*. (Q1)

Debrah, C., Chan, A. P. C., and Darko, A. (2022a). Green finance gap in green buildings: A scoping review and future research needs. *Building and Environment*, *207*, 108443. (Q1)

Debrah, C., Chan, A. P. C., and Darko, A. (2022b). Artificial intelligence in green building. *Automation in Construction*, 137, 104192. (Q1) – **Highly Cited Paper**

Debrah, C., Darko, A., and Chan, A. P. C. (2022c). A bibliometric-qualitative literature review of green finance gap and future research directions. *Climate and Development*, 0(0), 1–24. (Q1)

Debrah, C., Darko, A., Chan, A. P. C., Owusu-Manu, D. G., and Edwards, D. J. (2022d). Green finance in green building needs under the Paris Agreement. *IOP Conference Series: Earth and Environmental Science*, 1085(1), 012033.

Debrah, C., Chan, A.P.C., Darko, A. Owusu-Manu, D.-G., and Ohene, E. (**Accepted**). "Green finance: A tool for financing green building projects." *In Rethinking Pathways to Sustainable Built Environment*. (Eds) Goh, C.S and Chong, H-Y. Taylor and Francis.

implications of the research findings, as well as the organisation and structure of the thesis, conclude this chapter.

1.2 Research Background

The buildings and construction sector are critical for socioeconomic development. It provides people with basic shelter and security (UKGBC, 2022), employs 7.7% of the global labour force (ILO, 2021), and accounts for 13% of the world's gross domestic product (GDP) (Robinson et al., 2021). As one of the largest economic sectors (Robinson et al., 2021), the construction sector remains critical for green economic recovery globally following the COVID-19 pandemic. However, buildings and construction have enormous negative impacts on the environment. It accounts for nearly 40% of the final energy consumption and 50% of all materials extracted, representing one-third of global carbon emissions (UNEP, 2021; WorldGBC, 2021). Moreover, building materials account for nearly half of all the solid waste generated annually (Transparency Market Research, 2022). Hence, buildings and construction consume substantial amounts of limited natural resources, leaving behind large waste. Unsustainable activities prevalent in the buildings and construction sector fuel the global challenge of climate change (Debrah et al., 2022a). However, climate change and its associated risks present an opportunity for the sector to become more environmentally responsible, highlighting the need for green building. Perhaps the most critical issue within the built environment sector is the decarbonisation of buildings and construction and the means to finance such innovation.

Green building (also known as green construction or high-performance building – hereafter "GB") is a means to lessen the harmful effects of construction activities on the environment as well as the economy and society (WorldGBC, 2022a). The US Environmental Protection Agency (2016) defines GB as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's lifecycle". GB can reduce or eliminate the negative impacts of buildings and construction design, construction, and operation and maintenance (O&M). Owing to their improved design, building techniques, and practices, GBs are known to be more affordable and durable and enhance the health and productivity of occupants (Kubba, 2012). Adopting green technologies reduces the operational expenditure of GB occupants owing to energy and water savings (Darko et al., 2017), thereby increasing household savings and wealth. Moreover, GB enhances the creditworthiness of green properties and environmentally conscious borrowers. According to the International Finance Corporation (IFC), GB augments property worth by 7% owing to its higher resale value than non-GBs in the US (IFC, 2022a). In addition, green cost premiums range from 5% to 10% depending on the project type and size (Hwang et al., 2017). More importantly, it protects our natural resources and improves the built environment so that the planet's ecosystems, people, enterprises, and communities can live a healthier and more prosperous life (Kubba, 2012).

Despite their known benefits, GBs face several challenges and barriers (Darko and Chan, 2017; Hwang and Tan, 2012). Perhaps financing for GBs is the sector's most significant challenge compared to conventional construction. Despite being projected to reach US$364.6 billion (Grand View Research, 2018), GB investment accounted for *just* US$237 billion in 2022 (UNEP, 2022). This represents less than 5% of the total investment in buildings and construction (UNEP, 2022)[2]. According to WorldGBC (2021), for every US$100 spent on new construction, less than US$3 goes into GB. This GB investment value still represents a small section of the US$24.7 trillion investment opportunity by 2030 (Likhacheva Sokolowski et al., 2019). The quest to achieve net-zero buildings by 2050 remains questionable at this investment

[2] US$7 trillion of investments was reported for overall buildings and construction sector in 2021 (UNEP, 2022).

rate. This is particularly alarming because, according to recent industry reports, although buildings constitute a significant source of greenhouse gas (GHG) emissions and the largest consumer of natural resources, there is a lack of political will and investment in this area (UNEP, 2021; WorldGBC, 2021). Green finance (GF), which supports green projects such as GB, provides opportunities for increased research and investment in this sector (Debrah et al., 2022a).

Green finance is "any structured financial activity created to ensure a better environmental outcome" (World Economic Forum, 2020). It supports environmental improvement, climate change mitigation, and more efficient resource utilisation (EIB and GFC, 2017). GF is a broad concept of *carbon finance* that targets reduction in GHG emissions and *climate finance*, focusing on climate change mitigation and adaptation initiatives (Noh, 2019). It focuses on financing, operation, and risk management for green projects such as environmental protection, energy savings, clean energy, green transportation, and GB (EIB and GFC, 2017). While traditional finance typically offers short-term financing focused mainly on return and risk (Sachs et al., 2019; Schoenmaker, 2017), GF provides long-term funding for green projects often perceived as riskier and sometimes lower returns (Sachs et al., 2019). GF supports the development and execution of these projects by supplying investment, financing, operational funds, and other financial services (Ji and Zhang, 2019). Consequently, GF plays a crucial role in enhancing environmental quality and improvement, climate change mitigation and resource efficiency (European Investment Bank [EIB] and Green Finance Committee [GFC] 2017). Further, GF proceeds are exclusively dedicated to financing or refinancing new and/or existing eligible green projects, including renewable energy, energy efficiency and conservation, pollution prevention and control, waste management and resource recovery, water and waste management, nature conservation/biodiversity, clean transportation, climate change adaptation, and green buildings (EIB and GFC, 2017; ICMA, 2021).

GF-in-GB has recently gained interest among green investors, issuers, governments, and academics. This is because both public and private sector organisations see their potential to limit GHG emissions from buildings. Generally, GF-in-GB products range from climate-certified bonds or green bonds linked to GB to green commercial building loans, green construction loans, green insurance, and green mortgages (Gholipour et al., 2022; IFC, 2019; Noh, 2019). These facilities are issued to raise finance for climate change solutions and are labelled green by the issuer (CBI, 2021; IFC, 2019). Without adequate GF-in-GB, the greenhouse effect and climate change will continue to threaten cities, neighbourhoods, and buildings for generations to come. Hence, increased support for GF-in-GB is required for research and development (R&D).

Despite its growing importance, research has shown that limited attention has been paid to GF-in-GB (Debrah et al., 2022a), presenting opportunities for increased research and investment. In addition, few empirical studies have been conducted in developing and developed countries (Debrah et al., 2022b; Gholipour et al., 2022). Arguably, GF-in-GB is currently in the growth stage, with theory and research still developing. However, some contributions have also been made. Several authors have explored different aspects of the adoption and implementation of GF-in-GB in recent years. This has attracted interest in research areas such as drivers of GB finance (Agyekum et al., 2021; Christensen et al., 2021; Kapoor et al., 2020; Tan, 2019; Wang et al., 2021). Empirical observations and the literature suggest that besides financial returns, other non-monetary drivers also promote GF-in-GB. However, research has demonstrated that critical risks and barriers are responsible for the slow uptake of GF-in-GB (Agyekum et al., 2020; Lee et al., 2013; Tan, 2019; Wang et al., 2021). Notwithstanding these contributions, past studies did not consider the interrelationships among these drivers, risks, and barrier factors (Debrah et al., 2022a). Other studies (An and Pivo, 2020; Lee et al., 2013) have suggested different strategies for promoting GB finance. However, the uncertainties and interconnections between these strategies remain unclear. Such clarity is necessary to aid policymakers and other stakeholders in identifying critical GF-in-GB issues that require urgent attention. Moreover, because green property finance enhances harmful and significant carbon dioxide (CO_2) emission reductions in the building sector (Gholipour et al., 2022), more research is needed to understand the economic and environmental value of GF-in-GB. This study has significant implications for research and practice. First, it offers valuable insights and recommendations for implementing GF-in-GB successfully, including critical drivers, barriers, risk factors, and promotional and implementation strategies. Furthermore, the comprehensive checklist of influential drivers, barriers, risk factors, and strategies developed in this study can aid in the effective planning and execution of GF-in-GB initiatives, thereby minimising the likelihood of failure. Managers can deduce which barriers or risk factors require significant attention and how to effectively utilise influential drivers and strategies to successfully implement a GF-in-GB system. Furthermore, managers can identify which GF-in-GB factors constitute cause-and-effect groups, thereby facilitating proper categorisation and prioritisation of the adoption and implementation of a robust GF-in-GB system. The models developed in this study contribute to comprehending the interrelations among the various criteria of drivers, barriers, risk factors, and strategies. This understanding is crucial for determining the level of dependence and the impact of each factor. The application of the interdependence framework in policy formulation can be facilitated by considering and giving due importance to the causal and influential drivers, barriers, risk factors, and strategies identified in this study. This study contributes to the existing body of knowledge on GF and GB by identifying several potential theoretical relationships that emerge from the interrelationships observed. The comprehensive checklist of influential factors and theoretical relationships can serve as a foundation for future research in this area. Additionally, the factors identified in this study were organised into major groups (attributes) and sub-groups (criteria) which helped bridge the gap in previous studies that did not fully explore the interrelationships between the key factors necessary for implementing a GF-in-GB system.

Several studies have analysed the costs and benefits of GB (Zhang et al., 2018). This has become necessary to attract more capital investment in GB (Tan, 2019). For instance, GBs value is higher owing to low energy consumption and has low operating costs (IFC, 2019). While the literature demonstrates that GB outperforms conventional buildings in all performance areas, evidence of the green cost premium is still evolving (Dwaikat and Ali, 2016). Similarly, there is mixed evidence of a premium in the GF market (Lau et al., 2022; MacAskill et al., 2021). Hence, further research is required to determine the economic feasibility of GF-in-GB. In addition, most of the existing research has focused on developed countries, with limited attention paid to developing countries. To date, few GF econometric studies have concentrated on GB (An and Pivo, 2020; Gholipour et al., 2022; Lee et al., 2013; Mensi et al., 2021) from the perspective of developed countries. As GF is a valuable tool for promoting the development of GB and climate change goals, further research is required. With limited techno-economic analysis of GF-in-GB, the cost-benefit analysis (CBA) remains unclear. For instance, while Agyekum et al.'s (2020, 2021) research on barriers and drivers of GB finance in Ghana serve as foundational studies, but the interdependencies are neglected. Moreover, there is a general lack of studies on the CBA of GB and GF-in-GB in developing countries, particularly Ghana. The literature review revealed a limited number of studies on GF-in-GB.

Therefore, to bridge the research gaps identified above, this thesis seeks to develop a CBA model to evaluate the economic feasibility of GF-in-GB projects in developing countries, using Ghana as a case study. The key barriers, risks, drivers, and strategies to be considered when assessing GF-in-GB were identified. The interrelationships between these factors were also determined. The frameworks and checklists provided in this study may serve as a guide for green project developers, GB experts and practitioners, real estate investment trusts, green investors, green banks, policymakers, decision-makers, and researchers. This will be key to facilitating and promoting GF-in-GB research and development. Moreover, the economic feasibility assessment model for GF-in-GB will be useful in aiding green investors and developers in evaluating financing options that could increase the profitability of GBs. The findings of this study also contribute to the debate on finding solutions to the existing GB finance gap. Additionally, this study serves as a foundation for further empirical studies on this topic. The following are the research problem, research questions, overall aim, and objectives guiding this study.

1.3 Research Problem and Statement

Non-GBs (also known as conventional buildings) create significant adverse environmental externalities. Both academic studies and industry reports published over the last two decades have thoroughly documented the diverse impacts of buildings and construction on the environment, society, and global economy. In contrast, emerging evidence shows that GBs benefit the environment and society (Darko et al., 2019; Zhang et al., 2018). However, the proliferation of GBs has been hindered by, among other factors, extra green costs and a lack of finance in the form of GF (Debrah et al., 2022a; Debrah et al., 2022c). Additionally, despite the significant impact of buildings and construction on communities and the environment, the sector has been largely overlooked as a vehicle for sustainable investments globally (UNEP, 2022, 2021). Therefore, it is critical to investigate and explore the dynamics of GF-in-GB.

First, the critical drivers of GF-in-GB were identified. Furthermore, the interactions between the identified drivers were assessed. The literature shows that several factors have been identified to influence and drive the adoption and implementation of GF-in-GB in different countries and regions. Emerging research on the drivers of GF-in-GB is nascent, with limited studies conducted in developing countries. Recent reviews (Akomea-Frimpong et al., 2022; Debrah et al., 2022a) indicate that few studies have attempted to analyse the factors driving GF-in-GB, particularly in developing countries. In most cases, available studies identify and rank drivers without considering the interrelationship between them. However, these drivers do not act in isolation but rather establish complex interrelationships that shape the acceptance and implementation of GF. Without examining the interrelationships between these factors, if not impossible, it will be challenging to zero in on the most crucial ones and devise effective plans for implementing GF. Hence, multi-criteria decision-making (MCDM) techniques were applied to analyse the complex interdependencies among drivers in this study. In line with this, the dependence relations between the drivers of GF-in-GB, which are currently lacking in the literature, were modelled.

Second, barriers impeding the adoption and implementation of GF-in-GB were identified and evaluated. Previous studies have revealed that while GF has received increased attention recently, some adoption and implementation barriers exist (Agyekum et al., 2020; Akomea-Frimpong et al., 2022; Debrah et al., 2022a). The literature argues that adoption and implementation barriers are interdependent and that one barrier can stimulate the occurrence of other barriers (Addae et al., 2019; Lin et al., 2018; Negash et al., 2021). In addition, few studies have been conducted on barriers to GF-in-GB using several methods and analytical tools. Moreover, previous studies have been based on single surveys, interviews, or focus groups. However, the interrelationships among these barriers have not been considered, particularly in fuzzy environments. Hence, identifying and prioritising barriers to GF-in-GB would provide essential information to enable policymakers to reduce decision inefficiencies, enhance stakeholder acceptance and investment, and strategically develop novel GF-in-GB initiatives.

Third, like other sectors, GF-in-GB faces several risk factors that threaten its growth and impact. For instance, there are uncertainties associated with climate change, the ability to alter future weather patterns, policy changes, and how economies adapt to such changes. This affects the value of loans and income borrowers use to repay their loans (Bellrose et al., 2021). Although all identified risk variables are prominent in the literature, it is apparent that their relative relevance varies (Darko, 2019). However, no study has critically evaluated GF-in-GB risk factors and their interdependencies to date. Therefore, it is necessary to assess the risk factors of GF-in-GB to identify and promote prudent risk management practices. To overcome this gap, a questionnaire survey regarding linguistic evaluation was submitted to a group of experts to develop a valid set of GF-in-GB risk attributes and their relationships.

Moreover, it is crucial to assess the strategies necessary to promote GF-in-GB. Emergent studies have revealed that barriers impede the adoption and implementation of GF-in-GB. As GF-in-GB is at the preliminary stages of development, it is necessary to devise strategies to promote and advance adoption and effective implementation. Such strategies must be purposefully and consciously designed ahead of applicable actions (Mintzberg, 1987). Although the literature review reveals various strategies to promote GF, little research has been conducted on developing a model and framework for assessing the critical strategies to promote the adoption and effective implementation of GF, particularly for the buildings and construction sector. This study fills this research gap by developing a conceptual framework to reveal the relationship between critical strategies for the adoption and effective implementation of GF-in-GB. The fuzzy Delphi method (FDM) and fuzzy decision-making trial and evaluation laboratory (FDEMATEL) methodologies were used to analyse the strategies and identify the interrelationship and cause-effect parameters.

Finally, the literature review reveals that most of the existing GB cost-benefit studies are from advanced economies. While GB appears to be a potent solution for building sustainability challenges globally, it is relatively new and less developed in emerging and developing economies. To date, few studies have assessed the economic feasibility of GBs from the perspectives of emerging and developing economies (Mushi et al., 2022), with the majority of studies utilising expert surveys (Mushi et al., 2022; Oyewole et al., 2019; Simpeh and Smallwood, 2020). Therefore, these studies are limited to perception rather than tangible performance measurement and cost analysis. In addition, with the impression of an increase in upfront costs to building green compared to non-GBs, research is needed on actual GB to uncover whether this perception is valid in emerging and developing economies. Therefore, this study examines the whole-building lifecycle cost (LCC) of GBs in emerging and developing economies. This is necessary to provide the cost-benefit results of actual GB from a whole-building lifecycle perspective: design to deconstruction. In addition, it is important to investigate the cost and benefits of different cases of GBs owing to the specific green solutions appropriate for different building typologies, usually making the CBA of GBs more case-specific. Given this background, this study presents a whole-building LCC for GB from the perspective of emerging and developing economies (i.e., from design and deconstruction) under renewable resource considerations using CBA. This study used the case of Ghana to represent developing countries. Although progress in GB development in Ghana is noteworthy, no research has been conducted on the lifecycle CBA of GB (Agyekum et al., 2019; Darko and Chan, 2018). Additionally, a GB database and the associated costs in Ghana are lacking (Ampratwum et al., 2021; Guribie et al., 2022). Hence, to bridge this gap, this study adopts a green office building in Ghana with Final IFC Excellence in Design for Greater Efficiencies (EDGE) certification to provide preliminary estimates for GB CBA for developing countries.

In addition, there is a lack of studies evaluating the economic feasibility of GF-in-GB projects. However, GF solutions such as green bonds and loans can enhance the feasibility of green projects (Taghizadeh-Hesary et al., 2022). To address these gaps, this study investigates the economic feasibility of GF-in-GB projects from the LCC perspective. This provides quantitative evidence of the attractiveness of GF-in-GB for increasing green investments in GB. In addition, no study has investigated the CBA of GB under a GF scenario in Ghana. This study aimed to bridge these gaps by evaluating GF and the economic feasibility of GB in Ghana. To this end, a lifecycle economic feasibility assessment model for GF-in-GB was developed using Ghana as a case study.

1.4 Research Aim and Objectives

1.4.1 Research Questions

The focus of this study is to explore the dynamism of GF-in-GB to aid the development of a CBA model to evaluate the economic feasibility of GF-in-GB projects. After a thorough exploratory and preliminary review, and following the background and problems mentioned above, the following questions were articulated based on the theoretical gaps identified:

1. How do the critical drivers of GF-in-GB interact with each other?
2. What are the relationships between the critical barriers to GF-in-GB?
3. Are there any notable risks in GF-in-GB projects? What are the effects of these risk factors on GF-in-GB?
4. What strategies can be adopted to promote GF-in-GB?
5. What are the cost benefits of GF-in-GB? How can they be analysed?

1.4.2 Research Aim

This study aims to explore the dynamism of GF-in-GB projects in developing regions using Ghana to aid in the development of a CBA model to evaluate the economic feasibility of GF-in-GB projects.

1.4.3 Research Objectives

To accomplish the above stated aim, the following specific objectives were established:

1. To evaluate the interactions between the critical drivers of GF-in-GB.
2. To investigate the interrelationships between the critical barriers of GF-in-GB.
3. To develop a risk assessment model for GF-in-GB.
4. To assess the interdependencies of the strategies that can be adopted to promote GF-in-GB.
5. To develop a CBA model to evaluate the economic feasibility of GF-in-GB projects.

Fig. 1.1 presents a summary of the interrelations of the research objectives. The study began with Objective 1, in which a comprehensive systematic literature review of the drivers of GF-in-GB was conducted. This was followed by an empirical analysis of the drivers of GF-in-GB to determine the interrelationships between the critical drivers. This approach was repeated for objectives 2, 3, and 4 to determine the interdependencies between the barriers, risk factors, and strategies of GF-in-GB. Finally, the initial assessment of barriers, risk factors, drivers, and strategies for GF-in-GB formed the basis for developing a CBA model for GF-in-GB projects. The GB case study aided in the development of an economic feasibility assessment model to evaluate the viability of GF-in-GB projects in Ghana.

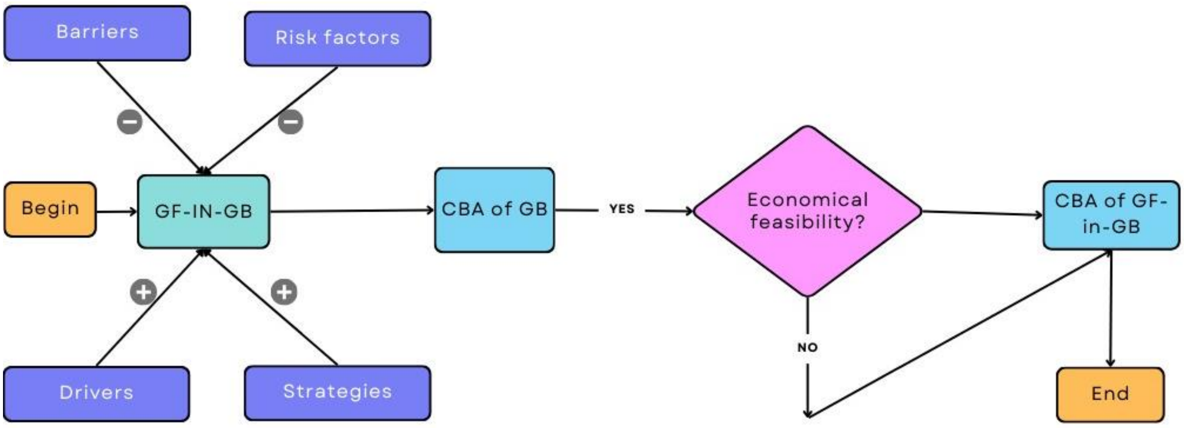

Fig. 1.1 Interconnections of research objectives

1.5 Research Scope

This study focused on GF-in-GB in developing countries. Geographically, Ghana was used as a case study. Theoretically, this study focuses on the dynamism of GF-in-GB. This served as a precursor for developing a CBA model to evaluate the economic feasibility of GF-in-GB projects. To this end, the interrelationship between the drivers of GF-in-GB was assessed. Additionally, barriers and risk factors associated with GF were examined. This served as a basis for determining the interactions between the barriers and risk factors. Finally, strategies appropriate for promoting GF-in-GB were assessed. Their interdependencies were evaluated to ascertain the critical strategies. The above objectives formed the basis for developing an economic feasibility assessment model for GF-in-GB projects.

1.5.1 Why Focus on Ghana?

Although GB development has grown over time, it still accounts for a small portion of the total building stock in developing and developed countries (UNEP, 2021). Notably, little evidence is available for developing countries, particularly Africa. Sub-Saharan African countries such as South Africa and Kenya are GB innovators and early adopters (Agyekum et al., 2019). In Ghana, GB is still viewed as a novel concept and development. Little research has been conducted on this subject. Certified GBs represent approximately 1% of all new construction projects by 2020 (IFC EDGE, 2020). To solve this problem, the Ghana Green

Building Council (GhGBC) was established in 2009. GhGBC is a non-governmental organisation and private-public partnership that commits to helping create sustainable buildings and communities in Ghana using sustainability techniques such as energy savings, water conservation, and resource management in a cost-efficient manner (GhGBC, 2022). The council is still developing country-specific green certification. However, in collaboration with the Green Building Council South Africa (GBCSA), GhGBC adapted Green Star South Africa-Ghana in 2009. The first evidence of its implementation is the One Airport Square in Accra (GBCSA, 2022). Subsequently, other certification systems, such as the US Leadership in Energy and Environmental Design (LEED) (Ofori-Boadu et al., 2020) and IFC EDGE certification (IFC EDGE, 2020) have been applied to a few GBs in the country. As of September 2023, 32 buildings in Ghana were certified or were undergoing a certification process. Table 1.1 shows 16 office buildings, seven residential housing, three hospitals, three hotels, two industrial buildings, and one retail space (Chan et al., 2018; IFC EDGE, 2023; USGBC, 2022). 50% of the certified buildings in Ghana are offices, and IFC EDGE appears to be the preferred certification in Ghana. IFC EDGE is a cost-effective GB certification system that allows design teams and project owners to assess measures to incorporate energy and water savings options into homes, hotels, hospitals, offices, and retail spaces. IFC-EDGE certification is widely used and preferable in emerging and developing economies. This certification specifies a minimum of 20% savings across three resource categories for GB: water, energy, and embodied energy in materials (GBCI, 2016). A summary of existing certified (and registered) GBs in Ghana is provided in Table 1.1.

Table 1.1 Summary of GBs in Ghana

Building name	Building type	Type of certification (level) - Year
One Airport Square	Office buildings	Green Star South Africa-Ghana - 2009
Atlantic Tower	Office buildings	Final EDGE certification – 2018
Cal Bank Head Office Tower	Office buildings	Final EDGE certification – 2019
World Bank Group Office Accra	Office buildings	Final EDGE certification – 2019
EY Office Building	Office buildings	Final EDGE certification – 2022
Standard Chartered Bank, Ghana	Office buildings	Final EDGE certification – 2022
Ecobank Ghana Plc Head Office	Office buildings	Final EDGE certification – 2023
Accra Financial Center	Office buildings	Final EDGE certification – 2023
SU Tower	Office buildings	Final EDGE certification – 2023
335 Place	Office buildings	Final EDGE certification – 2023
Ghana Infectious Disease Center	Hospital	Final EDGE certification – 2020
MBU at Komfo Anokye Teaching Hospital	Hospital	Final EDGE certification – 2018
Tema Port – Terminal Three	Industrial building	Final EDGE certification – 2019
Takoradi Mall	Retail spaces	Final EDGE certification – 2018
Tesano Lofts	Residential housing	Final EDGE Advanced certification – 2022
Lahagu Housing Project	Residential housing	Final EDGE certification – 2021
Ultimo Gardens	Residential housing	Preliminary EDGE Advanced certification – 2022
National Homeownership Fund Estates (Model Community 22 Project)	Residential housing	Preliminary EDGE Advanced certification – 2022
Rehoboth Palm	Residential housing	Preliminary EDGE certification – 2021
Rehoboth Knightsbridge	Residential housing	Preliminary EDGE certification – 2021
The Genesis Residences	Residential housing	Preliminary EDGE certification – 2022
Earlbeam One Place	Hotels	Preliminary EDGE certification – 2022
Crown Forest Safari and Hotel	Hotels	Preliminary EDGE certification – 2022
Ridge Hospital	Hospital	LEED v2009 NC (Silver) – 2016
CONSAR LTD New Head Office Accra Ghana	Office buildings	LEED v4 BD+C NC (Registered) – 2017
Google Office Ghana	Office buildings	LEED v4 ID+C IC (Registered) – 2020
GNPC Research and Technology Center	Office buildings	LEED v4 BD+C NC (Registered) – 2018
GNPC Operational Head Office Building	Office buildings	LEED v4 BD+C NC (Registered) – 2020
GNPC Head Office	Office buildings	LEED v4 BD+C NC (Registered) – 2022
NPA Head Office Building Annex	Office buildings	LEED v4 BD+C NC (Registered) – 2022
Guinness Ghana Achimota Brewhouse	Industrial building	LEED v4 BD+C NC (Registered) – 2020
Silver Breezes	Hotels	LEED v2009 BD+C NC (Registered) – 2011

Note: LEED v4 BD+C NC – LEED v4 for Building Design and Construction
LEED v4 ID+C IC – LEED v4 for Interior Design and Construction

Source: Compiled by author from multiple sources (IFC EDGE, 2023; USGBC, 2022)

As an emerging and developing economy, an office GB in Ghana was selected as a case study for this CBA. The Ghanaian case study was selected because it presents specificities and commonalities with other emerging and developing economies. The country has a great potential to deviate from its counterparts' entrenched high-carbon development pathway. For instance, 64% of buildings in Ghana use concrete in external envelope construction, with cement alone contributing to 10% of Ghana’s CO_2 emissions (UNEP, 2022). These unsustainable practices could explain the growing interest of private commercial and residential developers in achieving green certification of their portfolios. Generally, reducing the overall demand for building materials and reusing construction materials are preferable. In addition, approximately 66% of electricity generation is fossil fuel-based, making it susceptible to fossil fuel price volatility and the resultant emissions (Ritchie et al., 2020; UNEP, 2022). While solar energy is one of the leading potential renewable energy resources for solving the energy deficit in Africa, issues such as high investment costs and lack of capital are cited as challenges in developing countries such as Ghana (Asumadu-Sarkodie and Owusu, 2016; Ofori et al., 2022; Ohene et al., 2022).

This could be because of Ghana's low inventory of the GBs population. While such small samples may not be representative of providing statistically valid estimates of the average price of a GB in comparison to a conventional building, they serve as the basis for preliminary estimates in cost analysis (Gabay et al., 2014). Additionally, a GB database and the associated costs in Ghana are lacking (Ampratwum et al., 2021; Guribie et al., 2022). As an initial study, this study adopts a green office building with the Final IFC EDGE certification to provide preliminary estimates for GB.

Additionally, the construction industry in Ghana is highly informal, with government support available to just the formal sector (which is dominated by privatised scions of former quasi-government corporations) and the few private developers who belong to the Ghana Real Estate Developers Association (GREDA). They come as subsidised land and tax breaks (UN-Habitat, 2011). The main financing mechanisms for housing facilities are personal savings, windfall gains, and family loans. The current mortgage outstanding in Ghana is less than 3% of the country's GDP. The lack of participation of banks or financial institutions in the housing supply process is a significant obstacle to housing development (UN-Habitat, 2011). The financing avenues and challenges identified in the country do not align with GB goals or achieve sustainability in the built environment sector.

To overcome the financing challenges of sustainable development, GF has emerged and is increasing, especially in developed countries. Only a few developing countries, particularly Africa, take advantage of this innovation. For instance, the African Development Bank (2022) estimates that African countries will have an annual climate finance gap of US$1,288.20 billion from 2020 to 2030. So far, evidence of GF products, such as green bonds, is seen in a few countries on the continent: Egypt, Cote d'Ivoire, Kenya, Mauritius, Morocco, Namibia, Nigeria, and South Africa (Mutarindwa and Stephan, 2022; Taghizadeh-Hesary et al., 2022b). Moreover, GF-in-GB is acknowledged as critical for achieving Nationally Determined Contributions (NDCs) to climate change mitigation and adaptation (Debrah et al., 2022a; Gholipour et al., 2022) and sustainable development goals (SDGs) (World Bank, 2012). Both public and private sectors are embracing GF to promote GB development and reduce GHG emissions from the building sector (Gholipour et al., 2022). Again, it accounts for less global green investment (Debrah et al., 2022a; IFC, 2019; WorldGBC, 2021). Hence, country-specific government policies and instruments such as standards and regulations, carbon markets and taxes, and financial support mechanisms are necessary (World Bank, 2012).

The Government of Ghana estimates that US$3,558 million is required to finance its citywide resilient housing development (IFC, 2022b). However, the government has yet to explore how GF products, such as green bonds, can fund the country's housing and infrastructure deficits. To date, there have been no green bonds, whether sovereign or corporate, in Ghana (FSD Africa, 2021). In addition, limited research and development exists on GF in Ghana, particularly in the building sector. Few studies have been conducted on GF-in-GB barriers and drivers (Agyekum et al., 2021, 2020). However, these studies failed to reveal the interrelationship between the drivers and barriers associated with GF-in-GB. Similarly, no studies have been conducted on the risk factors and strategies to promote GF-in-GB in Ghana. Hence, to bridge these knowledge gaps, this thesis utilised fuzzy Delphi-

DEMATEL methods to analyse the interrelationships between the factors. This study contributes to the global discussion of GF in promoting GB and bridging the investment gap in the sector. To do so, a case from a developing country's perspective was adopted using the case of Ghana. Additionally, no study has investigated the CBA of GB under a GF scenario in Ghana. This study aims to bridge these gaps by evaluating GF and the economic feasibility of GB in Ghana.

While there may, of course, be some limitations on generalisation, which is a common problem associated with country-specific, regional, or focused studies (Darko, 2019), as this focused on the developing country of Ghana, the findings and implications could still be of benefit to green investors, policymakers, advocates, and other stakeholders within other developing countries globally. Conducting such studies in different countries is valuable for several reasons: providing contextual relevance, uncovering market-specific insights, policy development, boosting investor confidence, and developing expertise in GF practices. Again, such studies may be useful for comparative analyses across different countries to outline local best practices and transferable lessons and reveal global trends in GF-in-GB adoption. However, conducting similar studies in different countries is still necessary to take explicit account of local situations, observe country- or market-specific differences, and more effectively and efficiently promote GF-in-GB adoption within specific countries, contexts, and markets.

1.6 Research Methodology

Research methodology involves the scientific principles and procedures of logical thought processes that are applied to an investigation (Fellows and Liu, 2015). This influences the outcomes of any study. Research methods, on the other hand, refer to the data collection and analysis techniques employed in research (Fellows and Liu, 2015). Qualitative (e.g., interviews and case studies) and quantitative research (e.g., questionnaire surveys) are popular methods adopted in construction research. Accordingly, GF-in-GB studies (Ojo-Fafore et al., 2019; Tan, 2019; Agyekum et al., 2020; Zhang et al., 2020; MacAskill et al., 2021) mostly employ case studies, interviews, and surveys. Primarily, in this study, a mixed-methods approach was adopted. Mixed methods involve the collection and "mixing" or integration of both quantitative and qualitative data in a study (Creswell and Creswell, 2017). Due to the research problem, adopting different data collection methods/techniques is necessary to acquire the needed knowledge (Dissanayaka and Kumaraswamy, 1999). Additionally, it focuses on issues such as validity, reliability and research constraints (Fellows and Liu, 2015).

Chapter two provided a detailed discussion of the research methodology adopted in this study. This section provides a brief overview of the methodology. This study focuses on developing a CBA model to evaluate the economic feasibility of GF-in-GB projects. Additionally, the interrelationship among the drivers, barriers, risk factors and strategies of GF-in-GB were examined. As described below, a five-phase methodology was adopted in this study. Fig. 1.2 provides a summary of the research methodology.

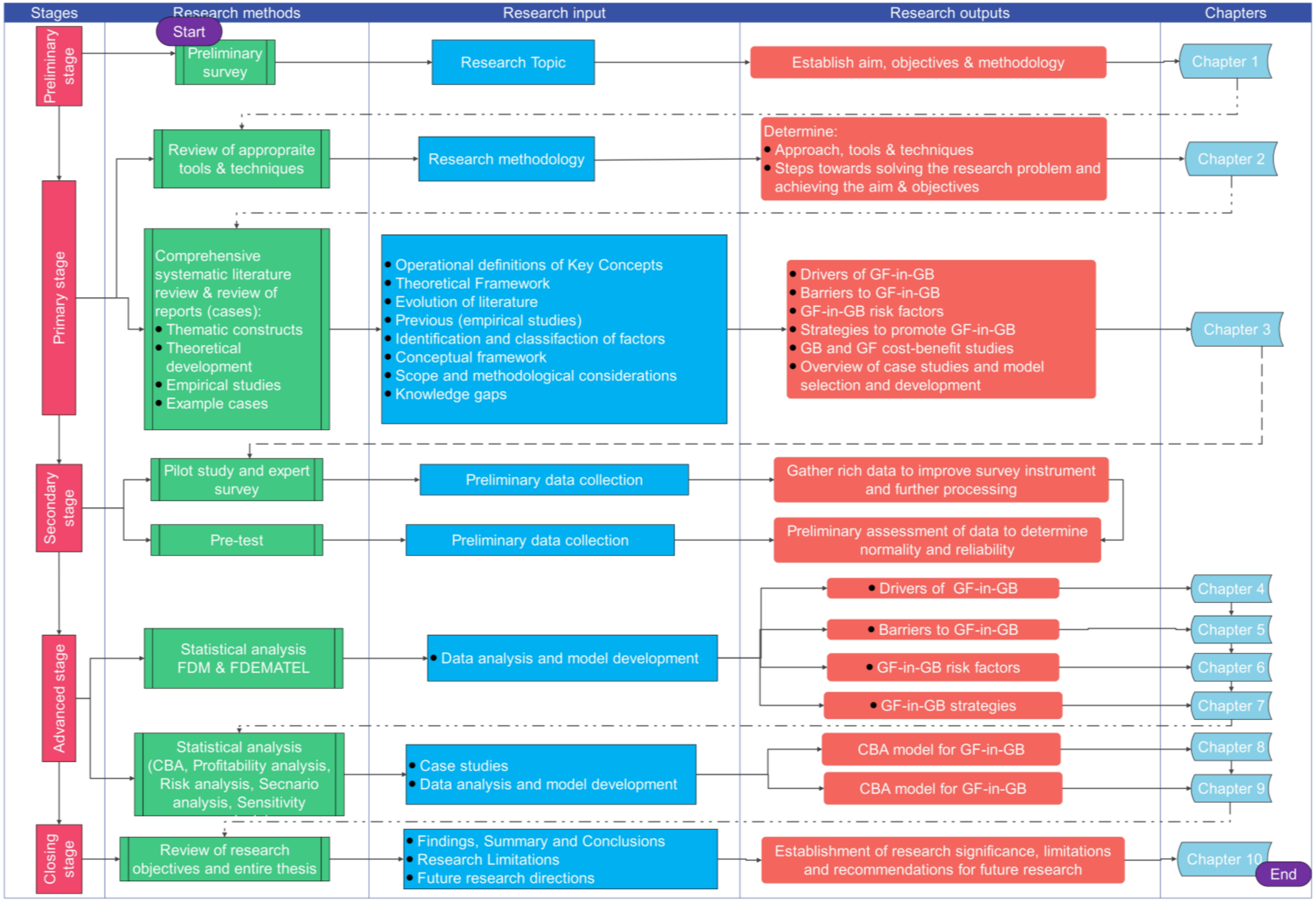

Fig. 1.2 Flowchart of the thesis

1.7 Significance and Contribution of Research

While there is a robust and growing body of knowledge about GB practices within the built environment sector and academia, there is still a lack of knowledge and limited studies on the sustainable financing of such green projects in the form of GF. This lack of understanding of GF and its impact on GB development could affect green investment decisions regarding green buildings and construction. Moreover, it could be responsible for defining the lack of green investments for GBs and the buildings and construction industry in general. The findings of this study provide initial attempts to address this gap and provide the basis for future studies on sustainable financing in the buildings and construction industry.

Theoretically, this study contributes significantly to the GF and GB literature through an in-depth study of the interrelationships among the drivers, barriers, risk factors, and strategies of GF-in-GB in the context of Ghana. In addition, the economic feasibility of GF-in-GB was assessed using a case study. Hence, this research increased the understanding of the parameters under which GF-in-GB thrives. Again, the findings of this research were an initial attempt to assess the lifecycle CBA of GB in Ghana. Hence, the findings provide an average overview of the cost-benefit estimates of certified GB office buildings in Ghana. Thus, this study serves as a precursor to boost GF-in-GB research, which is currently under-researched.

Practically, the outcomes of this study can aid practitioners and policymakers in assessing their readiness to adopt GF-in-GB. This study identified investment opportunities and gaps in GF-in-GB. A CBA can be useful for evaluating the economic value of GBs to foster development. It is expected that the economic analysis of GF-in-GB, particularly in Ghana, will increase the understanding of both green investors and GB developers to pursue gains that come with accessing GF, such as green bonds and loans, to finance the development of GB.

The findings could be a key source of reference for potential investors to assess project-related costs and gains. Again, this is key to attracting socially responsible investors.

1.8 Structure of Thesis

This thesis is structured into ten chapters. Chapter 1 introduces the research, identifies and defines the relevant terms, and outlines the scope of the study. The research problem was clearly explained, leading to the formulation of the study's research questions, aims, and objectives. A brief outline of the research methodology is provided below. A detailed review of the research methodology and justifications is provided in Chapter 2. Chapter 3 presents a comprehensive systematic literature review of the drivers, barriers, risk factors, and strategies of GF-in-GB. An overview of the global cost studies related to GB and GF was further reviewed. A systematic review of GF-in-GB drivers, barriers, and risk factors associated with GF-in-GB was provided. Similarly, Chapter 3 systematically reviews the strategies for promoting GF-in-GB. Chapter 3 also reviews the literature on the CBA of GB and GF. In addition, a brief overview of Ghana as the selected case to represent developing contexts is provided. Chapters 4 to 7 present the empirical findings of the fuzzy Delphi-DEMATEL analysis of the drivers, barriers, risk factors, and strategies to promote GF-in-GB. In Chapter 8, the whole LCC CBA of a green office building in Ghana was evaluated using the net present value (NPV) and the internal rate of return (IRR) techniques. Furthermore, the economic feasibility of GB under GF considerations was assessed to determine its profitability. Chapter 10 concludes this thesis, identifies its limitations, and provides recommendations.

1.9 Chapter Summary

This section presents the introduction and background of this research. The rationale behind the study was provided leading to the identification of the aim and objectives of the study. A brief overview of the methodology and significance of the research has also been provided.

Finally, the structure of the report is outlined. The next chapter details the research methodology adopted in this study.

CHAPTER 2 - RESEARCH METHODOLOGY[3]

2.1 Introduction

The previous chapter presented an introduction and overview of this thesis, research problems and questions, research aim and objectives, research focus and scope, relevance of the study, and the structure of the thesis. This chapter focuses on details of the research methodology adopted in this study. The research methodology describes the "principles and procedures" – system of methods – appropriate for the objectives and aim of the study (Fellows and Liu, 2015 pp. 31). Because the methodology shapes the outcomes and contributions of any research (Darko, 2019), a critical approach to selecting research methods is adopted by underlining the strengths and weaknesses of each method, as well as providing justifications for their selection. This section focuses on the procedures of enquiry (*research design*) and specific *research*

[3] This chapter is largely based upon:

Debrah, C., Chan, A.P.C., Darko, A., Ries R.J., Ohene, E. and Tetteh, M.O. (2024) Driving factors for the adoption of green finance in green building for sustainable development in developing countries: The case of Ghana. *Sustainable Development*. (Q1)

Debrah, C., Chan, A. P. C., and Darko, A. (2022a). Green finance gap in green buildings: A scoping review and future research needs. *Building and Environment, 207*, 108443. (Q1)

Debrah, C., Chan, A. P. C., and Darko, A. (2022b). Artificial intelligence in green building. *Automation in Construction*, 137, 104192. (Q1) – **Highly Cited Paper**

Debrah, C., Darko, A., and Chan, A. P. C. (2022c). A bibliometric-qualitative literature review of green finance gap and future research directions. *Climate and Development*, 0(0), 1–24. (Q1)

Debrah, C., Darko, A., Chan, A. P. C., Owusu-Manu, D. G., and Edwards, D. J. (2022d). Green finance in green building needs under the Paris Agreement. *IOP Conference Series: Earth and Environmental Science*, 1085(1), 012033.

Debrah, C., Chan, A.P.C., Darko, A. Owusu-Manu, D.-G., and Ohene, E. (**Accepted**). "Green finance: A tool for financing green building projects." *In Rethinking Pathways to Sustainable Built Environment*. (Eds) Goh, C.S and Chong, H-Y. Taylor and Francis.

methods of data collection, analysis, and interpretation to be employed in this study. To enrich the research outcomes, this study draws on the knowledge and expertise of professionals.

Similar to previous construction management research, this study employed several methods, such as systematic literature reviews, case studies, expert surveys, archival data analysis, and mixed methods (Adabre, 2021; Darko, 2019; Debrah et al., 2022a; Owusu, 2020). In the present study, a mixed-methods approach was adopted. Mixed methods involve the collection and "mixing" or integration of both quantitative and qualitative data in a study (Creswell and Creswell, 2017). This study employed a combination of data collection methods, such as expert surveys and a case study analysis, to investigate the underlying research problem. Prior to the design of the data collection instruments, an extensive systematic literature review was conducted. A literature review provides a solid basis for knowledge progression (Webster and Watson, 2002), which is useful for both academia and industry (Darko and Chan, 2017). Data analyses were performed using Microsoft Word, Microsoft Excel, Expert Choice Software, MATLAB 2023a, and other online software/tools.

2.2 Research Design

Research design, also known as *strategies of enquiry* (Denzin and Lincoln, 2011), specifies the type of enquiry (Creswell and Creswell, 2017) or methodological approach to answering the underlying research questions (Fellows and Liu, 2015). This can be seen as the master plan or framework for the study and as a guide for data collection and analysis.

2.2.1 Research Design for Objectives 1-4

A qualitative design was adopted to evaluate the interactions between the critical drivers of GF-in-GB (objective 1), to investigate the interrelationships between the critical barriers of GF-in-GB (objective 2), to develop a risk assessment model for GF-in-GB (objective 3), and (4) to assess the interdependencies of strategies that can be adopted to promote GF-in-GB (objective 4). Following the literature review, a questionnaire on linguistic evaluation was administered to a group of experts. For Objective 5, a case study of a green office building in Ghana was used to analyse the LCC CBA of GBs in developing countries. Additionally, an economic feasibility model for GF-in-GB was developed. Both primary and secondary data were used in the cost-benefit analysis and the economic feasibility assessment model development. Table 2.1 presents a summary of the respective methods to be adopted for each objective to achieve the aim of this research.

Table 2.1 Summary of research methodology

	Research design							
Research Objective	Data collection				Data analysis			
	LR	PS	LEQS	CS	FDM	FDEMATEL	NPV	IRR
Objective 1	√	√	√		√	√		
Objective 2	√	√	√		√	√		
Objective 3	√	√	√		√	√		
Objective 4	√	√	√		√	√		
Objective 5	√			√			√	√
Remarks	To underpin the concepts of a study (Nakano and Muniz Jr, 2018)	A trial execution of the project on a small scale with experts for external validity and ensure that questions are clear and answerable (Ritchie et al., 2013)	A two-round questionnaire survey to obtain the judgement of a panel of independent experts (Hallowell and Gambatese, 2010)	To examine real life contemporary situations (Yin, 1994)	To convert qualitative data (from Delphi survey) into quantitative information (i.e., translate linguistic preferences into crisp values) (Negash et al., 2021)	To identify the causal interrelationships that exist among variables (Addae et al., 2019; Negash et al., 2021)	To evaluate the economic feasibility using CBA (Dwaikat and Ali, 2018; Miraj et al., 2021)	To evaluate the economic feasibility using NPV and IRR (Taghizadeh-Hesary et al., 2022).

LR – Literature review; PS - Pilot survey; QS – Linguistic evaluation questionnaire survey; CS – Case studies; FDM – Fuzzy Delphi Method; FDEMATEL – Fuzzy decision making and trial evaluation laboratory; NPV- Net Present Value; IRR – Internal Rate of Return

2.3 Data Collection Methods

Data is acknowledged as an essential element in research. This is because it has a significant effect on the study results, conclusions, usefulness, validity, and reliability (Fellows and Liu, 2015). In this study, a mixed method was used by combining qualitative (questionnaire surveys regarding linguistic evaluation) and quantitative (case study) data. This study adopted a qualitative assessment of the GF-in-GB drivers, barriers, risk factors, and strategies. Qualitative data regarding linguistic evaluation from the questionnaire surveys were converted into quantitative information. In this study, the CBA of the GF-in-GB was quantitatively assessed.

2.4 Comprehensive Literature Review

A literature review provides a solid basis for knowledge progression (Webster and Watson, 2002), which is useful for both academia and industry (Darko and Chan, 2017). This is a means of identifying and summarising studies on a topic (Creswell and Creswell, 2017). Hence, a literature review must be critical and comprehensive to provide the "state of the art" – the extent of knowledge and the key issues related to the topic that inform and provide rationale for the research being undertaken (Fellows and Liu, 2015).

The entire study commenced with a comprehensive review of both academic and non-academic materials, such as journal articles, conference papers, doctoral theses, industry reports, textbooks, book chapters, and other relevant information from the grey literature. This was necessary to identify the scope of GF-in-GB research and development using the scoping review method (Debrah et al., 2022a). This was key to providing a framework to establish the importance of the study and how it relates to ongoing dialogue in the literature (Creswell and Creswell, 2017). Additionally, the literature review formed the basis for identifying the research gap and extending prior studies, thus establishing the grounds for realising the aim and objectives, as well as addressing the research problems.

Therefore, the literature review was conducted with the following objectives: (1) to evaluate the interactions between the critical drivers of GF-in-GB; (2) to investigate the interrelationships between the critical barriers of GF-in-GB; (3) to develop a risk assessment model for GF-in-GB; (4) to assess the interdependencies of strategies that can be adopted to promote GF-in-GB; and (5) to develop a CBA model for GF-in-GB. Finally, the literature review formed the basis for the development of the survey for data collection and the identification of methodological approaches to be adopted for this study. The literature reviews are summarised, examined, and reported in Chapter 3. A comprehensive literature review was conducted to develop a checklist of potential drivers, barriers, risk factors, and strategies for GF-in-GB in Ghana. The barriers to GF-in-GB and risk factors associated with GF-in-GB were reviewed. The review focused on the GF-in-GB sector and GF in other fields that could be applicable to the GB sector. Similarly, the drivers of GF-in-GB and strategies for promoting GF-in-GB were reviewed. Similarly, a review of the cost-benefit studies of GB was conducted, which formed the basis for the theoretical framework and the development of the GB CBA and the economic feasibility assessment model for GF-in-GB.

The literature review included a selection of suitable data analytical tools employed in this study. The comprehensive literature review followed systematic and well-established protocols. This study used the PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) methodology. The search strategies typically include electronic databases, reference lists, hand searches, and grey literature search (for conference papers, regulatory data, working papers, etc.) (Arksey and O'Malley, 2005). To identify relevant studies, this study adopted a *systematic search* of academic databases and a *non-systematic search* of grey literature and reference lists. First, a *systematic search* of the two academic databases, Scopus and Web of Science, as well as Google Scholar, was conducted. These databases were chosen because of their large size and relevant disciplinary focus. In addition, two or more databases are deemed adequate to accurately retrieve relevant studies (Hussein and Zayed, 2021). The search terms included the combination of two strings of keywords, as outlined in Table 2.2. Additionally, *a non-systematic extensive search* of Google Scholar and reference lists was conducted. Further, a normal Google search of the grey literature for conference papers, working papers, academic theses, and government and regulatory reports was conducted. Finally, using backward and forward snowballing techniques, additional studies were found through reference list searches. Table 2.2 summarises the keyword strings used to search for articles addressing GF-in-GB. Owing to the novelty and number of limited available studies on GF-in-GB (Debrah et al., 2022a), a general search of the overall GF field was conducted. This is necessary to complement the few available GF-in-GB studies.

Table 2.2 Keywords and literature search results.

Topic	String 1	Link	String 2
GF-in-GB	Green finance, climate finance, sustainable finance, carbon finance, carbon financing, sustainable financing, environmental finance, green bonds, climate bonds, green loans, green loan, green credit, green securities, green investing and green securities	AND	Green building*, green technolog*, green housing, green retrofit*, green project*, green construction, sustainable building*, sustainable housing, sustainable project*, sustainable construction, high performance building*, high performance project*, high performance construction*, high-performance building*, high-performance project*, high-Performance construction*
Drivers	drivers, motivations, determinants	AND	Green finance, climate finance, sustainable finance, carbon finance, environmental finance, green bonds, climate bonds, green loans, green credits, green securities and green investing
Barriers	barriers, challenges, obstacles	AND	Green finance, climate finance, sustainable finance, carbon finance, carbon financing, sustainable financing, environmental finance, green bonds, climate bonds, green loans, green loan, green credit, green securities, green investing and green securities
Risk factors	risk*	AND	Green finance, climate finance, sustainable finance, carbon finance, carbon financing, sustainable financing, environmental finance, green bonds, climate bonds, green loans, green loan, green credit, green securities, green investing and green securities
Strategies	strategies	AND	Green finance, climate finance, sustainable finance, carbon finance, carbon financing, sustainable financing, environmental finance, green bonds, climate bonds, green loans, green loan, green credit, green securities, green investing and green securities
Cost-benefit analysis	Cost benefit analysis, CBA, cost-benefit-analysis	AND	Green building*, green technolog*, green housing, green retrofit*, green project*, green construction, sustainable building*, sustainable housing, sustainable project*, sustainable construction, high performance building*, high performance project*, high performance construction*, high-performance building*, high-performance project*, high-Performance construction*

TITLE-ABS-KEY – Title-Abstract-Keywords

It should be noted that the above keywords were not intended to be exhaustive but to overcome the challenge of obtaining a workable number of relevant papers for this research (Debrah et al., 2022b). Again, it is impractical to consider all potential keywords in a single study (Darko and Chan, 2017). It should be noted that relevant documents were retrieved and filtered. During the rapid screening of titles, abstracts, and keywords of the search outputs, documents without full text or non-English publications were excluded. The search had no date limitations. The selected articles were subjected to a full-text screening. During this stage, only articles that specifically evaluated relevant topics were included. Subsequently, the full texts of the included studies were critically evaluated, and relevant metadata were extracted. Fig. 2.1 shows the literature process as discussed above.

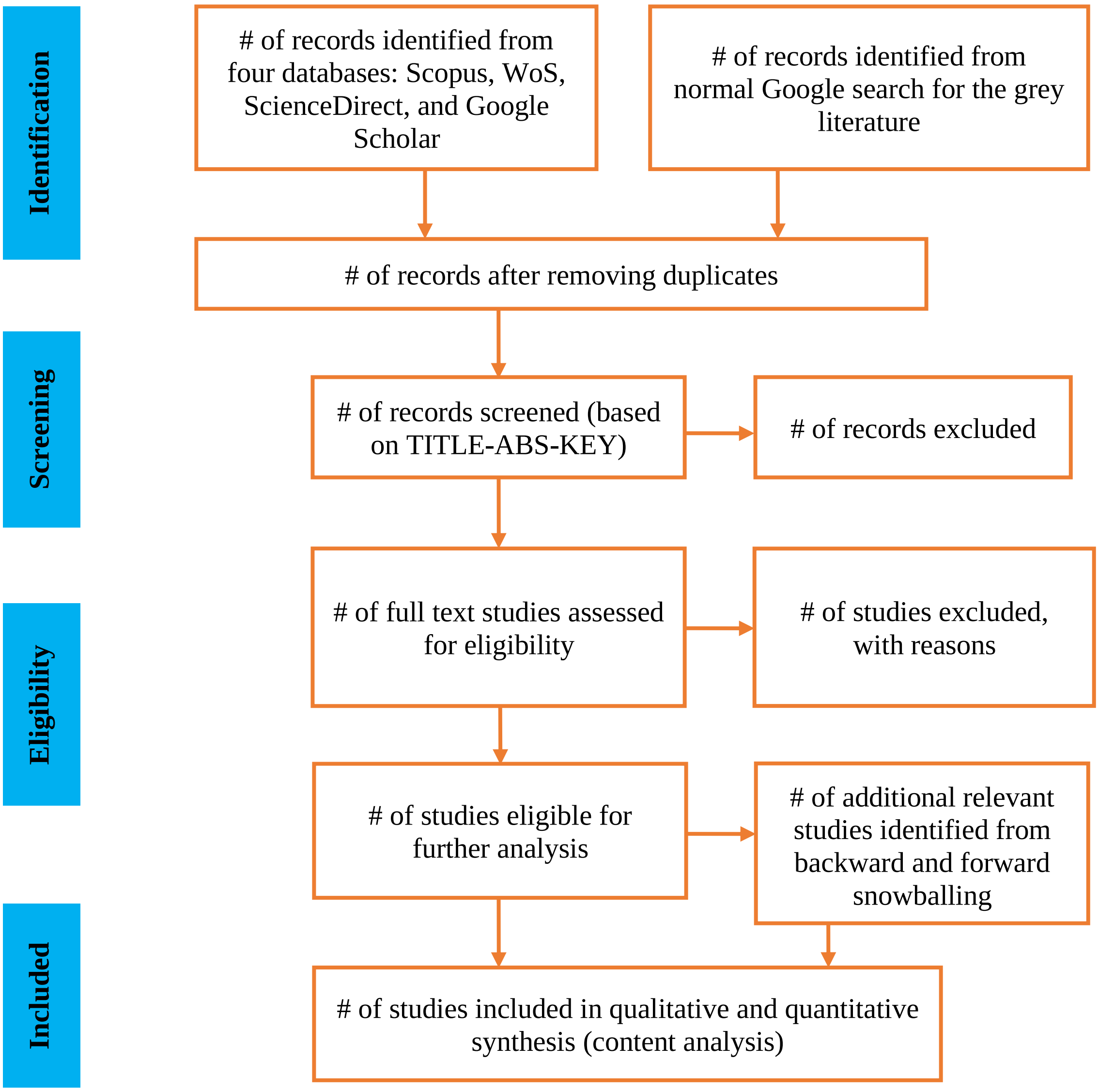

Fig. 2.1. Flowchart of the literature process
Modified from Debrah et al. (2022a)

2.5 Questionnaire Survey regarding Linguistic Evaluation

Following the literature review, a questionnaire survey regarding linguistic evaluation was administered to a group of experts. In construction engineering and management research, alternative techniques, such as the Delphi method, are used when traditional methods fail. According to Hallowell and Gambatese (2010), the Delphi technique is suitable for obtaining highly reliable data from certified experts using strategically designed surveys. This study employed improved versions of the Delphi method, FDM and FDEMATEL. This approach was adopted to obtain highly reliable data and the judgement of a panel of independent experts on GF-in-GB. In addition, since this topic is still emerging, the FDM and FDEMATEL approaches are more suitable for obtaining consensus and analysing the interrelationships between the factors of study in a more efficient and cost-effective manner. Hallowell and Gambatese's (2010) proposal for the Delphi procedure was adapted and summarised in Fig. 2.2.

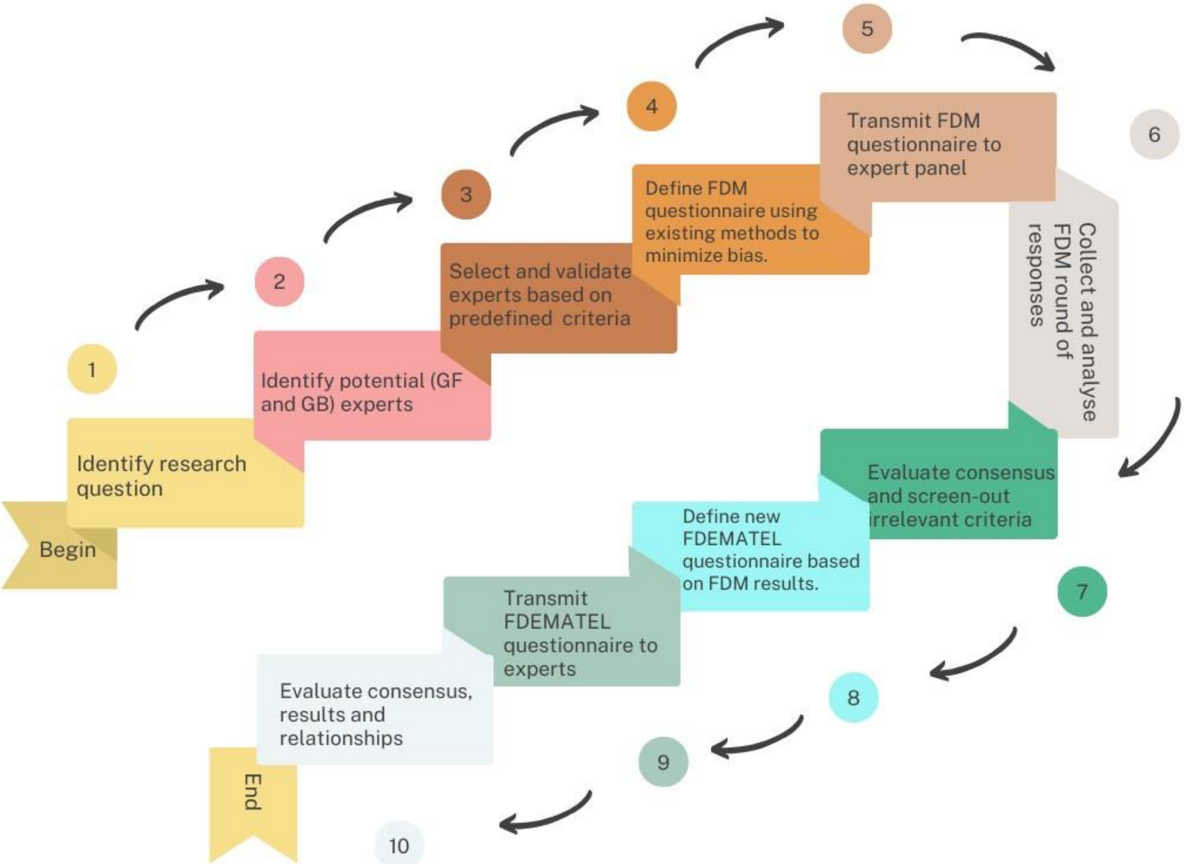

Fig. 2.2 FDM-FDEMATEL Procedure
Source: Adapted from Hallowell and Gambatese (2010)

The questionnaire survey regarding the linguistic evaluation process systematically followed the following steps:

2.5.1 Expertise requirements

The expertise level of the panel members is critical to this questionnaire process. The selection criteria should be unbiased and strategic (Hallowell and Gambatese, 2010). A summary of the guidelines for identifying potential and qualifying panellists as experts is provided in Table 2.3.

Table 2.3 Guidelines to identify and qualify panel of experts

Characteristics	Minimum requirement	Points (each)
Identifying potential experts	Membership in a nationally recognised committee in the focus area of research (e.g., Green Building Council) Primary author of publication in peer-reviewed journals Invited to present at a conference Recognised participation in similar expert-based studies	
Qualifying panellists as experts	Experts must fulfill at least four of the criteria below in related research topics	
	Primary/secondary author of at least three peer-reviewed journal articles	2
	Invited to present at a conference	0.5
	Member (M) or chair (C) of a nationally recognised committee	M (1), C (3)
	Faculty member at an accredited institution of higher learning	3
	Writer or editor of a book (B) or a book chapter (C) on the topic	B (4), C (2)
	Advanced degree in the field of construction or civil engineering management and/or finance and/or other related fields (minimum of a bachelor's degree)	BS (4), MS (2), PhD (4)
	Professional registration such as (e.g., Certified finance expert, licensed quantity surveyor, etc.)	3

Source: Modified from Hallowell and Gambatese (2010).

As shown in Table 2.3, the panellist must satisfy at least four key requirements. This is key to obtaining a healthy balance between professional and academic experience on the topic. Similar to Hallowell and Gambatese's (2010) recommendation, a flexible point system was adapted to qualify experts in this study. As presented in Table 2.3, it is suggested that panellists score at least one point in four different categories and a minimum of 11 points as a requirement to qualify for participation.

2.5.2 Number of rounds and panel members

Unlike the Delphi survey, which requires multiple rounds to reach a consensus to reduce variance in responses and improve precision (Hallowell and Gambatese, 2010), FDM does not require multiple investigations. Therefore, It has become preferred due to its simplicity, requiring only a single investigation, making it a more efficient option than the classical Delphi method. The FDM does not mandate that experts modify their extreme opinions like the Delphi method. Moreover, FDM aids experts in distinguishing their optimistic, pessimistic, and realistic opinions by utilising triangular fuzzy numbers (TFNs) (Hashemi Petrudi et al., 2022; Negash et al., 2021). Hence, this study applied the FDM to validate the factors of study for GF-in-GB under uncertainties. The FDM combines the advantages of incorporating the fuzzy set theory and the standard Delphi procedure to validate the criteria gathered from the literature.

Furthermore, the FDEMATEL was employed in the second round of surveys. In the FDEMATEL method, the fuzzy set theory was utilised to resolve the fuzziness in expert judgements, while the DEMATEL was employed to evaluate the cause-effect links between factors. This entailed collecting qualitative evaluations and converting the linguistic terms into equivalent TFNs. Common MCDM techniques such as DEMATEL, Analytical Network Process (ANP), Analytical Hierarchy Process (AHP), and Interpretive Structural Modeling (ISM) enhance the understanding of a specific issue or a cluster of interconnected issues and aid in identifying feasible solutions through a hierarchical structure (Farooque et al., 2020; Khoshnava et al., 2018; Tsai and Chou, 2009). MCDM methods are particularly effective in dealing with complex, interrelated problems with uncertainties, converting qualitative assessments into quantitative data, unlike traditional surveys, which assume independence among factors (Tsai and Chou, 2009; Wu and Lee, 2007). A recent comparison of the widely used MCDM methods revealed that the DEMATEL is superior to the AHP, ANP and ISM in terms of effectiveness (Farooque et al., 2020), primarily because it quantifies the influence levels of various factors and accommodates heterogeneous elements in its analysis (Alam-Tabriz et al., 2014). DEMATEL identifies direct and indirect connections between factors and visualises these relationships through impact diagrams (Kumar and Dixit, 2018). Consequently, the DEMATEL was selected as the most suitable method for this study. To further refine decision-making accuracy and mitigate biases and fuzziness, fuzzy set theory was incorporated into the DEMATEL approach (Negash et al., 2021). Hence, this study employed the fuzzy Delphi-DEMATEL approach to investigate the interdependent cause-effect dynamics within the factors influencing GF-in-GB.

Similar to the Delphi method, the accuracy and effectiveness of the FDM and FDEMATEL method depended on the number of panellists. A minimum of eight panel members is suggested because most studies incorporate between eight and 16 panellists (Rowe and Wright, 1999). Similarly, Hallowell and Gambatese (2010) recommend that the number of panellists range from eight to 12. This study conducted a two-round questionnaire survey regarding linguistic evaluation to obtain expert opinions from 12 panellists (out of 30 experts initially identified) with GF-in-GB experience. The relatively large sample of expert panellists considers issues such as some panellists dropping out due to other commitments or disinterest (Hallowell and Gambatese, 2010). Besides, similar studies incorporating FDM and FDEMATEL approaches employed eight to 16 experts (Addae et al., 2019; Negash et al., 2021; Oteng et al., 2022).

2.6 Linguistic Evaluation Questionnaire Survey Development

As discussed above, a two-round questionnaire survey was used in this study. FDM was used to express linguistic measurements in quantitative terms to model experts' subjective judgement. This approach is also key to eliminating or minimising the uncertainties associated with experts' perceptions (Tavana et al., 2016). The structure of the FDM questionnaire survey is as follows.

The questionnaire was developed after conducting a comprehensive systematic literature review of the specific objectives of the study, as outlined above. The questionnaire was structured into five sections with 15 questions. Prior to this, a cover letter that clearly explained the survey and rationale for the study was provided. The respondents were assured of their confidentiality, and their expectations were clarified. Section A requested respondents' personal data. This was necessary to qualify the potential experts for the survey. Section B focuses on the critical drivers of GF-in-GB projects. Respondents were required to assess the interactions between the attributes and categories of the drivers. Similarly, Section C evaluates the interactions between the GF-in-GB barriers and the categories. Section D assesses the interrelationship between the risk factors associated with GF-in-GB projects and their categories. Section E focuses on strategies to promote GF-in-GB, grouped into five categories. All the questions in Sections B to E were generated after a comprehensive literature review. The questionnaire survey adopted linguistic ratings ranging from 0 to 4, as explained in Section 2.3. Details of the linguistic evaluation questionnaire survey can be found in Appendix A.

2.6.1 Pilot Study for Survey

A pilot study was conducted prior to the first round of the FDM questionnaire survey. This was undertaken to assess the comprehensiveness, relevance, and reliability (Owusu, 2020) before disseminating to the targeted experts for their invaluable opinions. In addition, a pilot study was also necessary to ensure the clarity and answerability of all questions and verify that no leading questions or assumptions were embedded in the questionnaire (Ritchie et al., 2013). Two experts were involved in the pilot study: an academic and an industry practitioner. This was necessary to avoid bias and to ensure representativeness. Interviews were conducted with two experts with at least ten years of work or academic experience in GB finance. They were asked to comment on the suitability of the factors identified in the literature review and suggest other relevant factors. Feedback from the experts was used to improve the questionnaire. From the experts' feedback, it was identified that while some factors, for instance, drivers, were dependent on others, it was necessary to combine others that appeared ambiguous and were likely to cause misunderstanding or were less relevant to the Ghanaian context. As a result, minor revisions were made to the shortlisted factors, and others were combined to improve clarity and ensure content validity (Farooque et al., 2020). Consequently, a final list of factors (Appendix A) was confirmed relevant to GF-in-GB in Ghana.

2.7 Questionnaire for the Case Study

A questionnaire was developed to investigate and gather the cost data of the selected case study of a green office building with Final IFC EDGE certification. The selected GB is in Accra, Ghana's capital city. The questionnaire consisted of 10 questions in two sections. Section A requested information on the participants in the case study in diverse ways. Section B was structured to gather the profile of the selected GB and cost estimates. The data for the case study were obtained from interviews with project participants such as project managers, quantity surveyors, clients, architects, and GB assessors, among others, who were involved in the selected green office building. Details of the questionnaire are provided in Appendix A.3.

2.8 Population and Sampling Techniques

The population is the entire group of individuals to which survey findings are to be generalised. The specific individuals within the target population whose characteristics are of interest are referred to as elementary units or elements of the population (Levy and Lemeshow, 2013). The population of the study consisted of experts in green building and green finance in Ghana. They included both industry and academic experts.

Sampling is important due to the inability to examine an entire population (Kuoribo et al., 2021). A sample should be adequately representative of the population (Fellows and Liu, 2015). Probability sampling and non-probability sampling are the two primary categories of sampling techniques. Probability sampling ensures that every member of the population has a known, nonzero chance of being included in the survey. In contrast, non-probability sampling is based on a specific sampling method (Levy and Lemeshow, 2013). The aforementioned approach is a technique for choosing units from a population utilising a non-random, subjective method (Alvi, 2016). In market research and public opinion surveys, non-probability sampling is often preferred due to its cost-effectiveness, efficiency, and practicality. Probability sampling, although reliable, may prove to be impractical and expensive in certain situations (Levy and Lemeshow, 2013).

This study adopted the "snowball" non-random sample method. Snowball sampling is a non-probability sampling design that may involve data that are difficult to access, perhaps because individual sources of data cannot be readily identified (Debrah et al., 2021; Fellows and Liu, 2015). Given the novelty of this research in Ghana, the utilisation of snowball sampling was deemed appropriate to access the limited pool of experts on this subject. This method is commonly employed when collecting data from a population that is difficult to reach (Heckathorn, 2011). In light of the limitations of conducting a census or random sample, this study opted for a non-probability snowball sampling approach. Two experts with established credentials in the field were selected as the initial sample, and additional experts were identified through referral. A total of 30 experts with experience in either GB or GF in Ghana were ultimately included in the sample. Similar to previous construction engineering and management studies, the snowball technique was adopted in this study because of the lack of a sampling frame for GF-in-GB (Debrah et al., 2022f; Guribie et al., 2022). Hence, for credibility, efficiency, sufficiency, and validity (Fellows and Liu, 2015; Guribie et al., 2022), a snowballing process was used to "purposively" select a group of experts with various levels of managerial responsibilities and diverse backgrounds with an average of ten years of experience in GF and/or GB research and development. The experts considered in this study included green construction professionals, GF experts, and academics.

Overall, 12 valid responses were received from two rounds of the linguistic evaluation questionnaire surveys. These responses formed the basis for the quantitative analysis and prioritisation of these factors. Table 2.4 shows the equal distribution of experts working in academia and industry. This sectoral distribution offers an opportunity to capture the views of both academics and industry practitioners. Moreover, it is interesting to note that academic experts usually have stronger ties with the industry and provide consultancy services to industry practitioners. Some academic experts have worked in the industry prior to joining academia (Wuni, 2022). The majority of the respondents had up to five years of experience on either GF and/or GB projects. This proportion is justified because the GF-in-GB concept remains novel in Ghana. Most experts (66.7%) had at least one master's degree. The literature argues that academic qualifications can help gain more knowledge for professional and organisational development (Debrah and Owusu-Manu, 2021a). Furthermore, most of the experts had knowledge of GF and GB and were identified as experts on both phenomena through practice and/or research. Table 2.4 summarises the demographic information of the respondents for FDM and FDEMATEL.

Table 2.4 Demographic information of the respondents

Attribute	Sub-attribute	Frequency (N=12)	Percentage (N=100%)
Education level	PhD degree	4	33.3
	Master's degree	8	66.7
	Total	***12***	***100.0***
Professional background [a]	Chattered Accountant	1	8.3
	Investment manager	1	8.3
	Quantity Surveyor	5	41.7
	Academic/Researcher	8	66.7
	Project/Construction Manager	8	66.7
	Engineer	2	16.7
Years of experience	1 – 5 years	6	50.0
	6 – 10 years	4	33.3
	> 10 years	2	16.7
	Total	***12***	***100.0***
Area of related expertise	Green finance	3	25.0
	Green building	2	16.7
	Both	7	58.3
	Total	***12***	***100.0***
Organisation	Academic or research institute	6	50.0
	Green certification firm	1	8.3
	Contractor firm	2	16.7
	Consultant firm	1	8.3
	Development/ commercial banks	2	16.7
	Total	***12***	***100.0***
Professional membership [a]	Association of Certified Chattered Accountants (ASCE)	1	8.3
	American Society of Civil Engineers (ASCE)	1	8.3
	Australian Institute of Project Managers (AIPM)	1	8.3
	Ghana Institute of Construction (GIOC)	6	50.0
	Ghana Institute of Surveyors (GhIS)	3	25.0
	Project Management Professional (PMP-Ghana)	3	25.0
	Institute of Engineering Technology Ghana (IETG)	1	8.3
	International Finance Corporation Excellence in Design for Greater Efficiencies (IFC EDGE) Expert	3	25.0
Type of GB certification involved in [a]	Green Star South Africa-Ghana	4	33.3
	IFC EDGE	6	50.0
	US LEED	5	41.7
GF certification/standards involved in [b]	Climate Bonds Initiative	3	25.0
	ICMA Green Bond Principles	6	50.0
	GRESB Green Bond Guidelines	1	8.3
Journal or book publications	≥ 3 publications	8	66.7
Presented in conferences	Yes	4	33.3
Type of GB supply involved in [b]	Commercial, public, and institutional buildings	6	50.0
	Residential buildings or homes	5	41.7
	Healthcare facilities and laboratories	1	8.3
	Green retrofitting of existing buildings	1	8.3
	All the above	2	16.7
Extent GF impact investment decision in GB [b]	Prefer GF such as green bonds where available and where competitively priced	7	58.3
	Mandates or targets	1	8.3
Preferred channels of green fixed income investments for GBs [b]	Development bank green bonds	5	41.7
	Corporate green bonds	8	66.7
	Private placement of green bonds	1	8.3
	Green loans	8	66.7
	Sovereign green bonds	3	25.0

[a] Some experts possess multiple professional backgrounds and memberships; hence, percentages may exceed 100%.
[b] Multiple answers were allowed

2.9 Description of Case Study

From Table 1.1, the majority (16) of the GBs are office buildings, and IFC EDGE certification is the preferred certification in Ghana. First, this study focused on green office building types due to data availability. Moreover, offices constitute about 50% of all certified buildings in Ghana (see Table 1.1). Hence, this study considered a green office building in Ghana with the Final EDGE certification, as shown in Table 2.5. While the scope of this study was limited to a single case of a green office building due to the scarcity of available data and low inventory of such buildings in Ghana, it is worth noting that previous research has demonstrated the feasibility of theoretically estimating the potential benefits of GBs when direct calculations are not feasible due to a limited inventory (Gabay et al., 2014). Despite the limitations of this study, the findings still offer some insights into a market lacking information. Additionally, due to the scarcity of data, several studies have utilised the CBA methodology through single case studies in countries such as Indonesia, Malaysia, and India (Dwaikat and Ali, 2018; Miraj et al., 2021). These considerations justify using a single green office building in the Ghanaian context.

Table 2.5 Profile of Final IFC EDGE certified green office buildings in Ghana

Building profile	Description
Construction period	2014 – 2019
No. of floors	12
No. of occupants	1,787 [a]
Shape	Square
GIFA [b] (m^2)	26,800
Life cycle	50 years
Building height (m)	51
Location	Urban – Accra, Ghana
Climate condition	Tropical
Certified (Level)	Yes (Final)
Type of certification (Year)	Final EDGE certification (2019)
Energy savings (predicted %)	36
Water savings (predicted %)	56
Less embodied energy in materials (%)	32

[a] Calculated based on Ghana's building standard (refer to Chapter 8)
[b] GIFA – Gross Internal Floor Area
Source: Compiled by author

The present study considered one of the green office buildings in Ghana with Final EDGE certification, constructed from 2014 to 2019. The GB has a GIFA of 26,800m^2. The building was commissioned in 2019, and its entire operation began in 2020. The building focuses on technical solutions that promote energy efficiency, water savings, and use less embodied energy in materials. The mechanisms adopted to increase energy savings in buildings include solar photovoltaics (PV), energy-saving lighting in internal and external spaces, lighting controls for corridors and staircases, and occupancy sensors in rooms and offices. Dual-flush water closets, water-efficient urinals, low-flow faucets, rainwater, and underground water harvesting systems have been adopted to reduce building water consumption. To reduce the embodied energy of the materials, an in-situ reinforced concrete slab floor and roof construction, plasterboards on metal studs for internal walls, and aluminium profile cladding were used for the external walls.

Interviews were conducted with the design and construction team and building management to obtain the GB's project details and cost indicators (primary data). Based on primary data (complemented with secondary data and local/internationally accepted standards), this study provides preliminary lifecycle CBA estimates for GB offices in Ghana. This study serves as an initial step in detailing the costs and benefits of GBs in Ghana. The GB cost breakdown components identified in the literature were adapted for the Ghanaian case (Dwaikat and Ali, 2018; Miraj et al., 2021). The selected building costs represent the building structure, core, envelope, electromechanical systems, finish of public spaces, and parking spaces. This analysis did not include land value, which tends to be exceptionally high in Accra (Ghana's capital city). In addition, land value has no effect on the varying cost-benefit results of the study (Gabay et al., 2014). Besides, existing cost-benefit studies exclude land values from the analysis (Dwaikat and Ali, 2018; Gabay et al., 2014; Miraj et al., 2021).

2.10 Data Analysis Methods

2.10.1 Multi-Criteria Decision-Making Techniques

This study employed MCDM techniques to convert qualitative data (FDM) into quantitative information (FDEMATEL). This was key in evaluating the cause-effect relationships among GF-in-GB drivers. Similar approaches were adopted for objectives 2-4: barriers, risk factors, and strategies to promote GF-in-GB. This is because it was expected that the factors determining GF-in-GB would include complicated qualitative features and uncertainties due to linguistic preferences. Besides, the *fuzzy philosophy* adopted for this study states that "everything is a matter of degree – a world of multivalence" (Fellows and Liu, 2015: pp. 76). To provide consensus on an emerging topic, such as GF-in-GB, expert views are critical for reducing or eliminating (if possible) uncertainties. For example, human perceptions and language preferences of decision-makers produce uncertainty (Tseng et al., 2018) that is difficult to quantify using formal models and procedures. Combining the fuzzy set theory is critical for solving uncertainties (Addae et al., 2019).

For a better understanding, the approaches involved in FDM and FDEMATEL are outlined below. This study adapted the approaches of Negash et al. (2021) and Addae et al. (2019), as explained below for FDM and FDEMATEL. In the first round, the proposed factors for objectives 1-4 identified from the literature and their descriptions were presented to the experts. To ensure the validity of the criteria and improve the dependability of the information sources, a combination of online and in-person interviews was conducted. The experts were sent FDEMATEL questionnaires in the final phase, and online and in-person interviews were conducted using the valid criteria discovered in the first round using the FDM. The following sections explain the FDM and FDEMATEL.

2.10.2 Fuzzy Delphi Method

The FDM is a refined and improved iteration of the classical Delphi method. The Delphi technique is a structured and interactive mode of research that seeks the opinions of a panel of unbiased specialists on a particular subject (Hallowell and Gambatese, 2010). Despite its widespread use, the Delphi method faces challenges related to ambiguity and uncertainty in experts' opinions. This is because the assessment of human judgment is a complex, subjective, and personal phenomenon that involves many domains of an individual's life experience. Generally, conventional rating scales, such as Likert scales, utilise crisp numbers to measure human cognitive applications (Roldán López de Hierro et al., 2021). Evaluation criteria of this sort are inherently subjective and qualitative, requiring linguistic information to describe them. As a result, it can be challenging for the decision-maker to assign precise numerical values to express their preferences (Tseng, 2011). Zadeh (1965) proposed the fuzzy set theory to handle uncertainties in decision-making and human judgement. The theory employs fuzzy numbers to represent linguistic variables, such as "very dissatisfied" or "not satisfied," by utilising TFNs within a scale ranging from 0 to 10. These linguistic variables are words or phrases in natural language that lack definite values (Tseng, 2011). In addition to the limitations previously mentioned, classical Delphi methods also have the disadvantage of low convergence of experts' opinions, high execution cost, and the potential for filtering out certain experts' opinions (Hashemi Petrudi et al., 2022).

The FDM was initially proposed by Murray et al. (1985) as an alternative to the classical Delphi method, which relies on a membership degree to determine each participant's membership function. FDM combines the fuzzy set theory with the Delphi methodology (Roldán López de Hierro et al., 2021). It has been recognized as a methodical, interactive, and predictive process (Hashemi Petrudi et al., 2022). Despite its relative novelty, the FDM has been employed in various domains, including humanities, management, business, physical science, and engineering (Saffie et al., 2016). FDM is preferred due to its simplicity, requiring only a single investigation, making it more efficient than the classical Delphi method. Unlike the Delphi method, FDM does not mandate that experts modify their extreme opinions. Moreover, FDM aids experts in distinguishing their optimistic, pessimistic, and realistic opinions by utilising TFNs, as discussed below (Hashemi Petrudi et al., 2022).

Hence, this study applied the FDM to validate the drivers of GF-in-GB under uncertainties. As noted above, this involved a combined strategy incorporating the fuzzy set theory and the standard Delphi procedure to validate the criteria gathered from the literature. To overcome the ambiguity in expert judgements, the fuzzy set theory was applied, and the Delphi approach was used to screen out non-significant criteria from the initial collection of drivers. It was hypothesised that GF-in-GB drivers were interconnected and entailed complicated qualitative traits and uncertainty due to language preferences for the attributes. Similar approaches have been adopted to analyse the barriers, risk factors, and strategies of GF-in-GB. As a result, the FDM was used to confirm and filter the variables discovered in the literature (Negash et al., 2021) under objectives 1-4 above. Expert opinions on the importance of individual criteria as linguistic variables were collected using FDM techniques (Hsu et al., 2010). Table 2.6 was used to convert the language evaluation scores into TFNs.

Table 2.6 TFNs for FDM assessment

Linguistic terms	Corresponding TFNs		
Extreme	0.75	1.00	1.00
Demonstrated	0.50	0.75	1.00
Strong	0.25	0.50	0.75
Moderate	0.00	0.25	0.50
Equal	0.00	0.00	0.25

Source: Negash et al. (2021)

The following procedures were used for aggregation and defuzzification. The geometric mean was used to aggregate the respondent scores and the fuzzy weight (w_j) of each criterion was determined.

$$w_j = \left\{a_j = min(a_{ij}), b_j = \left(\sum_{i=1}^{n}(b_{ij})\right)^{\frac{1}{n}}, c_j = max(c_{ij})\right\} \tag{2.1}$$

where j indicates the criterion being evaluated for its significance, i denotes the expert evaluation of criterion j, n is the number of experts, and a, b and c are the lower, middle, and upper values of the TFNs, respectively.

The aggregated weights of each criterion are defined as follows:

$$s_j = \frac{a_j+b_j+C_j}{3} \; j = 1,2,3 \dots m \tag{2.2}$$

where m represents the number of criteria.

The threshold (α) was chosen to screen out non-significant criteria: if $s_j \geq \alpha$, then the jth criterion is accepted; otherwise, the jth is rejected if $s_j \leq \alpha$. In most cases, α value of 0.5 is utilised.

2.10.3 Fuzzy DEMATEL

The DEMATEL method was first introduced by the Battelle Institute in 1971 (Gabus and Fontela, 1972). DEMATEL is a rigorous technique that aims to elicit expert responses to construct and examine a structural model, which includes revealing sub-systems and complex causal relationships through the use of a causal diagram (Kayikci et al., 2023). The DEMATEL diagrams, also known as directed graphs, are valuable tools for separating relevant factors into cause-and-effect groups. Directed graphs (or diagraphs) are significantly more useful than their directionless counterparts as they can accurately depict the directed relationships within sub-systems. Such diagrams are often used to represent communication networks or dominance relationships between individuals, and they effectively convey the contextual connections between the various elements in a system, with the numbers indicating the strength of influence (Wu and Lee, 2007). Thus, the DEMATEL method can convert the relationship between the causes and effects of factors into an intelligible structural model of the system (Tseng, 2011). However, similar to the Delphi method explained above, the DEMATEL is unable to handle uncertainties in decision-making and subjectivity in human judgement. To overcome this limitation, the fuzzy DEMATEL (FDEMATEL) method has been proposed. The FDEMATEL method, which merges the linguistic aspect of fuzzy theory with the DEMATEL approach, is a valuable tool for researchers seeking to investigate the causal relationships of fuzzy variables and assess the degree of interactivity between these variables in a fuzzy environment (Tsai et al., 2015). In the context of FDEMATEL, fuzzy theory serves as a critical tool for researchers to tackle the imprecision of human judgement and language in decision-making processes, as the outcome of these processes is primarily influenced by subjective, vagueness and uncertain judgements (Wu and Lee, 2007).

FDEMATEL, with qualitative data, was utilised to evaluate the interaction between GF-in-GB drivers. Owing to the complexities associated with decision-making in real-world problems, researchers have accepted DEMATEL as an effective MCDM (Negash et al., 2021). TFNs handle qualitative data and convert linguistic preferences into crisp values, whereas DEMATEL identifies causal interrelationships between factors. Likewise, the same approaches were used to determine the effectual relationship among the barriers, risk factors, and strategies of GF-in-GB.

Expert judgement entails decision-making in the face of ambiguity. Lin et al. (2018) recommended FDEMATEL to address such uncertainties and ambiguities during decision-making. Meanwhile, the fuzzy set theory was utilised to resolve the fuzziness in expert judgements. DEMATEL was employed to evaluate the cause-effect links between factors. This entailed collecting qualitative evaluations and utilising Table 2.7 to convert linguistic terms into equivalent TFNs.

Table 2.7 TFNs for FDEMATEL assessment

Linguistic terms	Corresponding TFNs		
Very high (VH)	0.70	0.90	1.00
High (H)	0.50	0.70	0.90
Medium (M)	0.30	0.50	0.70
Low (L)	0.10	0.30	0.50
Very low (VL)	0.00	0.10	0.30

Source: Negash et al. (2021)

There are n members in the decision group, and $\tilde{z}_{ij}^{f}$ denotes the fuzzy weight of the ith characteristic impacting the fth evaluator. The following procedure was followed to implement FDEMATEL in this study.

Normalise the fuzzy numbers:

$$S = \left(s\tilde{z}_{lij}^{f}, s\tilde{z}_{mij}^{f}, s\tilde{z}_{uij}^{f}\right) = \left[\frac{\left(\tilde{z}_{lij}^{f} - min\tilde{z}_{lij}^{f}\right)}{\left(max\tilde{z}_{uij}^{f} - min\tilde{z}_{lij}^{f}\right)}, \frac{\left(\tilde{z}_{mij}^{f} - min\tilde{z}_{mij}^{f}\right)}{\left(max\tilde{z}_{uij}^{f} - min\tilde{z}_{lij}^{f}\right)}, \frac{\left(\tilde{z}_{uij}^{f} - min\tilde{z}_{mij}^{f}\right)}{\left(max\tilde{z}_{uij}^{f} - min\tilde{z}_{lij}^{f}\right)}\right] \tag{2.3}$$

where $\left(s\tilde{z}_{lij}^{f}, s\tilde{z}_{mij}^{f}, s\tilde{z}_{uij}^{f}\right)$ reflects a TFN's normalised values; S is the resultant normalised fuzzy number for each criterion and expert, i.e., the i-th expert for the j-th criterion; $\tilde{z}_{lij}^{f}, \tilde{z}_{mij}^{f}, \tilde{z}_{uij}^{f}$ are the original lower, middle and upper values of the fuzzy number before normalisation, associated with the i-th expert for the j-th criterion; $min\tilde{z}_{lij}^{f}, min\tilde{z}_{mij}^{f}$ are the minimum values observed across all experts for the lower and middle components, respectively, and $max\tilde{z}_{uij}^{f}$ is the maximum value observed across all experts for the upper component.

Compute the left $\left(s\tilde{z}_{ltij}^{f}\right)$ and right $\left(s\tilde{z}_{rtij}^{f}\right)$ normalised values, total normalised crisp values (Eqn. (2.4)), and crisp values (Eqn. (2.6)).

$$\left(S_{ltij}^{f}, S_{rtij}^{f}\right) = \left[\frac{s\tilde{z}_{mij}^{f}}{\left(1 + s\tilde{z}_{mij}^{f} - s\tilde{z}_{lij}\right)}, \frac{s\tilde{z}_{uij}^{f}}{\left(1 + s\tilde{z}_{uij}^{f} - s\tilde{z}_{mij}^{f}\right)}\right] \tag{2.4}$$

$$S_{ij}^{f}=\left[\frac{S_{ltij}^{f}+\left(1-S_{ltij}^{f}\right)+\left(S_{rtij}^{f}\right)^{2}}{\left(1-S_{ltij}^{f}+S_{rtij}^{f}\right)}\right] \quad (2.5)$$

$$\widetilde{w}_{ij}^{f}=min\tilde{z}_{lij}^{f}+S_{ij}^{f}(max\tilde{z}_{uij}^{f}-min\tilde{z}_{lij}^{f}) \quad (2.6)$$

The synthetic value was determined by defining an initial direct relation matrix (IDRM) that aggregates the subjective assessments of n evaluators.

$$\widetilde{w}_{ij}^{f}=\frac{1}{n}\left(\widetilde{w}_{ij}^{1}+\widetilde{w}_{ij}^{2}+\widetilde{w}_{ij}^{3}+\cdots+\widetilde{w}_{ij}^{f}\right) \quad (2.7)$$

where w_{ij} specifies how much criteria i influences criterion j.

To build the normalised direct relationship matrix (U), the IDRM was standardised.

$$U=w\otimes IDMR \quad (2.8)$$

where $w=max\ (\sum_{j=1}^{n} w_{ij}^{f})$ for every i ranging from 1 to n.

Calculate the entire interrelationship matrix (Y) using the total relation matrix and matrix U.

$$Y=U(I-U)^{-1} \quad (2.9)$$

Where I represent the size n and an identity matrix.

Vector D represents the total of the rows, while vector R represents the sum of the columns. The horizontal axis $(D+R)$ reflects "prominence" and denotes significance. The vertical axis $(D-R)$ denotes the causal qualities and signifies "relation". When the total of $(D-R)$ is negative, the barrier or criteria is recognised as the effect group, and when it is positive, it is identified as the cause group.

$$D=\sum_{j=1}^{n} U_{ij} \text{ for all } j \text{ from 1 to } n \quad (2.10)$$

$$R=\sum_{i=1}^{n} U_{ij} \text{ for every } i \text{ ranging from 1 to } n \quad (2.11)$$

The strength of the cause-effect link was determined by obtaining the inner dependency matrix.

2.11 Proposed Analytical Processes for the FDM and FDEMATEL

This section focuses on the analytical processes of the FDM and FDEMATEL processes. For illustration, GF-in-GB drivers were used to explain the analytical process (Objective 1). The same process was repeated for objectives 2-4.

1. An initial set of 16 GF-in-GB drivers was found in the literature and analysed using FDM, and 12 experts from Ghana were used to evaluate the drivers using linguistic terms. Using Table 2.6, experts' qualitative assessments were converted into equivalent TFNs. Using Eqn. (2.1) and (2), the FDM was used to remove non-significant criteria. Using the above equations, the acceptance threshold was determined as 0.521.
2. Based on acceptable criteria, a new set of questions was examined using FDEMATEL. This included a new set of eight drivers after screening for non-significant drivers. The same experts were contacted for the second round of data collection, and Eqn. (2.3) was used to normalise the assessed TFNs. To determine the normalised values, total normalised crisp values, and crisp values for each expert, Eqns. (2.4) - (2.6) were used.
3. Eqns. (2.7) and (2.8) were utilised to produce the IDRM and normalised direct relationship matrix (2.8). Eqn. (2.9) was used to compute the influence or significance level of the complete interdependence matrix.
4. The horizontal axis $(D + R)$ and vertical axis $(D - R)$ were determined using Eqns. (2.10) and (2.11). Drivers in the first quadrant are called driving attributes with causal features and are of higher importance. If a driver is in the second quadrant, then it is a voluntary attribute; this type of barrier has a causal function but lower importance. The third quadrant consists of less important and independent barriers. Core problems are those mapped to quadrant four, indicating a higher importance. The core problems rely on the driving attributes in the first quadrant and are unable to be improved by

themselves and are required to address the root problems. The analytical steps proposed in this study are summarised in Fig. 2.3.

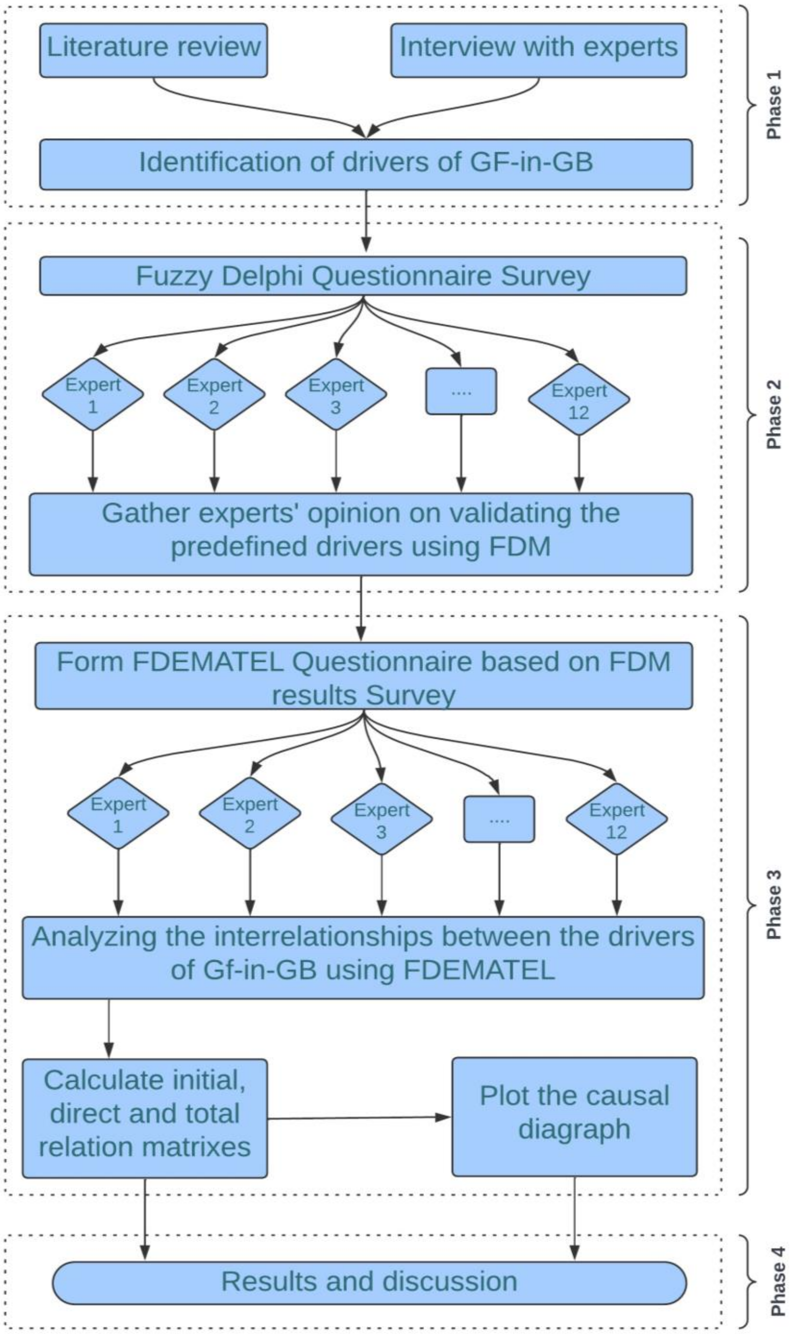

Fig. 2.3 Proposed fuzzy Delphi-DEMATEL framework for this study.
Source: Author's

2.12 Cost-Benefit Analysis Model and Methodological Considerations

GB is a good economic investment if the entire benefits throughout the building's lifecycle outweigh any additional costs (Gabay et al., 2014). Thus:

$$CCB > CGB - BGB \tag{2.12}$$

where CCB is the cost of conventional building, CGB is the cost of GB, and BGB is the benefits of GB. The various aspects considered in this study are described below:

2.12.1 Lifecycle Cost

LCC, or whole-life costing analysis, examines investments by considering the entire project's lifecycle. This is essential when comparing different building designs because it allows the measurement of cost advantages against any initial cost increase (Cole and Sterner, 2000). LCC analysis includes both initial and recurrent investments in all materials, plants, and labour used for construction (Ansah et al., 2020). Hence, costs, savings, and revenues over the asset life are measured using the time value of money to provide accurate and efficient assessments of the projects under consideration (Yang and Zou, 2016). In building and construction, the costs considered include the initial investment, O&M costs, and demolition costs (Miraj et al., 2021).

The initial investment covers construction, development, and extra expense costs such as licensing, fees, and other additional costs. O&M costs are annual expenses, along with other recurring costs (i.e., management overheads) necessary to make the building perform as planned. The demolition cost is the cost of demolition at the end of a building's service life (Miraj et al., 2021). This stage involves salvage value, which may benefit from lowering demolition costs from material transactions or other commercial strategies from this activity (Guy, 2006).

For LCC, a discounted present value that enables the comparison of values from cost- and asset-based alternatives is considered. Hence, sensitivity and probability analyses based on the net present value (NPV) method are used to measure the LCC by considering the time value of money. This allows cash flows to be discounted at the present value (Guy, 2006). This study adopted the new rules of measurement (NRM) series LCC component by the Royal Institution of Chartered Surveyors (RICS) being the CROME (construction costs, renewal costs, operation and occupancy costs, maintenance costs, and environmental and/or end-of-life costs respectively) (RICS, 2021). In addition, design and planning, supervision, construction management, and other cost considerations, such as inflation, are discussed below (Miraj et al., 2021). A summary of the cost categories (Miraj et al., 2021) for this study is summarised in Table 2.8.

Table 2.8 Cost categories of LCC

Non-construction cost	Construction costs	Maintenance and repair costs
Design and planning	Substructure	Main building
Supervision	Superstructure	Plumbing and sanitary
Construction management	Finishes	Electrical installation
	Fittings and equipment	HVAC
	MEP	Lift
	External works	Communication and security system
	GB features	Fire protection
	Others	GB features
Operational costs	**Renewal costs**	**End of life costs**
Energy	Replacement of solar PVs	Waste and transport
Water		Labour works
Cleaning		
Health, safety, and management		

MEP – Mechanical, Electrical and Plumbing; HVAC – Heating, Ventilation, and Air Conditioning

Source: Miraj et al. (2021)

2.12.2 Investment Cost

Investment costs include construction and non-construction costs, which involve building components (Miraj et al., 2021). The construction costs comprise eight major components: substructure, superstructure, finishes, fittings and equipment, services, external works, GB features, and others. The non-construction costs include design, planning, supervision, and construction management. The total investment cost in the completion year (s) is calculated as follows:

$$IC_v = \sum_{w=1}^{3} ND_w + \sum_{k=1}^{8} CC_k, \tag{2.13}$$

where ND_w is non-construction cost (US$) of components w, while CC_k represents construction cost (US$) of materials or components k that follows categorisations in Table 2.8.

2.12.3 Building Operation and Maintenance Cost

Building maintenance costs are related to labour costs, materials, or associated costs related to the physical attributes or components of a building. This study considers eight maintenance components: main building, electrical installation, plumbing and sanitary, air conditioning and HVAC, fire protection, communication, lift, and GB features. Operating costs may include several components related to utility services, such as rent, tariffs, local taxes, insurance, energy, charges, and other environmental/regulatory inspection costs (International Organisation for Standardisation, 2020). The total O&M costs are the sum of the present values of the cost components, as categorised in Table 2.8.

$$OM_T = \sum_{x=1}^{5} OM_x + \sum_{y=1}^{8} OM_y, \quad (2.14)$$

where OM_x is the operating cost, and OM_y is the maintenance costs. Both are annual recurring costs over the building's lifecycle in light of the inflation rate of construction and are computed as:

OM_x: the operating cost, OM_y: maintenance cost. Both are annual recurring costs over the building's lifecycle, considering the inflation rate of construction and are computed as:

$$F = P(1 + e)^n \quad (2.15)$$

F is the future value (nominal cost), P is the cost of specific components in the base year of the building's O&M (US$), e is the sectoral inflation rate (%), and n is the difference in years between the base year and the occurrence of the cost.

2.12.4 Renewal Cost

Renewal (R) costs comprise the materials and components that need to be replaced at the end of their service life.

$$RC_x = \sum_{i=1}^{t} RC_i \frac{1}{(1+s)^f} \quad (2.16)$$

where RC_i is each component requiring replacement; t is the number of occurrences; s is the general inflation rate (%); f is the event of renewals (in years).

The renewal cost was evaluated using Eqn. 2.16 considering the essential cost, number of occurrences, and life expectancy adjusted using the present value to reveal the present cost.

2.12.5 End of Lifecycle Cost

The end of the building life cycle plays a crucial role in the calculation of the overall LCC. This represents the cost of activities related to the disposal of assets at the end of the building service. The end of the LCC consists of demolition, scrapping, selling building assets or materials, tax allowance, or even a resale charge (Paredes and Skidmore, 2017). Implosion, a hybrid technique of mechanical demolition and deconstruction, has been adopted to balance cost and environmental concerns (Miraj et al., 2021). Mechanical demolition requires the least amount of labour through the use of heavy equipment, such as excavators and bulldozers (Liu et al., 2003). On the other hand, deconstruction selectively dismantles building structure to recover the maximum amount of primary reusable and secondary recyclable materials in a safe and cost-effective manner (Guy, 2006). This method is preferred when sustainability is the primary goal (Liu et al., 2003).

Demolition costs include labour, material (benefits from salvaged materials), plant, environmental compliance, and administrative costs (Liu et al., 2003). Estimates, permits, and general business overhead incur administrative costs. While plant costs include transportation, machinery, equipment, and site security, labour costs are personnel expenditures during demolition. Others have proposed cost data to include labour rates, disposal costs, demolition costs, and salvage value (Dantata et al., 2005). Due to inadequate data, this study adopts a less-complex proposal that includes waste, transport, and indirect costs in calculating the end of the building lifecycle (Dwaikat and Ali, 2018; Miraj et al., 2021), as shown in Eqn. 2.17:

$$E = v\left(\left(w_i w_j\right) + \left(l_i l_j\right)\right) + r \tag{2.17}$$

where v is the GIFA (m^2), w_i is the waste factor (m^3/ m^2); w_j is the waste transport (US$/ m^3); l_i is the labour factor (h/ m^2); l_j is the labour price (US$/h); l_j is the indirect cost (US$).

For indirect costs, 10% of the total waste, transport costs, and labour work were assumed. A summary of the other assumptions adopted in this study is presented in Table 2.9.

Table 2.9 Assumptions for end-of-lifecycle cost

Components	Assumptions	References
Waste factor	1.2676 m^3 waste per m^2	Solís-Guzmán et al. (2009)
Waste transport	8 US$/h	Guy (2006)
Labour factor	0.06h/m^2	Guy, 2006; Miraj et al., 2021
Labour price	17.64 US$/day or 2.21 US$/h*	Local rate (Interview)
Indirect cost	10% of waste & transport and labour works	Miraj et al. (2021)

*1 day = 8 working hours

2.12.6 Inflation Rate

Inflation refers to an increase in prices over time. The inflation rate is how quickly prices rise (Bank of England, 2022). In CBA, it is recommended that the analysis be undertaken using an entirely nominal value with a nominal discount rate or entirely real values with a real interest rate (Kokoski, 2010). According to Miraj et al. (2021), for LCC analysis, academics and practitioners prefer real values when comparing macro investment alternatives.

The inflation rates in Ghana are accessible from the monthly reports issued by the Ghana Statistical Service. This was measured using the combined consumer price index (CPI). The CPI measures the change over time in the general price level of goods and services households acquire for consumption. In Ghana, inflation has been classified into two major groups: (1) the food and non-alcoholic beverages group and (2) the non-food group (Ghana Statistical Services, 2022).

Based on the available inflation data from Ghana Statistical Services (2022) and the World Bank (2022), the present study compared the inflation rates for the past decade from 2011 to 2020 (the base year for the study), as shown in Fig. 2.4.

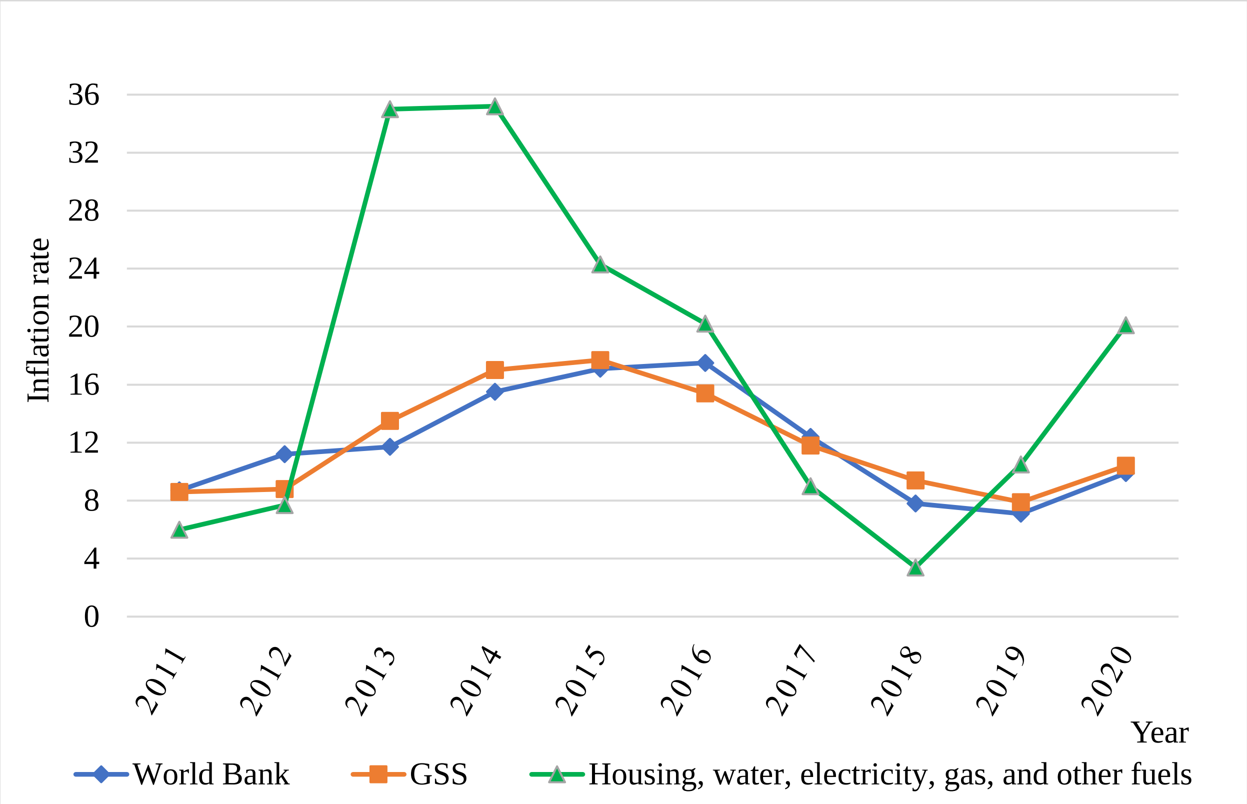

Fig. 2.4 Inflation rates in Ghana between 2011 and 2020
General inflation rates in Ghana between 2011 and 2020 from the World Bank (*in blue*) and the GSS (*in orange*). This figure also highlights the inflation rates for housing, water, electricity, gas, and other fuels from the GSS (*green*).
Sources: Ghana Statistical Services (2022); World Bank (2022)

The average inflation rate for the period from the Ghana Statistical Service was 12.05%, whereas that of the World Bank was 13.21%. To provide a more accurate analysis, this study used the average inflation rate for housing, water, electricity, gas, and other fuel subgroups estimated at 17.14% by the Ghana Statistical Service. Hence, the inflation rates for the general, energy, and water sectors were used based on the average inflation reported by the Ghana Statistical Service, estimated at 12.05% and 17.14%, respectively. It is argued that such uniformity is key in CBA studies, and international bodies may overlook domestic considerations in calculating average inflation rates (Miraj et al., 2021). The change in the cost (inflation rate) is expressed as a constant compound rate. Once inflation is determined, the change in cost can be calculated using Eqn. (2.15) (Dwaikat and Ali, 2018).

2.12.7 Building Life Span

Building life services plays a significant role in determining the study's time to be conducted and analysed. This refers to the time in which the overall building may satisfy a targeted performance level during the initial stage and design planning (Dwaikat and Ali, 2018). The assumption of a building lifespan can differ between publications and previous building studies. Overall, it is not easy to reach a consensus on the exact length of the lifecycle analysis because of factors such as geographical considerations and the design life of building components (Miraj et al., 2021). Based on the literature, building services range from 40 to 100 years, with an average building lifespan of 50 years (Islam et al., 2015). Consequently, an average lifespan of 50 years, consistent with international practices, was adopted for the Ghanaian case.

2.12.8 Cost Benefit Analysis

Research has shown that GB investments seem feasible or profitable from a life cycle perspective (Zhang et al., 2018). The economic impact of GB can be measured based on the building's physical cost or environment (Carter and Keeler, 2008). Physical impacts include construction and maintenance expenditures, energy-related benefits, water and stormwater management, and indoor air quality. Environmental issues include green spaces, urban heat islands, emission reduction, and occupant-related issues such as comfort and health (Miraj et al., 2021).

Similar to Miraj et al. (2021), CBA considers three major components: energy costs, water consumption, and carbon emissions. Furthermore, GB has demonstrated an increase in worker productivity through improved working environments, such as natural light and air, as well as reduced exposure to harmful compounds (CBPD, 2007). According to Gabay et al. (2014), research has shown that worker productivity increases from 2-20%. To be modest, this study adopted a 3% increase in worker productivity for GBs. Although other components may be relevant for the economic evaluation of GB, they cannot be used in this case study because of the lack of or insufficient data for the CBA.

Savings from GB features were compared to additional costs throughout the building life cycle to evaluate GB benefits. The energy savings were measured using the present value approach.

$$Present\ Value\ (US\$) = A \times \frac{(1+f)^n - 1}{(1+f)^n \times f} \quad (2.18)$$

where A is the annual cost savings (US$/year); f is the annual discount rate (%); n is the building lifespan (in years).

2.13 Economic Feasibility Assessment Model for Green Finance in Green Building

2.13.1 Project Profitability: Net Present Value and Internal Rate of Return

Various methods exist for evaluating the economic feasibility of investment projects. Among them, NPV is considered superior and leads to better results than other criteria, such as NPV/K (Taylor, 1988). Its features make it possible to consider the risks and calculate the value created by investing in GB. An NPV of more than zero implies a project of value and, therefore, justifies economic feasibility (Taghizadeh-Hesary et al., 2022). The NPV criterion is expressed as follows:

$$NPV = -I + \sum_{j=1}^{n} \frac{CF_j}{(1+k)^j} \quad (2.19)$$

CF_j denotes the cash flow in period j, while k represents the minimum attractiveness rate (the minimum that the investor wants to obtain in the GB project investment), I stands for investment. In Eqn. 2.19, cash flow (CF) shows the money value of the GB project, whereas a discount rate is employed to explore the value of the project. Therefore, the flow volume is determined by the project developer's view, including that of both the client and investor. Furthermore, the internal rate of return (IRR) was used to determine the profitability of the GB project investment based on Eqn. 2.20:

$$0 = \sum_{t-1}^{n}(C_t - C_0)(1 + IRR)^{-t} \quad (2.20)$$

where $C_t - C_0$ depicts net cash flow at t_{th} year.

2.13.2 Sensitivity Analysis

Sensitivity analysis was used to explore the major parameters that significantly impact costs under different scenarios. In this study, gradient sensitivity analysis (GSA) and Monte Carlo simulation using MATLAB 2023a software were used to prioritise the financing cost impacts on the NPV of the GB project discussed below.

The financing cost indicators employed in this study were based on the CBA results of the case study. Additional parameters are presented in Table 2.10.

Table 2.10 Financing costs of GB projects

Project parameters
Discount rate
Loan interest
Repayment period

Source: Adapted from Taghizadeh-Hesary et al. (2022)

The values for the cost indicators were obtained from interviews with project managers of the GB project under study, as described in the subsequent sections. The GF data were based on archival data analysis, as discussed later in this thesis. Fig. 2.5 provides a summary of the research process.

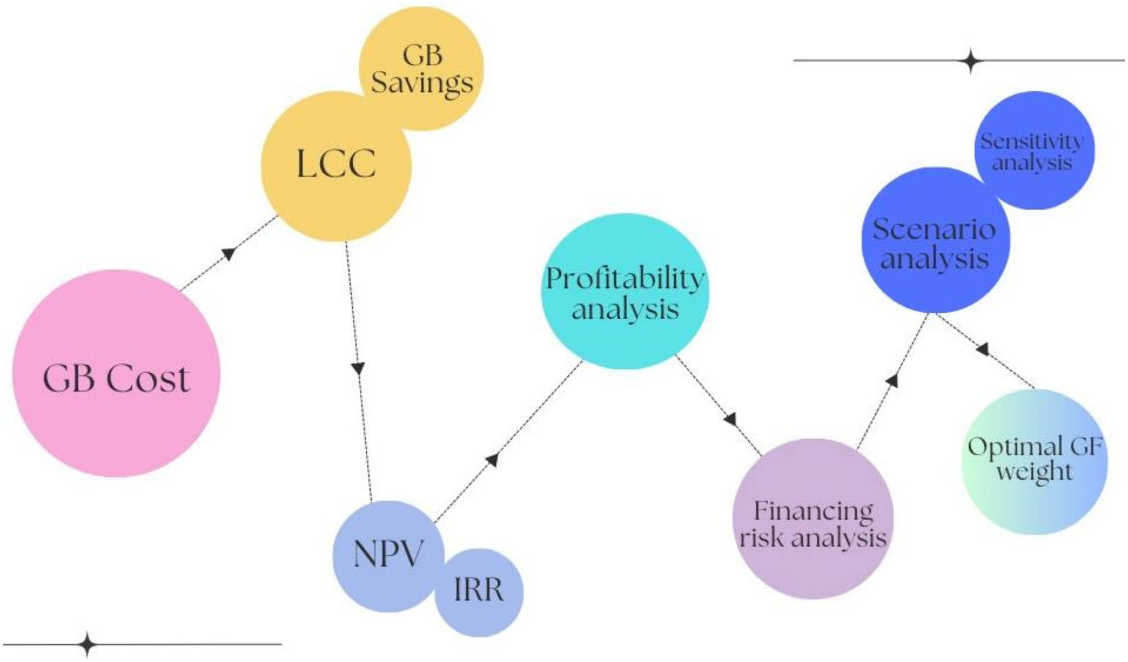

Fig. 2.5 Conceptual framework of the economic feasibility assessment of GF-in-GB
Source: Author's

2.13.3 Financing Risk Analysis

This section underscores the financing solutions aimed at reducing a project's financing risk. It employs scenario analysis based on the CBA and NPV assessment of the case study to determine the expected NPV of the GB project, considering various financing solutions. Scenario analysis, as defined by Tourki et al. (2013), refers to a set of possible future scenarios that describe the potential state of affairs within a specified time frame. It offers conjectures about future events (Cornish, 2004) and serves to heighten decision-makers' awareness, framing alternate future scenarios to address their existing decision-making requirements (Tourki et al., 2013). This analysis introduces different allocations of bank loans and green bonds and different shares of bank loans and green bonds (see Table 2.11) to incorporate GF into the GB project.

Table 2.11 Input-Output table for NPVs based on varying funding scenarios expressed in percentages

NPV	Share of Bank Loans	Share of Green Bonds
NPV0	100	0
NPV1	90	10
NPV2	80	20
NPV3	70	30
NPV4	60	40
NPV5	50	50
NPV6	40	60
NPV7	30	70
NPV8	20	80
NPV9	10	90
NPV10	0	100

The equation for the calculation of NPV is based on Eqn. 2.21:

$$NPV = \sum_{t=1}^{n} \frac{(C_t - C_0)}{(1+i)^t} \tag{2.21}$$

where t, i, c indicate the time of cash flow, discount rate and net cash flow, respectively. The financing risk (δ^2) can be included in Eqn. 2.21 as follows:

$$E(NPV) = \sum_{t=1}^{n} \frac{(C_t - C_0)}{(1+i)^t + \delta^2} \tag{2.22}$$

Calculating the $E(NPV)$, considering the financing risks at different interest rates, represents a new version of the NPV considering financing risks. Now, based on Eqn. 2.21, the $E(NPV)$ is considered, which explains the expected NPV of a GB project based on different financing risks. More information on the GF archival data used for the $E(NPV)$ is discussed in Chapter 3.

It is a fact that investors always try to optimise their financing portfolio (Taghizadeh-Hesary et al., 2022). For the GB projects, the utility of the investors U can be written as Eqn. 2.23:

$$U = r - \beta\delta^2 \tag{2.23}$$

Where U is the utility function of investors, r denotes the IRR of the project depending on the different financing risks (δ^2) depending on different financing schemes. Thus, δ^2 being the variance of the return indicates risk; β is a coefficient of risk aversion. Utility function measures investor's preferences for wealth as well as the amount of risk they are willing to undertake in order to attain greater wealth. According to Zahirović and Okičić (2016), expected return determines the risk premium, representing the compensation investors require for taking on the additional risk. As the risk premium increases, so does the risk aversion. Risk premium must remain positive because it rewards investors for taking the risk. More details on the utility function are provided by Zahirović and Okičić (2016) and Taghizadeh-Hesary et al. (2022).

Defining r_L and r_B as IRR in the case of 100% bank loan financing and 100% financing by green bonds, respectively we can write Eqns. 2.24-2.26 as:

$$r = \alpha r_L + (1 - \alpha) * r_B \tag{2.24}$$

$$\delta^2 = \alpha^2 * \delta_L^2 + (1 - \alpha^2) * \delta_B^2 + 2\alpha * (1 - \alpha) * \delta_{L*B} \tag{2.25}$$

$$U = \alpha r_L + (1 - \alpha) * r_B - \beta\{\alpha^2 * \delta_L^2 + (1 - \alpha)^2 * \delta_B^2 + 2\alpha * (1 - \alpha) * \delta_{L*B}\} \tag{2.26}$$

where U and δ^2 show the utility of the investors and the project's financing risk, respectively. δ_L^2 represents the variance of returns from bank loans, indicating the risk associated with this investment; δ_B^2 represents green bond's financing risk; U is utility of the investment portfolio; α is the proportion of the total investment allocated to bank loans; r_L is the expected return from bank loans; r_B denotes expected return from green bonds; β is the risk aversion coefficient, indicating how much the investor dislikes risk; δ_{L*B} refers to the covariance between the returns on bank loans and green bonds. This accounts for how the returns of the two investment types move in relation to each other.

To solve the agent's utility maximisation problem, the first-order condition to α (share of financing from bank loans) was applied. Then, the optimal weight is derived using Eqn. 2.27:

$$\frac{\delta U}{\delta \alpha} = r_L - r_B - 2\beta * \alpha * \delta_L^2 - 2\beta * (1 - \alpha) * \delta_B^2 + \beta(2 - 4\alpha) * \delta_{L*B} = 0 \tag{2.27}$$

Consequently, the optimal weight of bank loans can be calculated as Eqn. 2.28:

$$\alpha^* = \frac{\frac{1}{\beta}(r_L - r_B) + 2\delta_{L.B} - 2\delta_B^2}{2\delta_L^2 - 2\delta_B^2 + 4\delta_{L.B}} \quad (2.28)$$

2.14 Chapter Summary

Chapter 2 explains the research methodology adopted in this study. This was necessary to justify the various methods and approaches implemented in this study. This consisted of a literature review process, data collection methods, and data analysis methods to be utilised in this study. The comprehensive systematic literature adopted for this study served as the basis for the development of a linguistic evaluation questionnaire surveys for the FDM and FDEMATEL methodologies. Additionally, the scope of the study was defined as GF-in-GB in the developing context (Ghana). A case study of a selected certified GB office in Ghana to assess the economic feasibility of GF-in-GB is presented in this chapter. The next chapter focuses on a literature review and identifies research gaps.

CHAPTER 3 - LITERATURE REVIEW, THEORIES AND CONCEPTUAL FRAMEWORK[4]

3.1 Introduction

The methodology used in this study has been discussed in the previous chapter. This chapter presents a literature review, underpinning theories and proposed conceptual frameworks. The key operational definitions and concepts used throughout the thesis are explained, followed by a brief description of the case study for cost analysis. Subsequently, the theories underlying this research are reviewed. Following were systematic reviews of the objectives of the study: drivers, barriers, risk factors, and promotional strategies of GF-in-GB, leading to the development of several conceptual frameworks. Moreover, case studies of the CBA of GBs and GF were reviewed to provide a basis for developing a CBA framework for GF-in-GB. Finally, it concludes with a summary of this chapter.

[4] This chapter is largely based upon:

Debrah, C., Chan, A.P.C., Darko, A., Ries R.J., Ohene, E. and Tetteh, M.O. (2024) Driving factors for the adoption of green finance in green building for sustainable development in developing countries: The case of Ghana. *Sustainable Development*. (Q1)

Debrah, C., Chan, A. P. C., and Darko, A. (2022a). Green finance gap in green buildings: A scoping review and future research needs. *Building and Environment*, *207*, 108443. (Q1)

Debrah, C., Chan, A. P. C., and Darko, A. (2022b). Artificial intelligence in green building. *Automation in Construction*, 137, 104192. (Q1) – **Highly Cited Paper**

Debrah, C., Darko, A., and Chan, A. P. C. (2022c). A bibliometric-qualitative literature review of green finance gap and future research directions. *Climate and Development*, 0(0), 1–24. (Q1)

Debrah, C., Darko, A., Chan, A. P. C., Owusu-Manu, D. G., and Edwards, D. J. (2022d). Green finance in green building needs under the Paris Agreement. *IOP Conference Series: Earth and Environmental Science*, 1085(1), 012033.

Debrah, C., Chan, A.P.C., Darko, A. Owusu-Manu, D.-G., and Ohene, E. (**Accepted**). "Green finance: A tool for financing green building projects." *In Rethinking Pathways to Sustainable Built Environment*. (Eds) Goh, C.S and Chong, H-Y. Taylor and Francis.

3.2 Operational Definitions of Key Concepts

3.2.1 Definition of Green Building

Several definitions of GB have been proposed in the literature. GB is also known as sustainable or high-performance building (US Environmental Protection Agency, 2016). The World Green Building Council (WorldGBC, 2022a) defines GB as:

> "*a building that in its design, construction, or operation, reduces or eliminates negative impacts and can create positive impacts on our climate and natural environment. GBs preserve precious natural resources and improve our quality of life.*"

The US Environmental Protection Agency (2016) defines GB as:

> "*the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout the building's lifecycle. This practice expands and complements the classical building design concerns of economy, utility, durability and comfort.*"

The above definitions suggest that GB is an effective and efficient means of implementing sustainable development principles in buildings and construction, considering the triple bottom line of environmental, economic, and social sustainability throughout the building life cycle (Darko, 2019). GBs, therefore, result in a healthier, more resource-efficient, and environmentally friendly built environment throughout the lifecycle – design, construction, O&M, renovation and retrofits, and demolition or deconstruction (US Environmental Protection Agency, 2016). GBs promote sustainability in the buildings and construction sector in terms of climate action, human health and well-being, as well as resources and circularity (WorldGBC, 2022a). As a result, it has gained popularity and rising interest among governments, developers, climate activists, non-governmental organisations, investors, and the public. The next section describes the origins and current state of GBs.

3.2.1.1 History of Green Buildings

The dire need to tackle global sustainability challenges, particularly within the built environment, gave birth to the "green building movement" (US Environmental Protection Agency, 2016). The genesis of the GB concept could be traced to the term "Archology" proposed by *Paolo Soleri* in 1960. This term, proposed by the Italian-American Architect, combined ecology and architecture (Soleri, 1969). Later, in the "Design with Nature" book authored by *Ian Lennox McHarg* in 1969, the "*ecological building*" concept was introduced (Darko, 2019). The 1970s energy crisis popularized the GB concept. During this period, energy-saving approaches became imperative owing to the energy crisis. This led to the adoption of active and passive building design principles, including solar PVs and more efficient building envelopes (Kibert, 2004, 1994; US Environmental Protection Agency, 2016). Since then, GBs have gained increasing popularity and seen widespread growth. Today, what began as *archology* and evolved into *ecological buildings* is known as *green buildings*.

The increasing demand for GBs is also due to changing government policies and initiatives as well as the availability of GB technologies. In addition, several GB rating systems have been developed to assess the environmental impact and facilitate decarbonisation in buildings and construction. GB rating systems or tools, also known as certifications, are used to assess and recognise buildings that meet certain green requirements or standards (WorldGBC, 2022b). Development of such tools commenced in 1990 when the world's first, the UK Building Research Establishment Environmental Assessment Method (BREEAM), was established. The French High Quality Environmental Standard (HQE) and US LEED were introduced shortly after that in 2000. Over the past few years, many countries have introduced their own rating tools, which are usually voluntary rather than mandatory. Most rating tools are developed by

Green Building Councils in each region or country. The World Green Building (WorldGBC) coordinates the activities of over 70 Green Building Councils worldwide to promote sustainability. WorldGBC members collectively support governments and businesses to promote environmental, social, and economic impacts and performance in the built environment at global, regional, and national levels, making GB projects a truly global agenda (WorldGBC, 2022c).

Growing evidence favours GB in terms of improved quality of life, reduced material and resource use, energy and water savings, etc. This has enhanced the business case for developing GBs (Kubba, 2012). GBs have profoundly influenced and reshaped the construction industry in recent years through their sustainable practices. Today, GB is perhaps the most effective approach for achieving sustainability goals in buildings and construction, influencing the development of sustainable and resilient buildings, neighbourhoods, communities, and cities.

3.2.1.2 Green vs Conventional Buildings

Conventional – also known as traditional – buildings prioritise the triple bottom line of cost, schedule and quality as their primary indicators, often neglecting sustainability considerations. Conventional buildings consume considerable energy, produce considerable indoor and outdoor air pollution, and waste significant amounts of water and materials (Kubba, 2012). They are usually criticised for their considerable resource consumption, carbon emissions, and adverse environmental and social impact. Limited efforts have been made to minimise these negative effects on the environment and society. Conventional buildings are also known to be carbon-intensive (Kibert, 1994; McKim et al., 2000).

By contrast, GB projects are inherently sustainable. Common GB features include energy efficiency, efficient water use, renewable energy generation, stormwater management, superior indoor environmental quality, green transportation capacity, GB technologies and materials, efficient structural design, easy and efficient maintenance, site sustainability, effective waste management, and minimisation of waste and toxins (Kubba, 2012). GBs lower annual O&M costs, reduce energy use, reduce material waste, save natural resources, improve employee productivity, reduce carbon emissions, reduce air pollutants, improve occupant satisfaction, improve occupant well-being, and improve the overall quality of life (WorldGBC, 2018; Zhang et al., 2018).

3.2.2 Green Finance Definitions

Various definitions of GF exist, and it is important to note that GF is sometimes used interchangeably with terms such as climate finance and sustainable finance. However, some differences exist between them, as explained below.

Carbon finance "provides resources to a project which aims to reduce emissions of carbon dioxide and other GHGs." (Noh, 2019). It also includes trading and investment in "carbon emissions rights" and their derivatives, as well as financing low-carbon projects and related activities (Debrah et al., 2022c; Zhou and Li, 2019).

Climate finance is "financing that supports the transition to a climate resilient economy by enabling mitigation actions, especially the reduction of GHG emissions, and adaptation initiatives promoting the climate resilience of infrastructures as well as generally of social and economic assets" – (ICMA, 2020).

Green finance is broader than climate finance in that "it also addresses other environmental objectives such as natural resource conservation, biodiversity conservation, and pollution prevention and control" – (ICMA, 2020).

Social finance "is financing that supports actions mitigating or addressing a specific social issue and/or seeking to achieve positive social outcomes, especially but not exclusively for a target population(s). Social finance project categories include but are not limited to providing and/or promoting affordable basic infrastructure, access to essential services (such as health and healthcare), affordable housing, employment generation, including through the potential effect of SME financing and microfinance, food security, and socioeconomic advancement and empowerment" – (ICMA, 2020).

Sustainable finance "incorporates climate, green and social finance while also adding wider considerations concerning the longer-term economic sustainability of the organisations that are being funded, as well as the role and stability of the overall financial system in they operate." – (ICMA, 2020).

According to the UNEP (2016), GF is a term that is often used to encompass a broader scope than climate finance. While climate finance primarily deals with financial support for activities related to mitigating and adapting to climate change, the GF extends its focus to address other environmental objectives and risks. GF refers to "financial services provided for economic activities that are supportive of environment improvement, climate change mitigation, and more efficient resource utilisation" (EIB and GFC, 2017). GF emphasises the mobilisation of private investment and capital for eligible green projects such as renewable energy; energy efficiency; pollution prevention and control; environmentally sustainable management of living natural resources and land use; terrestrial and aquatic biodiversity; clean transportation; sustainable water and wastewater management; climate change mitigation; circular economy adapted products, production technologies, and processes and/or certified eco-efficient products; and GBs (EIB and GFC, 2017; ICMA, 2021). In addition to financing, it considers the operation and risk management of these projects (EIB and GFC, 2017). Unlike climate finance, which often involves public and public-leveraged financial flows, GF places greater emphasis on encouraging private sector participation and directing private funds towards eligible green projects, as outlined above (UNEP, 2018, 2016). GF extends beyond climate-related issues and addresses a wider range of environmental concerns. It seeks to promote the integration of environmental sustainability into various aspects of financial decision-making, including private sector investments and market-driven initiatives, rather than relying solely on public funding and interventions. GF covers a wide range of instruments, from private loans to insurance, and includes equity, derivatives, and fiscal and investment funds (Taghizadeh-Hesary et al., 2021). Other related finance terms include environmental finance, impact finance, responsible or ESG (environmental, social and governance) investing, socially responsible investment (SRI), climate bonds, green bonds, green loans, green credits, green banking, and sustainability bonds (see Debrah et al., 2022c; ICMA, 2020; Noh, 2019). The interaction between the key GF terms is illustrated in Fig. 3.1.

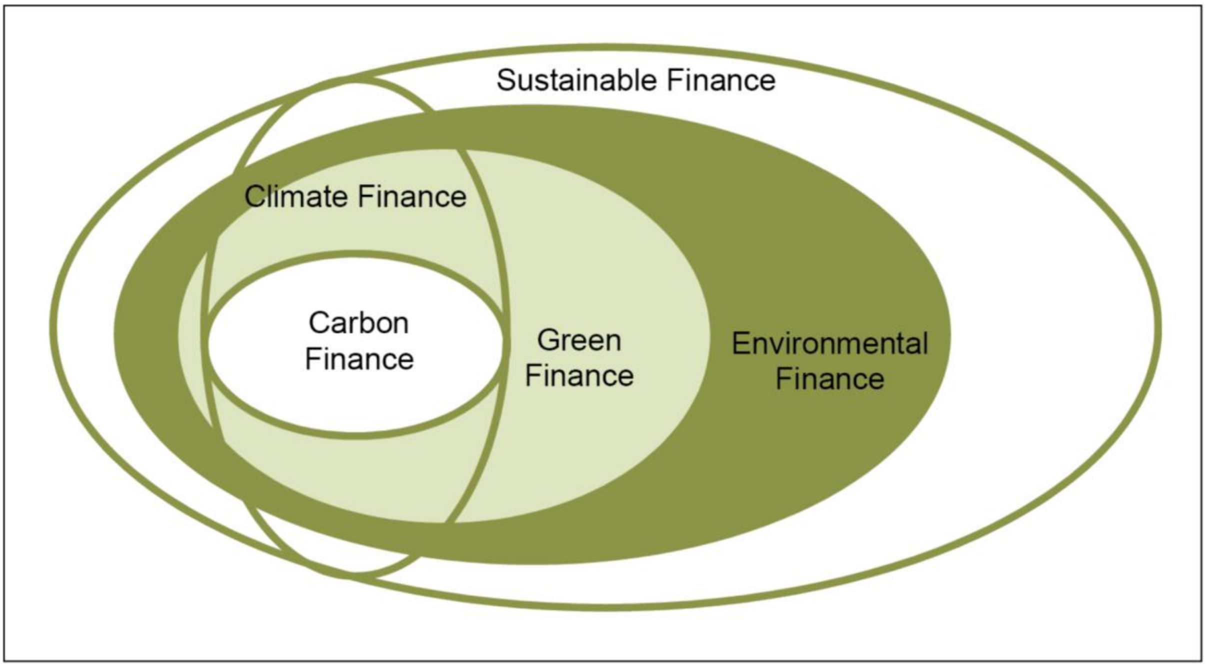

Fig. 3.1 Interaction between key related green finance definitions
Source: Noh (2019)

3.2.2.1 Green vs Conventional Finance

All types of projects, including those in the buildings and construction industry, require financial support to move forward (Merna and Njiru, 2002). Financial instruments are used to secure the necessary funding for these projects. Traditionally, there are three main forms of instruments, whether they are for short-term or long-term needs: debt, equity, and mezzanine financing. *A debt instrument* is a financial claim that requires payment of interest, principal, or both by the debtor to the creditor at a future date (Hakura, 2020). It involves borrowing money through methods such as term loans obtained from financial institutions, including commercial banks, merchant banks, investment banks, development agencies, pension funds, and insurance companies (Merna and Njiru, 2002). Debts have two types of interest rates: fixed and floating (Longstaff and Schwartz, 1995). In the hierarchy of financial claims in a project's cash flow, debt takes precedence over equity and mezzanine financing. *Equity* is a common investor ownership stake in projects. *Mezzanine finance*, positioned between the equity and debt markets, offers additional financing options (Merna and Njiru, 2002). Conventional or traditional finance usually provides short-term funding, focusing primarily on the returns and risks associated with the project (Sachs et al., 2019; Schoenmaker, 2017). Traditionally, sources of finance for construction projects include bank loans and government allocation (Zhang et al., 2021). Typically, the repayment period for construction loans aligns with the duration of projects, which can span three or more years for commercial construction projects (Ross et al., 2021). Self-financing, in which the project developer uses its own resources, is another common source of finance in the construction sector (Chiang and Cheng, 2010).

In contrast to conventional financing, GF is structured to yield better environmental outcomes. GF has evolved as a financing mechanism to support climate and sustainable development goals. As an alternative to traditional finance, which focuses on profit maximisation (Schoenmaker, 2017), GF extends the debate to include climate goals and environmental objectives (ICMA, 2020). It intends to increase the level of financial flow (from banking, micro-credit, insurance, and investment) from the public, private, and not-for-profit sectors to sustainable development priorities (UNEP, 2018). In summary, GF represents a comprehensive approach to financing projects that promote environmental sustainability, address climate change, and support green growth. With more than US$2 trillion in volume to date, green/climate bonds, green loans, and other long-term markets have traditionally been the domain of GF (CBI, 2022a). Other GF instruments are green investment funds, green insurance, green mortgages, green credit, and green securitisation, which are described subsequently in this chapter. Generally, GF facilitates the formulation and implementation of green projects by providing investment, financing, operating funds, and other financial services (Ji and Zhang, 2019). Comparatively, GF provides long-term financing for green projects that are considered riskier and, in some cases, have low returns (Sachs et al., 2019). In addition to the global bond/loan market, the estimated US$55 trillion global value of short-term debt markets provides a huge source of financing for GF expansion. These include green commercial paper, green revolving credit facilities, short-term bank loans for green projects, export letters of credit for green projects, green deposits, green structured notes, green repurchase agreements, green leases, green trade finance, green supply chain financing, stock/inventory financing, and green bank guarantees (CBI, 2022b). Arguably, there is enormous potential for GF in both short- and long-term markets.

3.3 Investment and Green Financing in Green Building

In this thesis, GF-in-GB refers to the following:

"*a financial instrument that supports green building and climate-resilient infrastructure development as a means of protecting the environment through emission reductions, reduced energy use, and reduced material use to create positive impacts on the climate*" – Author's.

The above GF-in-GB definition was adapted from the literature for the purposes of this study. Next, global investments and the evolution of GF-in-GB are discussed.

The global building sector investment in energy efficiency or GBs has increased to nearly US$237 billion by 2021 (UNEP, 2022). This reveals a growing interest in green financing for GBs. The GF-in-GB landscape encompasses a variety of financial products tailored to support environmentally friendly construction and sustainable building projects. These financial instruments include climate-certified bonds or green bonds linked to green or low-carbon buildings, green commercial building loans, green construction loans, green insurance, green mortgages, green credit, and green securitisation for GB (Gholipour et al., 2022; IFC, 2019; Noh, 2019). GF-in-GB has witnessed significant growth, becoming the second-largest use of proceeds in the GF market, following energy-efficient investments. By the end of 2021, it accounted for approximately US$449 billion, representing 28% of the total volume of US$1.6 trillion (CBI, 2022c). Table 3.1 presents the GF-in-GB trend (2014-2021). It reports the total annual issuance amount (in US$ billion) as well as the number of GF deals linked to GB on an annual basis.

Table 3.1 Green finance in green building

Year	Number of deals	Number of issuers	Amount issued (US$ billion)
2014	122	31	8.2
2015	132	37	9.7
2016	256	60	18
2017	1335	84	49
2018	1316	133	49
2019	1403	216	81
2020	1164	245	80
2021	1305	433	147
Total	7208	736	449

Source: CBI (2022b)

This growth trend is evident from the increasing number of issuers and deals in the sector since 2014, signifying a growing interest in green investments in GBs and construction projects. Fig. 3.2 shows a pictorial representation of the number of deals, issuers, and volume of GF-in-GB (2014-2021).

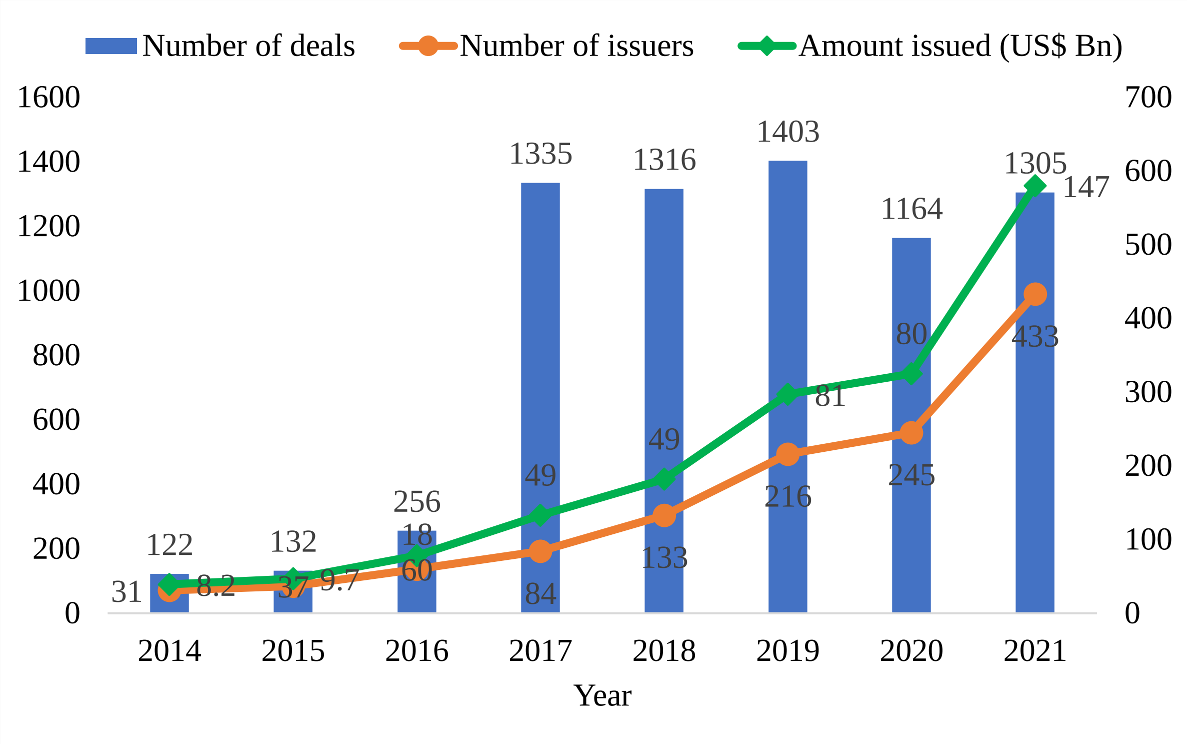

Fig. 3.2 Green bonds for GB (2014-2021).
Source: CBI (2022b)

Despite the fluctuations observed in Fig. 3.2, the long-term outlook for GF-in-GB is optimistic. It is anticipated that green bonds associated with low-emission or zero-carbon building projects will continue to represent a substantial portion (approximately 40%) of the overall green bond market. This indicates an enduring commitment to sustainable construction and the potential for further growth in this sector.

3.3.1 Green Finance in Green Building Products or Typologies

As noted above, several GF products or instruments are available to finance the transition to GB portfolios. The influence of GF products on GB projects has led to several universally accepted typologies of GF-in-GB (Akomea-Frimpong et al., 2022). A summary of GF-in-GB products and typologies is presented in Fig. 3.3.

Fig. 3.3 Typology of GF-in-GB
Source: Author’s

Table 3.2 provides a summary of the unique characteristics and arrangements of the various GF-in-GB products/typologies in terms of procedures, provisions, and guidance.

Table 3.2 Summary of the unique characteristics and special arrangements of GF-in-GB

GF products	Unique characteristics	Special arrangements: Procedures, provisions, and guidance	References
Green/climate bonds for GB	• Applied to finance or re-finance new/existing GB. • Bigger in volume • Higher transaction costs • Could be listed on an exchange or placed privately. • Lower interest rates	• Adherence to green bond frameworks: use of proceeds, process for project evaluation, management of proceeds and reporting • External reviews: consultant review (including second party opinions), verification, green certification, and rating by qualified third parties or rating agencies	ICMA (2021); IFC (2021); IFC (2019)
Green loans for GB	• Applied to finance or re-finance new/existing GB. • Smaller in volume • Higher transaction costs and lower interest rates • Usually placed privately.	• Adherence to international standards or eligibility criteria, e.g., green loan framework • External review • Application is similar to green/climate bonds for GB above	ICMA (2021); IFC (2021); Loan Market Association (2021)
Green mortgage	• Lower interest rates • Higher loan-value ratio • Lower down payments	• Applicable to green-certified buildings or existing buildings with proof of green retrofits • Independent green certification/assessment may be required	WorldGBC (2022); IFC (2019)
Green leases	• Landlord-tenant collaboration and agreement to implement green goals. • Landlord-tenant cost and profit sharing due to green features	• Tenants commit to or gain incentives by participating in building sustainable practices such as water/energy conservation, waste reduction, etc. • Specifies who is responsible for larger projects such as energy efficiency renovations and who benefits from the resulting savings. • Penalties for non-compliance may apply.	Green Building Alliance (2023); JLL (2021); The Institute for Market Transformation (2015)
GB insurance	• Identifies and reduces risk through GB certification. • Premium discounts for GB • Coverage for replacing/rebuilding after loss using GB technologies	• Green recertification costs following loss of or substantial damage to green property. • Extra expense coverage for GB features	Ochenkowski and Dennis (2008); IFC (2019)
Green securitisation for GB	• Financing GB through the issuance of asset-backed securities (ABS), which are backed by financial assets such as mortgages or lease receivables, i.e., securitisation. • Typically targeted at small-scale low-carbon and climate-resilient infrastructure. • Usually loans for small-to-medium GB firms and for energy efficiency upgrades • Sustainable securitisation • Liquidity in GF	• Loans and leases on existing assets, such as certified buildings, are issued, and new projects are financed. • These loans and leases are packaged together into different types of green ABS, such as green mortgage-backed securities. • Securities are then sold to investors, who are currently signalling high demand for green-labelled products. Investors can trade securities on the secondary market. • The proceeds and/or freed-up capital (depending on the type of deal), are used then to finance other green projects and assets. • Third-party verification or certification of GB assets is required	CBI (2018); Barmes (2019)
Green/carbon credits for GB	• Constraints investment to heavily polluting firms. • Incentives for environmental protection investments	• Earning green/carbon credits by meeting specific certification criteria in new GB or green retrofits of existing buildings, e.g., LEED, IFC EDGE, etc • Trading green credits on secondary markets for additional liquidity • Some green credit programs may provide bonus credits or incentives for buildings in areas of high pollution or social vulnerability	Hu et al. (2021); Woo et al. (2021); Debrah et al. (2022c)
GB investment funds	• Interest-free loans from the government • Government grants for green retrofits • Green subsidies	• Multi-stakeholder and publicly sponsored funds for financing residential, commercial, and public facilities to meet emissions reduction targets. • Exposure to diversified GB portfolio	Siew (2015); Akomea-Frimpong et al. (2022)

Source: Author's compilation

3.4 Theoretical Framework

It is common knowledge that finance and capital markets are *rationally driven by profit* opportunities to maximise shareholder *wealth*. Therefore, conventional finance is rooted in the "neoclassical economics theory" and the "efficient market hypothesis" (Fama, 1970; UNEP, 2015). Proponents of GF argue that conventional finance is unable to address the great sustainability challenges of our time, such as global poverty and the threat of climate change (Debrah et al., 2022c; UNEP, 2015). GF plays a crucial role in supporting low-carbon investments, resulting in reduced GHG emissions. It is essential to maintain an ecological balance between conventional financial practices and environmental preservation, which is paramount for addressing climate change impacts. However, scholars and industry professionals are still engaged in discussions and debates regarding the theoretical foundation of GF. A central question remains unresolved: whether GF is rooted in existing financial theories or relies on new principles (Debrah et al., 2022c; Zhang et al., 2019). GF theories continue to be a source of contention and deliberation among stakeholders.

Wuni (2022) agreed with Koskela and Howell (2002), who emphasised the importance of relying on well-established theories to guide and inform practice. This distinction separates a well-established profession from a craft. According to Johnson and Onwuegbuzie (2004), it is both possible and justifiable for multiple theories to be applicable to a single set of empirical data that addresses a specific research problem. This underscores the flexibility and complexity of applying theory in empirical research. Therefore, following a comprehensive literature review of evolving GF theories and aligning them with the focus of this study, two major theoretical categorisations have been selected to underpin this research: (1) stakeholder and institutional theories and (2) evolutionary and ecological economics theory. The selected theories are explained as follows.

3.4.1 Stakeholder and Institutional Theories

Stakeholder theory is a set of propositions that suggest that "managers of firms have obligations to some set of stakeholders" (Freeman, 2015). Stakeholders are groups or individuals that affect or are affected by an organisation. Generally, they include *primary stakeholders* (customers, financiers – stockholders and creditors –, suppliers, employees, and local communities) and *secondary stakeholders* (political groups, governments, media, competitors, consumer advocate groups, and special interest groups). The theory suggests that organisations must be managed in the interest of all stakeholders to maximise shareholder wealth (Freeman, 2015; UNEP, 2015). It highlights how business works at its best and how it could work (Freeman et al., 2010). According to Freeman et al. (2010), "most people, most of the time, want to, and do, accept responsibility for the effects of their actions on others."

Consequently, organisations are now more concerned about the negative impacts of their activities on the environment and society. More intentional efforts have been devised to address and/or correct such unintended implications by adopting a sustainability mindset in operations and activities. Hence, corporations are redefining, re-describing, and reinterpreting stakeholder interests to satisfy both or create more value for both primary and secondary stakeholders through sustainability principles. Schaltegger et al. (2019) describe this as "stakeholder business cases for sustainability". According to Schaltegger and Co., a stakeholder business case for sustainability aims to create value (not only economic) for a larger group of stakeholders by solving sustainability problems such as the GHG effect, housing affordability, land degradation, and so on. Therefore, companies in the GB sector, for example, contribute to the solution of a sustainability-related problem (climate change) and consequently create manifold benefits for their stakeholders. GF firms supporting GB firms act as agents to support climate change mitigation and adaptation actions in the buildings and construction industry. The benefits created include orders for their green suppliers, long- and short-term profits for investors, creating greener jobs, thereby reducing unemployment, reducing the negative impacts of buildings and construction on the environment and society, creating taxes for the state, and perhaps most obviously, providing an option for customers who are willing to pay for GBs. Ultimately, GB and GF firms solve environmental and social problems simultaneously. Additionally, employee awareness and management-level engagement in climate-change-related decision-making are associated with higher levels of GF engagement (Kawabata, 2019). This indicates the importance of stakeholder engagement in climate change-related issues and financing.

On the other hand, *institutional theory* considers how various groups and organisations better secure their positions and legitimacy by conforming to the rules (such as regulatory structures, governmental agencies, laws, courts, professions, scripts, and other societal and cultural practices that exert conformance and pressures) and norms of their institutional environment (DiMaggio and Powell, 1983; Scott, 2008). It is concerned with regulatory, social, and cultural influences that promote the survival and legitimacy of an organisation rather than solely on efficiency-seeking behaviour (Roy, 1999). *In this context, institutions refer* to the formal rule sets, ex-ante agreements, less formal shared interaction sequences, and taken-for-granted assumptions that organisations and individuals are expected to follow (Bruton et al., 2010). *Legitimacy* refers to the adoption of proper and acceptable sustainable practices as perceived by stakeholders (DiMaggio and Powell, 1983). Institutional theory has been used to explain how changes in social values, technological advancements, and regulations affect decisions regarding “green” sustainable activities (Ball and Craig, 2010). This theory describes three typologies of rules: regulative, normative, and cognitive. Also known as coercive drivers, *regulative rules* are formal rules that constrain behaviour and regulate interactions, such as governance and regulatory frameworks (Foxon, 2011; Glover et al., 2014). These are the influences exerted by those in powerful positions (Glover et al., 2014), in this case, within the

GF-in-GB sector. Hence, regulatory or coercive pressure is crucial for driving sustainability issues.

On the other hand, *normative rules* are the values, norms, and expectations by which behaviour is formulated and assessed, and they are often internalised through socialisation processes (Foxon, 2011). They ensure that organisations conform to be perceived as partaking in legitimate actions (Glover et al., 2014). *Cognitive rules* are the frames and concepts used to make sense of reality (Foxon, 2011). Behavioural economics uses cognitive ideas to highlight the limitations of human decision-making processes. In addition, institutional economics emphasises regulative and normative rules governing social interaction, providing the basis for the next theory, *coevolutionary economics theory*.

3.4.2 Coevolutionary Economics Theory

Evolution is the process of change over time, and all systems, including economic activities, undergo evolution (Common and Stagl, 2005). *Evolutionary theory* is a theory of forces. It focuses on the causes of change in the processes that produce a certain sequence of events and entities (Sober, 2014). Hayek (1945) argued that economic problems are recurrent and occur only in response to change. This implies that evolutionary theory is one way of studying economic problems, hence the evolutionary economics theory (Langlois and Everett, 1994). The *adaptive market hypothesis* is grounded in the evolutionary economics theory (Nelson and Winter, 1985). The adaptive markets hypothesis considers the structural and behavioural constraints on investments and long-term systems change as more suitable (Hall et al., 2017). This theory incorporates long-term and progressive changes in economic or "profit-seeking" decisions. Evolutionary economists argue that what happens within the economy within any period cannot be separated from but must be involved in an integral way: explicit recognition of the dynamic processes involved in ongoing innovation-driven economic change (Nelson et al., 2018). Thus, the importance and nature of innovation must be considered in economic development. The emerging literature suggests that the investment environment and investor behaviour evolve with time by considering the realities and problems of today, including climate change impacts and sustainable development (Lo, 2012).

On the other hand, *ecological economics* is the study of human economy as part of nature's economy (Common and Stagl, 2005). Ecological economics grounds economic thinking in the dual realities and constraints of biophysical and moral environments (Daly and Farley, 2011). Most ecological economists believe that natural and man-made capital are more often complements than substitutes and that natural capital should be maintained on its own because it has become the limiting factor (Daly, 2007). According to Lagoarde-Segot and Martínez (2021), ecological finance considers the complex interaction between the financial, socio-economic and the biophysical realms, and the impact of financial models in shaping reality. While conventional economics sees just the economy, ecological economics, in contrast, envisions the macroeconomy as part of a larger enveloping and sustaining the *whole*. Whole here refers to the earth, its atmosphere, and its ecosystems (Common and Stagl, 2005). Conventional (or neoclassical) finance pursues efficiency, shareholder value, exponential growth, and perfect market prices. By contrast, ecological finance seeks resilience, diversity, self-thinning, organic growth, and transparency. Ecological economics embeds financial systems with social and ecological constraints to ensure social resilience (Lagoarde-Segot and Martínez, 2021).

In light of evolutionary economics and ecological economics, a *coevolutionary framework* that combines the two theories has emerged (Foxon, 2011). Coevolution refers to the fact that the niche for any population is affected by evolutionary changes that involve other populations (Common and Stagl, 2005). A coevolutionary, socio-technical systems approach offers a broad, institutionally focused understanding of how innovations, such as GB, proliferate through complex physical and social systems (Foxon, 2011). Due to the changing climate and its impacts, it is believed that the coevolution theory best explains the concept and promotion of GB and GF today.

3.5 GF-in-GB for Global Sustainable Development and Climate Goals

3.5.1 GF-in-GB vs Sustainable Development Goals

Sustainable development is defined as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*." (Brundtland, 1987) The above definition, which became known as "*Our Common Future*", was adopted in 1987 in the Brundtland Report of the World Commission on Environment and Development of the United Nations (UN). Since then, the negative implications of global development amid scarce resources have been of immense concern. In this light, the UN adopted 17 Sustainable Development Goals (SDGs) in 2015. The 17 SDGs comprise 169 targets and 7632 actions categorised under three dimensions: economic, social and environment (UN, 2023). SDGs are intended to promote human well-being and protect the environment. The 2030 UN SDGs Agenda has been accepted, and it is applicable to all its 193 member states. These common objectives of the SDGs cover five areas (also known as the five Ps): People, Planet, Prosperity, Peace, and Partnership. The SDGs are critical for achieving a sustainable built environment.

A critical look at the SDGs reveals that 12 (out of the 17) SDGs will be achieved when green buildings and construction are promoted. These include no poverty (SDG #1), good health and well-being (#3), clean water and sanitation (#6), affordable and clean energy (#7), decent work and economic growth (#8), innovation and infrastructure (#9), reduced inequalities (#10), sustainable cities and communities (#11), responsible consumption and production (#12), climate action (#13), life on land (#15), and partnerships for the goals (#17). The literature explains the impact of GB towards achieving the above SDGs. In contributing to achieving the UN SDG-1 of ending poverty in all forms everywhere, GBs reduce energy and water usage and costs, thereby increasing household savings and wealth. Moreover, GBs align with SDG-3 by reducing carbon emissions and air pollutants, thereby promoting indoor environmental quality and leading to improved health and well-being, occupant satisfaction, and overall quality of life (Ries et al., 2006). To achieve SDG-6, GBs promote clean and reduced water and reduce material waste through circular economy practices (Antwi-Afari et al., 2021). To achieve SDG-7 and, take advantage of abundant solar energy and reduce over-reliance on fossil fuels, GBs primarily incorporate renewable energy through solar PVs, thereby promoting net-zero buildings (Ohene et al., 2022). Through GB development, many green jobs have been created globally (SDG-8). Climate mitigation and adaptation actions and innovations in the built environment (SDG-13) ensure that buildings and infrastructure are resilient to the impact of climate change (SDG-9). As noted above, circular economy practices in buildings and construction promote responsible consumption of scarce resources and cleaner production (SDG-12). Altogether, GBs make cities and human settlements inclusive, resilient, and sustainable (SDG-11) and are critical to combating climate change and its impact (SDG-13) (Debrah et al., 2021; Debrah et al., 2022e; Debrah and Owusu-Manu, 2021). Finally, GBs development considers the negative impact of construction activities on the environment by reducing biodiversity loss through practices such as green roof construction and landscaping to protect life on land (SDG-15). All the above SDGs are achievable through international, regional, local, private, and public partnerships for global sustainable development (SDG-17).

GF is a vital tool for sustainable development. Wang et al. (2022) demonstrated that GF produces positive impacts on achieving the SDGs. It is critical to achieve the environmental dimension of the SDGs by increasing investments in clean and green technologies, financing sustainable natural resource-based green economies or materials, and increasing the use of green bonds, green loans, and green insurance, among others (UNEP, 2018). Previous studies have shown that GF instruments, such as green bonds, produce positive environmental externalities and are utilised in environmental projects (Maltais and Nykvist, 2020; Reboredo, 2018). It has been argued that with increasing awareness and interest, green bond investments and green loans will come at a lower price or greenium (Agliardi and Agliardi, 2019, 2021). Overall, sustainability-themed investments are becoming prominent with rising awareness of challenges such as climate change, energy, and water security (Volz, 2018). Consequently, more GF will become available for financing SDGs, particularly towards a more sustainable built environment in the future. Furthermore, GF-in-GB plays a crucial role in realising the Paris Agreement Goals. A more detailed discussion is provided in the next section.

3.5.2 GF-in-GB vs Paris Agreement Accord

GB is a key mitigation and adaptation measure in the Paris Agreement (Debrah et al., 2022d). The *Paris Agreement* is a "legally binding international treaty on climate change." It was adopted by 196 Parties at the UN Change Conference (COP21) in Paris (France) on 12 December 2015. It entered into force on 4 November 2016. Its primary goal is to *limit the increase in the global average temperature below 2ºC above pre-industrial levels* and pursue efforts "*to limit the temperature increase to 1.5ºC above pre-industrial levels*" (UNFCCC, 2015). Mitigation and adaptation actions must work together to reach the targets set in the Paris Agreement for a sustainable low-carbon future.

The Paris Agreement reaffirms that developed countries should take the lead in providing financial assistance to countries that are less endowed and vulnerable while encouraging voluntary contributions by other parties (UNFCCC, 2015). The OECD estimates that €6.35 trillion is required annually to meet the Paris Agreement goals by 2030. The financial system can contribute to addressing these needs through climate finance, GF, and sustainable finance

(Spinaci, 2021). To significantly reduce emissions, increasing green investments in the form of climate finance is needed. Similarly, significant amounts of climate finance are needed to adapt to the adverse effects and reduce the impact of climate change (UNFCCC, 2015). One of the primary instruments for achieving the Paris Agreement goals is the Nationally Determined Contributions (NDCs). These NDCs are essentially climate pledges that individual countries make under the agreement. They are self-defined, outlining each country's plans and strategies for addressing climate change in the short to medium terms. More importantly, NDCs are subject to regular updates every five years with the aim of developing more ambitious commitments. Aside from climate commitments and strategies, NDCs highlight the financial support required for these activities, with an emphasis on climate and GF as vital tools for achieving these objectives (UNDP, 2023). For example, it is estimated that over US$474 billion is required to support the mitigation and adaptation needs of developing countries by 2030 (Zhang and Pan, 2016). In support of this, developed countries have committed to providing annual financial assistance of US$100 billion to developing countries. This funding is intended to support a wide range of climate change mitigation and adaptation initiatives and help developing countries address the challenges posed by climate change impacts and the transition to sustainable and resilient practices (UNFCCC, 2009).

In this section, specific NDCs related to the buildings and construction industry are reviewed and discussed. According to UNEP (2022), approximately 80% of countries now refer to buildings as part of their NDC action plans. This is because more governments recognise the role of buildings in their decarbonisation actions (Debrah et al., 2022a). Therefore, building codes are vital for addressing buildings sector emissions and providing clear guidelines for their features. As of 2022, 40% of the countries have mandatory or voluntary regulations or codes for building energy performance. In addition, GB certification offers a way to adopt and recognise higher standards of building energy performance and broader metrics of building sustainability (UNEP, 2022). Moreover, a comprehensive meta-synthesis conducted by Debrah et al. (2022d) revealed that only 20 countries offer well-defined estimates for climate-related projects within the buildings and construction industry. Adaptation and mitigation actions within the buildings and construction sector are estimated at US$42 billion by 2030. More than 80% of these are attributed to developed countries.

Interestingly, in many developing countries, the success of adaptation and mitigation initiatives hinges significantly on securing international climate (green) finance. Although some domestic funding sources are acknowledged, the predominant emphasis in these countries lies in the necessity of fiscal policy reforms, whether on a national or international scale. These reforms are essential for mobilising the financial resources needed to propel climate action within the countries (Debrah et al., 2022d). Hence, the NDCs and Paris Agreement provide mechanisms to track and measure individual countries' commitments to emissions reduction within the buildings and construction industry. The next section reviews the opportunities and challenges associated with GF-in-GB due to the COVID-19 pandemic.

3.5.3 GF-in-GB vs COVID-19

The COVID-19 pandemic has resulted in unprecedented global changes, particularly in the buildings and construction sectors. This included a major drop in demand for construction across major economies, workplace shutdowns due to lockdown, labour and material shortages, changing work patterns, and energy affordability challenges, all of which persist today (UNEP, 2022). More people spent their time indoors because of the pandemic, resulting in work-from-home orders. Even before the COVID-19 pandemic, people spent about 90% of their time indoors (Awada et al., 2021). Hence, the quest to develop more GBs that promote occupant comfort and indoor environmental quality. Compromised GBs, in terms of poor indoor environmental quality, can increase the health risk of buildings, particularly during extreme events such as a global pandemic.

Consequently, unhealthy buildings result in increased sick leave (absenteeism) among employees and reduced productivity while working (presenteeism) owing to health conditions and major financial losses for companies (Awada et al., 2021; McArthur and Powell, 2020). For instance, in the US alone, sick building syndrome in commercial workplaces costs the country approximately US$10 – US$70 billion annually (Awada et al., 2021). Similarly, building-related illness accounts for productivity losses ranging from US$20 – US$70 billion in the US alone (Mendell et al., 2002). Therefore, it is important to safeguard occupants by reducing the health risks in buildings. However, the construction sector remains essential for the economic recovery from the COVID-19 pandemic. It offers a pathway for building a more sustainable future aligned with the Paris Agreement Goals (UNEP, 2022).

With financial markets not immune to instabilities due to market stress and periods of uncertainty, such as the COVID-19 pandemic (Baruník and Křehlík, 2018), it is important to understand the risks and opportunities available for GF-in-GB during global pandemics. A substantial body of literature has examined how the pandemic triggered a worldwide economic and financial crisis, particularly in 2020, which negatively impacted GF (Pisani and Russo, 2021; Yi et al., 2021; Zeidan, 2020). However, the COVID-19 pandemic has presented a pressing need for coordinated action to finance a more sustainable economy at the global level (Spinaci, 2021). It has been suggested that construction, for instance, has great potential to stimulate economic growth and recovery through increased employment and support the sector's transformation to sustainability (ILO, 2021; Robinson et al., 2021). For instance, many countries have invested in supporting the buildings and construction industry through economic stimulus packages and policies, and as a reaction to the global pandemic. These stimulus packages were directed towards decarbonisation initiatives within the sector to align economic investments with the Paris Agreement (UNEP, 2022). In addition, emerging evidence shows that GF provides a 'safe-haven' against financial shocks, making it important for portfolio management and risk diversification. Therefore, it serves as an incentive for both pro-environmental investors and those that consider only profitability to manage risk because of the hedging and diversification benefits of GF (Debrah et al., 2022c; Pham, 2021; Tu et al., 2021). The next few sections review and summarise the existing literature on the specific objectives of the study: drivers, barriers, risk factors, and strategies of GF-in-GB.

3.6 Drivers for Green Finance in Green Building

Although there are many motivating factors for GF implementation, a *comprehensive taxonomy* of these variables is lacking in the literature, especially for GBs. Although GF adoption is driven by several factors, a systematic literature review is lacking. This section presents a systematic review of both academic and practitioner-based empirical studies on GF drivers. Following the PRISMA-ScR (Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews) methodology, a systematic search was conducted across the four databases of Scopus, Web of Science, Google Scholar, and normal Google. Using the keywords outlined in Table 2.2, a total of 55 studies were retrieved. After a comprehensive review, 16 drivers were identified from 28 documents and classified into four major categories: regulatory, financial, organisational, and environmental and social drivers, as listed in Table 3.3.

Table 3.3 List of potential drivers of GF-in-GB

Category	Criteria (Drivers)		Description	References
Regulatory drivers	DC1	Government participation and support for GF	Credit enhancement available from multilaterals or government-related entities; government-issued bonds	[1-2]
	DC2	Regulatory incentives for GF	Tax incentives, subsidies, exemptions, price support	[3-4]
	DC3	Mandatory legislation, standards and climate-relative financial disclosures	Using or developing mandatory green standards and legislation (e.g., the EU Task Force Climate-related Financial Disclosures (TCFD)	[2,5]
Financial drivers	DC4	Favourable macroeconomic conditions and investment returns	Sound financial system conducive to low interest rates; better financial returns or incentives	[2,5-10]
	DC5	Improved access to and lower cost of capital	Broadened investor base or attracting more investors	[7,9,11-12]
	DC6	Reduced business and financial risk	Reduces overall portfolio risk	[13-14]
	DC7	Reasonable maturity/investment period	Long-term investment opportunity/maturity period	[1,9,15]
	DC8	Preferential capital requirements for low-carbon assets	Penalising capital requirements for high-carbon assets (e.g., carbon pricing, higher prices for unsustainable energy forms and non-GB)	[2]
Organisational drivers	DC9	Improve corporate branding or reputation	Protection of investors' reputation; preventing damage to or improve corporate reputation	[1,13-14]
	DC10	Institutional/peer pressure	External pressure from peers and large (and presumably powerful) institutions or early adopters; pressure from stakeholders or consumers	[16-17]
	DC11	Management commitment	Support and commitment by internal stakeholders or senior management	[18-19]
	DC12	Positive fundamentals or green credentials of issuer/developer	Satisfactory credentials or green labels and their impact at issuance and post-issuance; external reviews; impact reporting	[2,8,20-22]
Environmental and social drivers	DC13	Ecological and corporate social responsibility	Conservation of resources; promoting social good beyond the firm's benefits and not mandated by law	[5,18]
	DC14	Climate commitment	Climate commitments such as the SDGs and Paris Agreement	
	DC15	Promotion of responsible and ethical investment	Climate commitments such as the SDGs and Paris Agreement	[10,23]
			Incorporating environmental, social and governance (ESG) factors when making investment decisions rather than purely relying on financial considerations	[5,24-27]
	DC16	Increased awareness of GF models in GB	Awareness creation of/media influence on GF-in-GB	[9,24-25,28]

[1] = Akomea-Frimpong et al. (2022); [2] = Sangiorgi and Schopohl (2021); [3] = Murovec et al. (2012); [4] = Ragosa and Warren (2019); [5] = Agyekum et al. (2021); [6] = Agliardi and Agliardi (2021); [7] = Keeley and Matsumoto (2018); [8] = Mielke (2019); [9] = Prajapati et al. (2021); [10] = Tolliver et al. (2020); [11] = Eyraud et al. (2013); [12] = Falsen and Johansson (2015); [13] = Krueger et al. (2020); [14] = Maltais and Nykvist (2020); [15] = Eccles et al. (2017); [16] = Contreras et al. (2019); [17] = Ming et al. (2015); [18] = Abdullah and Keshminder (2020); [19] = Kawabata (2019); [20] = Barua and Chiesa (2019); [21] = Chiesa and Barua (2019); [22] = Hyun et al. (2020); [23] = Tolliver et al. (2019); [24] = Gutsche et al. (2020); [25] = Gutsche and Ziegler (2019); [26] = Singh et al. (2020); [27] = Zerbib (2019); [28] = Bae et al. (2021)

Fig. 3.4 provides the conceptual structure of the principal drivers of GF-in-GB.

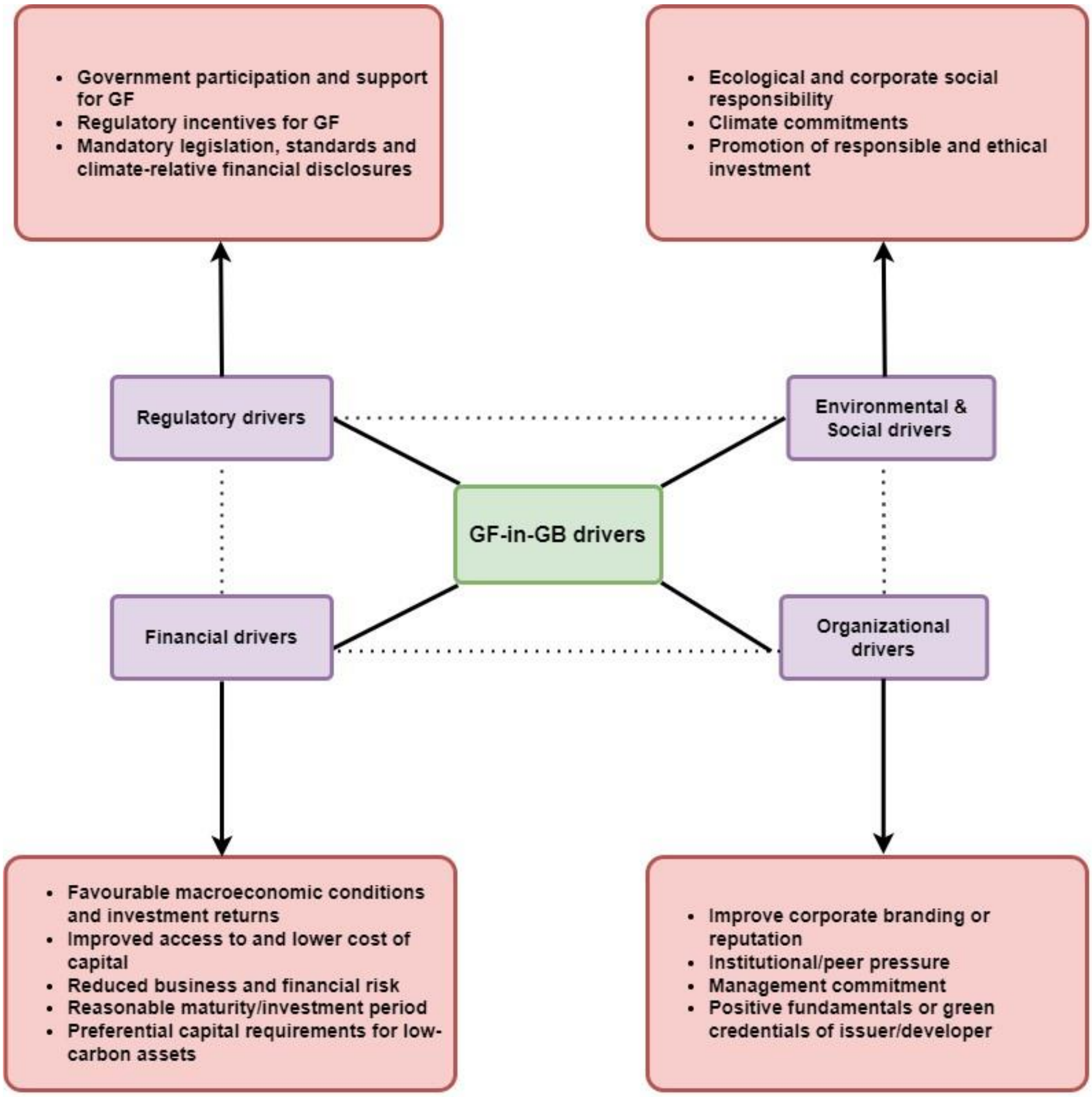

Fig. 3.4 Conceptual structure of the principal drivers of GF-in-GB
Source: Author's

Based on an extended classification in the literature, the identified drivers were grouped into four categories: regulatory drivers, financial drivers, organisational drivers, and environmental and social drivers. Fig. 3.4 displays the categories of GF drivers, which are discussed below. These categories are defined based on common groups of drivers (Rakhshan et al., 2020). For instance, favourable investment returns and 'better access to capital' are grouped under the "financial drivers" category in Fig. 3.4. This is because higher returns on investments can stimulate easy access to finance. A further discussion of the proposed GF-in-GB driver categories is provided below.

3.6.1 Regulatory Drivers

This category focuses on the influence of institutional arrangements, regulations, and government policies on GF growth. Three drivers were included: government participation and support for GF; regulatory incentives for GF; and mandatory legislation, standards, and climate-related financial disclosures. Regulatory incentive policies, such as tax incentives, subsidies, exemptions, and price support, are strong drivers of GF (Murovec et al., 2012; Ragosa and Warren, 2019). These regulatory requirements have been informed by climate commitments such as the Paris Agreement and the UN-SDGs, which are also unique drivers of GF (Tolliver et al., 2020, 2019). To meet these climate goals, several governments have introduced penalising capital requirements for high-carbon assets and preferential capital treatment for low-carbon assets (Sangiorgi and Schopohl, 2021). Mandatory climate-relative financial disclosures, bonds included in indices, GF certification, and international credit ratings that integrate environmental risk analysis are known GF drivers (Sangiorgi and Schopohl, 2021). Additionally, the new markets created by GF (Maltais and Nykvist, 2020), together with the availability of full/partial investment guarantees (Sangiorgi and Schopohl, 2021), have been noted as GF drivers. These guarantees include partial/full credit guarantees, debt repayments to investors, and insurance equity to investors.

3.6.2 Economic/Financial Drivers

The reviewed studies show that financial motives largely influence GF growth. Five economic drivers are shortlisted: favourable macroeconomic conditions and investment returns, improved access to and lower cost of capital, reduced business and financial risk, reasonable maturity/investment period, and preferential capital requirement for low-carbon assets. First, the macroeconomic drivers behind conventional capital market growth, such as stock market capitalisation (Tolliver et al., 2020), exchange rate stability and currency risk (Keeley and Matsumoto, 2018; Sangiorgi and Schopohl, 2021), liquidity/issue size (Barua and Chiesa, 2019; Sangiorgi and Schopohl, 2021), and credit rating constraints (Prajapati et al., 2021; Sangiorgi and Schopohl, 2021) drive GF growth. The literature shows that GF investors are motivated by higher returns on investments (Agyekum et al., 2021; Mielke, 2019). This is because climate considerations improve investment returns (Krueger et al., 2020; Maltais and Nykvist, 2020). For instance, research shows that GF has *a negative premium* or *greenium*, which is the yield difference between a conventional bond and a green bond with the same characteristics. This is regarded favourably by issuers because it can lower their funding costs, while investors will receive slightly lower yields than existing similar bonds (Agliardi and Agliardi, 2021). Other financial drivers, such as reduced business and financial risks (Krueger et al., 2020; Maltais and Nykvist, 2020), lower interest rates (Eyraud et al., 2013; Prajapati et al., 2021), and market competition (Christensen et al., 2021), also contribute to higher investment returns. This broadens the investor base (Maltais and Nykvist, 2020) by improving access to capital for GF (Falsen and Johansson, 2015; Keeley and Matsumoto, 2018). Lastly, the long-term investment or maturity of GF further drives growth. Therefore, GF helps foster a long-term investment mindset (Eccles et al., 2017).

3.6.3 Organisational Drivers

Organisations play a critical role in the global sustainability agenda. Darko and Chan (2017) stressed the importance of understanding the intrinsic organisational drivers that promote sustainability in business. Four drivers were identified under this category: improved corporate branding/reputation, institutional/peer pressure, management commitment, and positive fundamentals or green credentials of issuers/developers. These drivers are seen as internal organisational actions that promote GF initiatives. Research has shown that institutional/peer pressure (Contreras et al., 2019; Ming et al., 2015) is more effective in stimulating the implementation of GF initiatives (Hoppmann et al., 2018). Other factors, such as management commitment to GF (Abdullah and Keshminder, 2020; Kawabata, 2019), are critical for improving corporate branding and reputation (Krueger et al., 2020; Maltais and Nykvist, 2020). Moreover, issuer or sector constraints have driven organisations to finance green projects. The viability of green projects/assets (Russo et al., 2021; Sangiorgi and Schopohl, 2021) and positive fundamentals or green credentials of bond issuers (Barua and Chiesa, 2019; Chiesa and Barua, 2019) play key roles. Such assessments are usually obtained through external reviews (Hyun et al., 2020; Sangiorgi and Schopohl, 2021) or available impact reporting (Mielke, 2019; Sangiorgi and Schopohl, 2021). Hence, an organisation's past environmental investments (Murovec et al., 2012) are likely to drive future GF.

3.6.4 Environmental and Social Drivers

GF primarily promotes initiatives to protect the environment (Fleming, 2020). Non-pecuniary drivers, such as investors' pro-environmental preferences, have been identified as a major reason for GF growth (Gutsche et al., 2020; Zerbib, 2019). This is because investors are willing to sacrifice returns for environmental objectives (Gutsche and Ziegler, 2019). Four environmental and social drivers were identified: ecological and corporate social responsibility (CSR); climate commitment; promotion of responsible and ethical investment; and increased awareness of GF. Agyekum et al. (2021) note that investors perceive GF as a CSR activity. Investors recognise this as a sense of social responsibility "to do the right thing" (Abdullah and Keshminder, 2020), which is achieved through collectivism (Singh et al., 2020). Increased awareness of GF (Prajapati et al., 2021) significantly drives GF growth. Increased awareness of GF is facilitated by other drivers, such as social signalling, word-of-mouth learning (Gutsche et al., 2021; Gutsche and Ziegler, 2019) and media visibility (Bae et al., 2021).

3.6.5 Gaps in Knowledge

GF-in-GB development has witnessed some amount of growth due to several drivers identified in the literature that seem to propel the noticeable growth. Wang et al. (2021) claimed that green financial support is a major influencing factor in GB development. Several studies have identified the drivers of GF-in-GB (Kapoor et al., 2020; Tan, 2019; Wang et al., 2021). In addition, little attention has been paid to evaluating how these drivers interact with each other to promote GF-in-GB. This study fills this gap by evaluating the interactions between the critical drivers of GF-in-GB through FDM and FDEMATEL questionnaire surveys using Ghana as a case study.

3.7 Barriers to Green Finance in Green Building

A systematic literature review and meta-analysis (PRISMA) was conducted to identify barriers to GF. Using the keywords in Table 2.2, 27 relevant papers were retrieved from Scopus, Web of Science, and Google Scholar. Thorough screening revealed that 22 barriers were relevant to GF-in-GB. The identified barriers were grouped into five major categories: financial, regulatory, organisational, technical, and structural barriers, as listed in Table 3.4.

Table 3.4 Proposed barriers to GF-in-GB in Ghana

Barriers	Criteria	Description	Reference
Financial barriers (B1)	BC1 Split incentives	Expected returns of financial suppliers differ from the GB firms' or green investors' goals.	[1-5]
	BC2 Short termism	Maturity mismatch between short-term bank loans and long-term GB	[6-8]
	BC3 Limited GF supply	Inadequate financing schemes	[1,5,6]
	BC4 Capital adequacy & liquidity issues	High and rigorous collateral requirements of SMEs, limited assets and weak balance sheets, limited capital, and liquidity of SMEs	[5,6,9,10]
	BC5 Costly process	Higher transaction costs or additional fees associated with "green."	[2,4,5,11]
	BC6 Economic instability	Uncertain economic conditions; high-interest rates; high inflation rates; unstable currency or exchange rates	[1,12]
Regulatory barriers (B2)	BC7 Policy & regulatory uncertainty	Conflicting government policy signals/framework to promote green transition	[9,13]
	BC8 Political instability	Unstable political atmosphere exposing the financial system to vulnerabilities.	[14]
	BC9 Regulatory requirement	Lack of guidelines for green bond issuance	[6,10,15]
Organisational barriers (B3)	BC10 Greenwashing	Reputational risk due to misleading information on environmental performance of green firms	[2,13,16]
	BC11 Inadequate management support	Failure of top and middle management to embrace GF in operation activities, unsupportive organisation structure for green transition	[6,17,19]
	BC12 Inadequate private investment	Low involvement of the private sector in GF	[18-20]
Technical barriers (B4)	BC13 Limited knowledge & technical expertise	Lack of knowledge or expertise regarding the financial policies or tools towards green projects	[5-7,11]
	BC14 R&D challenges	Inadequate research and development on GF-in-GB	[21,22]
	BC15 Technological uncertainty	Technology-risk associated with uncertain GB technologies	[1,6,23]
Structural barriers (B5)	BC16 Limited green projects	Lack of identifiable GF/bankable green projects	[6]
	BC17 Lack of harmonised global standards & guidelines	Lack of standardised framework/guidelines or global standards to structure green projects.	[6,16]
	BC18 Risks perception	Risk factors such as climate-related risk, reputational risk, systemic risk	[1,6,23]
	BC19 Lack of universal definition for "green projects"	Lack of a clear definition of what is GF-in-GB.	[17,25]
	BC20 Inadequate transparency & consistency with GF	Absence of adequate accountability and transparency in assessing green projects, lack of reporting/disclosure regulations.	[6,25]
	BC21 Information asymmetry	Imperfect information where parties to a transaction have access to different levels of information.	[26,27]
	BC22 Lack of quality historical data	Problems of data accessibility, lack of clear and reliable data to inform decisions.	[1,26]

[1] = Agyekum et al. (2020); [2] = Deschryver and De Mariz (2020); [3] = Shishlov et al. (2016); [4] = Yamahaki et al. (2020); [5] = Zhang et al. (2020b); [6] = FSD Africa (2021); [7] = Hafner et al. (2020); [8] = Zheng et al. (2021); [9] = Nelson and Pierpont (2013); [10] = Setyowati (2020b); [11] = Donastorg et al. (2021); [12] = Owusu-Manu et al. (2020); [13] = Berensmann and Lindenberg (2016); [14] = Wyman (2015); [15] = Setyowati (2020a); [16] = Taghizadeh-Hesary et al. (2022); [17] = Akomea-Frimpong et al. (2022); [18] = Clark et al. (2018); [19] = Dmuchowski et al. (2021); [20] = Kann (2009); [21] = Chen (2018); [22] = Toxopeus and Polzin (2021); [23] = Bank of England (2018); [24] = Paranque and Revelli (2019); [25] = Febi et al. (2018); [26] = Cheung et al. (2022); [27] = Schuetze (2020)

Fig. 3.5 provides the conceptual structure of the principal barriers to GF-in-GB.

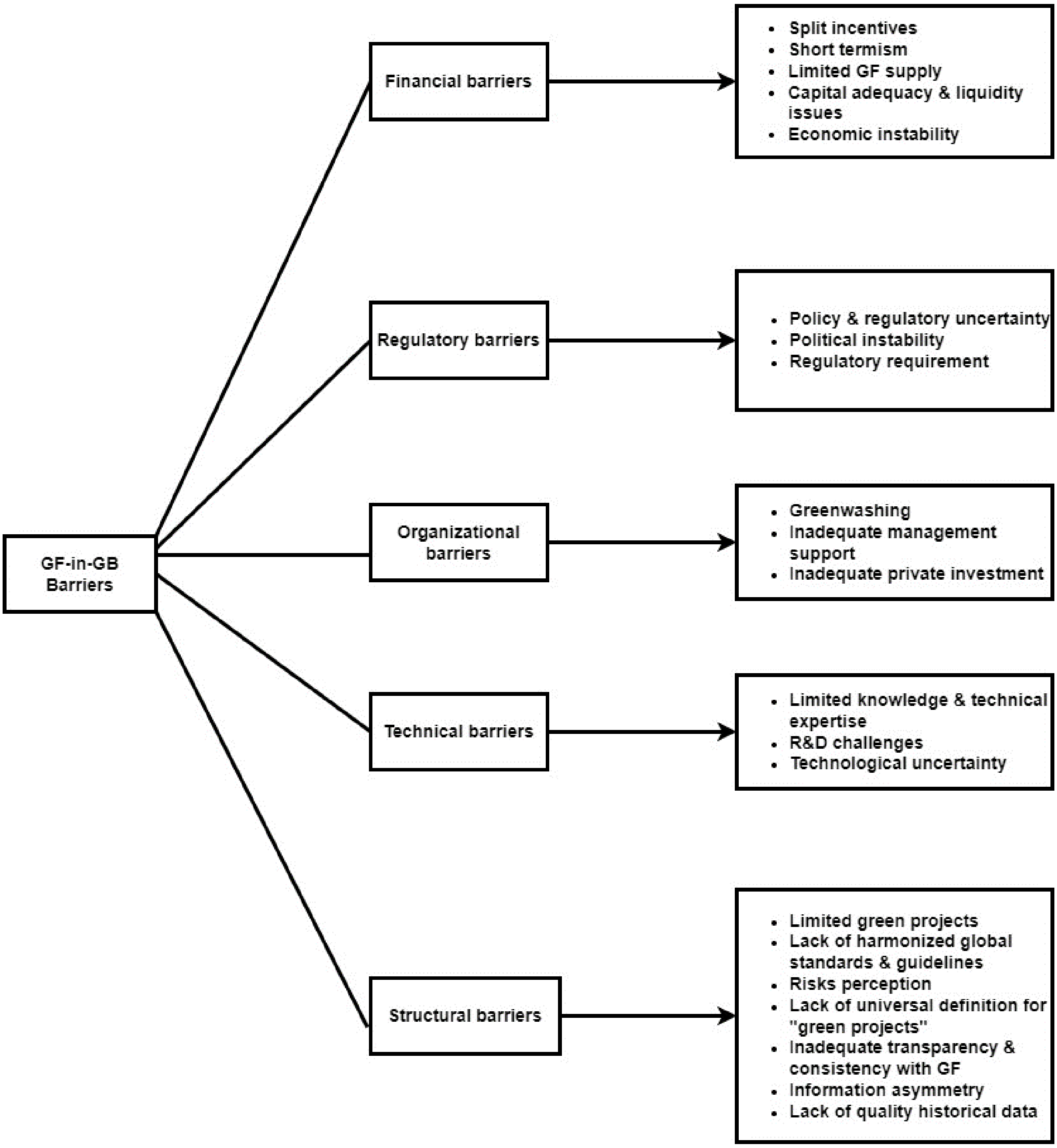

Fig. 3.5 Conceptual structure of the principal barriers to GF-in-GB
Source: Author's

A summary of the identified barriers is provided below:

3.7.1 Financial Barriers

Financial barriers relate to when high costs make certain activities problematic to afford (Hamel, 2021) (i.e., all cost-related GF barriers). Following the literature review, six financial barriers to GF-in-GB were identified: split incentives, short-termism, limited GF supply, capital adequacy and liquidity issues, costly processes, and economic instability. The main challenge of GF is incentives (Donastorg et al., 2021). According to Deschryver and De Mariz (2020), there is a perception of the uncertain benefits of green bond issuances. For instance, split incentives were identified as a significant barrier to GF in building energy efficiency retrofits in China (Zhang et al., 2020b). Similarly, Agyekum et al. (2020) find split incentives to be a major barrier to financing GBs in Ghana. This lack of incentive for GF or the structure of green bonds originates from the certification process (Yamahaki et al., 2020) and its inability to show tangible benefits (Shishlov et al., 2016). A survey revealed that the potential mismatch between investor and issuer expectations poses pricing uncertainty in the Ghanaian market (FSD Africa, 2021). Maturity mismatches and short-termism remain critical issues in the global development of GF (Hafner et al., 2020; Zheng et al., 2021). Again, the underlying liquidity profile of the potential GF product issuers is crucial.

Similarly, SMEs lack capital requirements for GF, leading to inadequate financing schemes (Agyekum et al., 2020). Owing to SMEs' inadequate capacity to develop qualified funding proposals that meet requirements (Zhang et al., 2020b), green banks are reluctant to support green projects. Additionally, the collateral obligations are extremely high and rigorous (Setyowati, 2020b; Zhang et al., 2020b). For example, SMEs require as much as 120% collateral from the total loans obtained and to have a creditworthy sponsor (Setyowati, 2020a). In addition, the minimum project finance size requirement of at least US$100 million makes it more challenging for SMEs to access GF (Nelson and Pierpont, 2013). Other stakeholders perceive GF as a costly process with higher transaction costs or additional fees (Deschryver and De Mariz, 2020; Yamahaki et al., 2020; Zhang et al., 2020b). The issue of high upfront costs related to the perceived high cost of low-carbon technology investments remains critical (Donastorg et al., 2021; Yamahaki et al., 2020). In addition, poor economic conditions, particularly exchange rate volatility and rising inflation, may dissipate interest in GF (Agyekum et al., 2020; Owusu-Manu et al., 2020).

3.7.2 Regulatory Barriers

Regulatory barriers include international, national, state, or local laws, regulations, policies, and structures that may restrict the growth and development of GF. The three major regulatory barriers affecting GF-in-GB are policy and regulatory uncertainty, political instability, and regulatory requirements. The literature shows that the biggest concern for investors is policy uncertainty (Nelson and Pierpont, 2013). Governments do not clearly signal how and to what extent they promote green transition (Berensmann and Lindenberg, 2016). In Ghana, the government has yet to implement its 2021 announcement of issuing a green bond (FSD Africa, 2021). Such uncertain signals created by the government could inhibit private-sector participation in the GF market. In contrast, the Nigerian government created the Green Bond Guidance, leading to its first green bond being issued in 2017 (Taghizadeh-Hesary et al., 2022). Similarly, the Hong Kong government is popular for its sovereign green bonds in GBs (HKSAR, 2021). These government signals enhance private investor confidence and interest in GF.

Again, a stable political climate is critical for investors' interests in a specific market. An erratic political atmosphere exposes the financial system to vulnerabilities, given the uncertainties in government policies (Wyman, 2015). Regulatory requirements may lead to regulatory risks that inhibit GF-in-GB growth. This results in cost increases for project developers, both in terms of the time implication to understand new regulations and additional related costs (Setyowati, 2020b). For instance, Setyowati (2020b) claimed that current regulatory frameworks have limited effectiveness in providing a clear direction for financial institutions to develop sustainable finance action plans capable of mainstreaming it within their business practice. A survey of experts in Ghana revealed that the lack of guidelines for green bond issuance is responsible for the lack of clarity market participants experience (FSD Africa, 2021).

3.7.3 Organisational Barriers

The context in which organisations operate can drive or frustrate development (Darko et al., 2017). The identified organisational barriers include greenwashing, inadequate management support, and inadequate private investment. The risk of greenwashing, also known as reputational risk, has been identified in the literature as a key GF barrier, and remains a serious risk for all stakeholders (Deschryver and De Mariz, 2020). *Greenwashing* is the issuance of so-called green securities that lack environmental benefits. This emanates from the lack of a clear GF definition, leaving room for misleading claims regarding green projects (Berensmann and Lindenberg, 2016). Emerging stories indicate that most GF are issued on greenwashing, which is a false representation that does not positively impact the environment (Taghizadeh-Hesary et al., 2022). Again, the failure of top and middle management to embrace GF in operational activities and an unsupportive organisational structure for green transition impede GF growth (Akomea-Frimpong et al., 2022). Additionally, insufficient private effort was identified as a GF barrier in the literature review. For instance, most renewable energy retailers in New South Wales are semi-privatised and barred from entering long-term public-private agreements (Kann, 2009). Dmuchowski et al. (2021) indicate that there is a low participation of the private sector in financing a green economy in Poland. Private sector efforts in GF are therefore very low and insufficient to meet the growing global need. However, to achieve meaningful sustainable development, there is a need to leverage private sector investments with current public spending on GF (Clark et al., 2018).

3.7.4 Technical Barriers

The lack of knowledge, technical capacity, or expertise of project developers, issuers, and investors has been identified in the literature as a barrier to GF (Hafner et al., 2020; Zhang et al., 2020b). While many experts lack knowledge regarding financial policies or tools for green projects (Donastorg et al., 2021), companies often lack the necessary financial management and accounting capacities required for a comprehensive green loan application (Zhang et al., 2020b). The Financial Sector Deepening Africa (FSD Africa) (FSD Africa, 2021) notes the importance of greater technical capacity in the Ghanaian market to enhance GF. Lack of knowledge regarding GF is also influenced by inadequate research and development (R&D) support for GF-in-GB (Chen, 2018; Toxopeus and Polzin, 2021). The perceived technology risk associated with uncertain GB technologies and products influences GF (Agyekum et al., 2020; Bank of England, 2018; FSD Africa, 2021).

3.7.5 Structural Barriers

Structural (or market) barriers are natural or strategic barriers that arise in the market to prevent new entrants. These barriers, both short- and long-term, collectively prevent GF products from gaining traction in the capital market. They include limited green projects; lack of harmonised global standards and guidelines; risk perception; lack of a universal definition for "green projects"; inadequate transparency and consistency with GF; information asymmetry; and lack of quality historical data.

Thus far, few market participants have identified a pipeline of eligible green projects for GF because of the novelty of the product. Despite the rising interest in potential issuers of GF, there is a lack of eligible pipelines (Deschryver and De Mariz, 2020; FSD Africa, 2021). Mielke (2019) agrees that the lack of bankable projects and project pipelines is a major barrier to GF. Although several initiatives have been introduced by the government of Ghana to support its transition to a green economy, GF remains nascent in the country, especially because of the almost non-existent GBs in Ghana. While there is a significant awareness of GF, few market participants have some level of understanding of GF across issuers and investors alike (FSD Africa, 2021). In addition, there is a lack of existing guidelines and regulations regarding GF. FSD Africa (2021) asserts that a functioning debt capital market is the key to GF issuance.

Hence, there must be appropriate legislative protection for investors showing a degree of transparency and good governance through credit ratings, market liquidity, and acceptable yields. Taghizadeh-Hesary et al. (2022) argued that the lack of a harmonised system affects GF. This further deepens the challenges posed by the lack of credible historical information or databases on green projects and various risk perceptions associated with green projects (Agyekum et al., 2020). Similarly, GF is plagued by imperfect information, where parties to a transaction have access to different levels of information (Cheung et al., 2022; Schuetze, 2020). Finally, the poor clarity of what can be classified as GF serves as a barrier to the demand for GF-in-GB (Akomea-Frimpong et al., 2022). This unending debate on what qualifies as "green" in project financing is a big challenge for GF stakeholders (Paranque and Revelli, 2019).

3.7.6 Appraisal of the Literature and Knowledge Gaps

The above literature review identifies barriers to GF-in-GB. Previous studies have identified several barriers that hinder GF adoption and implementation. Few available studies specific to GB have focused on Ghana, Europe, and China (Agyekum et al., 2020; Mielke, 2019; Zhang et al., 2020b). To complement these studies, some general barriers to GF have been reviewed. Until recently, GF experienced unsteady growth due to barriers to its adoption (Zhang et al., 2019). Similarly, GF-in-GB has seen little growth owing to several barriers, as reported in the literature (Agyekum et al., 2020; EBRD, 2017; Kapoor et al., 2020; Pradmod Chakravarthi and Aravindan, 2019). However, due to the local market conditions in the study areas, the reported barriers are inconsistent. It is therefore important to examine the criticalities of existing barriers and how they interrelate with each other. No study has focused on investigating the interrelationships between the critical barriers of GF-in-GBs. While there is a single study on the obstacles to GB finance in Ghana from the perspective of construction professionals, developers, and GB experts (Agyekum et al., 2020), the views of other stakeholders, such as GF experts, are ignored. While these studies provide significant findings, the interrelationships among the barriers were not considered. To overcome these barriers, a holistic approach that considers barrier interactions is suggested as more effective than a unilateral approach (Addae et al., 2019; Negash et al., 2021). Hence, this section assessed the interactions between barriers to GF-in-GB in Ghana through expert knowledge using FDM and FDEMATEL questionnaire surveys regarding linguistic evaluation. These techniques allow experts to reassess their views based on the consolidated responses of all experts. This reflection is missing from previous studies based on single surveys, interviews, or focus groups.

3.8 Risk Factors of Green Finance in Green Building

A systematic literature review was conducted to identify the principal risk factors for GF-in-GB. Utilising the keywords outlined in Table 2.2, this study retrieved 50 documents from Scopus, Web of Science, and Google Scholar in January 2022. Thorough screening led to the identification of 30 relevant documents that specifically addressed GF risk factors that can be adapted to the GB sector. The identified risk factors were grouped into seven major risk attributes: climate transition risks, climate physical risks, liability risks, market risks, liquidity risks, credit risks, and sector risks, as summarised in Table 3.5. Although all identified risk variables are prominent in the literature, it is apparent that their relative relevance varies (Darko, 2019). Linguistic questionnaire surveys were conducted with a group of experts to develop valid GF-in-GB risk criteria.

Table 3.5 List of potential GF-in-GB risk factors

Attributes	Risk code	Criteria (Risks)	References
Climate transition risks	RC1	Regulatory and policy risks (e.g., prohibitions, environmental taxes, carbon pricing)	[1-8]
	RC2	Technological innovation risk	[1-7]
	RC3	Reputation risk due to shifting consumer and investor preferences	[1-4,6,7,9]
Climate physical risks	RC4	Risks associated with the occurrence of climate- and weather-related events leading to property damage	[1-7]
	RC5	Low adaptation capabilities of GB and GF firms	[7-8]
	RC6	Mismatch between the short-term financial decision-making and long-term impacts of climate change	[7,10-12,16]
Liability risks	RC7	Compensation for climate-related losses or damages	[1-2,13-15]
	RC8	Judicial decisions and sanctions imposed by laws	
Market risks	RC9	Sluggish demand for high-rated GBs	[8]
	RC10	Long payback period for GBs	[8,16-17]
	RC11	Uncertain market value for GBs	[8-9,16,18]
	RC12	Uncertain macroeconomic factors	[19]
Liquidity risks	RC13	Insufficient cash flow of GB firms	[8,20]
	RC14	Up-front risks or capital-intensive nature of GBs	[8,17]
Credit risks	RC15	High income tax rates	[8,21,29-30]
	RC16	Inadequate credit rating of GB firms	[8,22,29-30]
	RC17	Breach of contract due to change of property owners	[8]
	RC18	Green level promised by real estate developers for GBs did not materialize	[8]
	RC19	Default risk of GBs	[2,17,23-25]
Sector risks	RC20	Construction delays owing to complicated permitting processes	[17]
	RC21	Lack of third-party evaluation of GBs	[8,16]
	RC22	Increased competition with conventional buildings	[17]
	RC23	Greenwashing risks	[5,16,26-28]
	RC24	Inadequate green experience or qualification	[8]
	RC25	Lack of transparency reporting in GB projects	[16,22]

[1] = Carney (2015); [2] = Bank of England (2018); [3] = Barrage and Furst (2019); [4] = Giglio et al. (2021); [5] = Esposito et al. (2019); [6] = Esposito et al. (2022); [7] = Venturini (2022); [8] = Mo (2016); [9] = Schuetze (2020); [10] = Cheung et al. (2022); [11] = Yoshino et al. (2019); [12] = Cao et al. (2021); [13] = Luo et al. (2021); [14] = Tsalis et al. (2020); [15] = Demertzidis et al. (2015); [16] = Wang et al. (2019b); [17] = Schmidt (2014); [18] = Arnold and Yildiz (2015); [19] = Yamahaki et al. (2020); [20] = Agliardi and Agliardi (2021); [21] = Taghizadeh-Hesary et al. (2022); [22] = Febi et al. (2018); [23] = An and Pivo (2020); [24] = Saidane and Abdallah (2021); [25] = Del Gaudio et al. (2022); [26] = Goh (2021); [27] = Baldi and Pandimiglio (2022); [28] = Lau et al. (2022); [29] = Taghizadeh-Hesary et al. (2022); [30] = Giraudet et al. (2021)

Fig. 3.6 provides the conceptual structure of the principal risk factors of GF-in-GB.

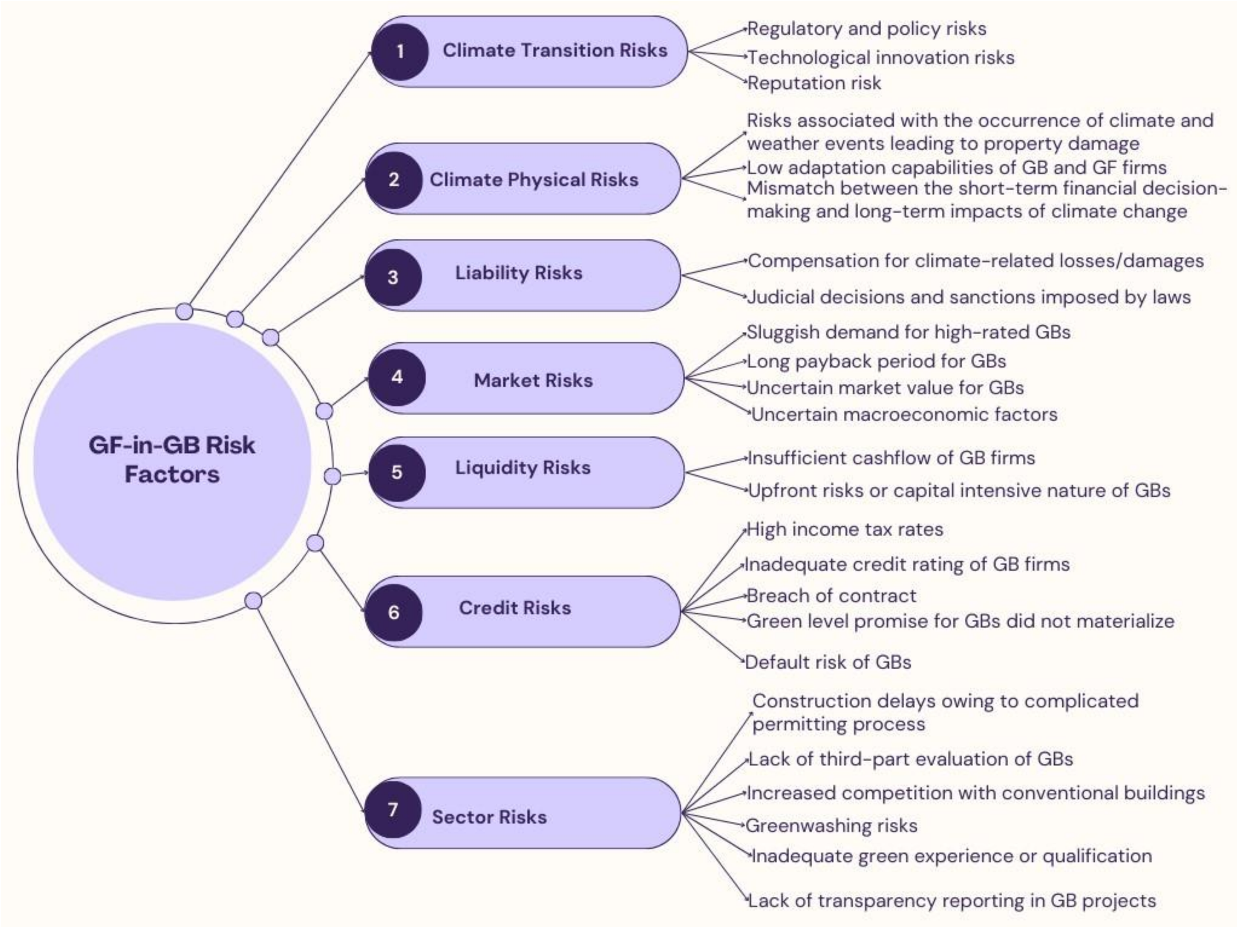

Fig. 3.6 Conceptual structure of the principal risk factors of GF-in-GB
Source: Author's

A summary of the identified risk factors is provided below:

3.8.1 Climate Transition Risks

Transitional risk refers to all possible scenarios aligned with a low-carbon economy and its implications (Venturini, 2022). GF-in-GB climate transition risks relate to policy and regulation, technological changes, and reputational risks that may arise because of changing or shifting consumer and investor preferences (Carney, 2015; Cheung et al., 2022; Giglio et al., 2021; Venturini, 2022).

3.8.2 Climate Physical Risks

Physical risk refers to the mainly negative impact of climate- and weather-related events on company operation, society, and supply chains (Carney, 2015). Climatic physical risks can be acute or chronic. Acute physical risks are related to *extreme weather events* such as floods, wildfires, and hurricanes, and chronic climate risks represent *slowly* evolving phenomena, such as sea-level rise, changes in precipitation patterns, and temperature rise (Venturini, 2022). Generally, the literature has discussed the hazards, exposure, and vulnerability of firms in relation to climate physical risks (Venturini, 2022). Hence, the low adaptation capabilities of energy service companies and GB firms (Mo, 2016; Venturini, 2022), and the short-term or maturity mismatches (Cheung et al., 2022; Venturini, 2022) are related to climate physical risks. For instance, extreme weather events can cause significant losses to homeowners, reducing their ability to repay their loans and damaging the value of the property (Bank of England, 2018).

3.8.3 Liability Risks

Liability risks arise if parties who have suffered climate change risks seek to recover these losses from those they view as responsible (Bank of England, 2018). GF-in-GB liability risks may include compensation for climate-related losses or damages (Bank of England, 2018; Tsalis et al., 2020), and information related to judicial decisions and sanctions imposed by laws (Demertzidis et al., 2015; Tsalis et al., 2020).

3.8.4 Market Risks

Market risk is caused by inadequate market depth and breadth, which leads to insufficient market trading volumes or inactive market transactions (Wang et al., 2019). From the review, four GF-in-GB market risks were identified including: sluggish demand for high-rated GB (Mo, 2016), long payback period for GB (Mo, 2016; Schmidt, 2014), uncertain market value for GB (Mo, 2016; Schuetze, 2020), and macroeconomic factors (e.g., inflation, economic growth, etc.) (Yamahaki et al., 2020). For instance, market risks such as future price developments or uncertain market values may hinder potential investors or institutional lenders from investing in GBs (Arnold and Yildiz, 2015).

3.8.5 Liquidity risks

Liquidity risk refers to an investor's inability to comply with the payment obligation upon contract expiration due to a lack of current funds or meeting margin calls in accordance with the contract at the time of settlement (Wang et al., 2019). High debt ratio of GB firms, insufficient cash flow of GB firms, and upfront risks or the capital-intensive nature of GB have been identified as liquidity risks of GF-in-GB (Agliardi and Agliardi, 2021; Mo, 2016; Schmidt, 2014).

3.8.6 Credit Risks

Credit risk, also referred to as default risk, is the likelihood of a loss to one trading party caused by the refusal of the other party to perform the agreed terms (Wang et al., 2019). For GF, the emergence of credit risk is related to the immature carbon trading market and imperfect relevant systems (Wang et al., 2019), inadequate credit rating of GB firms, inability to execute contracts due to changes in property owners (Mo, 2016), split incentives (Agyekum et al., 2020; Mo, 2016), the green level promised by real estate developers for GB that did not materialise (Mo, 2016), default in payment leading to loss of assets (An and Pivo, 2020; Bank of England, 2018; Schmidt, 2014), high interest rates and high income tax rates for GF (Giraudet et al., 2021; Mo, 2016; Taghizadeh-Hesary et al., 2022), and increased investor equity expectations on returns due to the high upfront cost of GBs (Mo, 2016; Schmidt, 2014). Other credit risks are associated with exchange rates owing to foreign capital investments (Granoff et al., 2016; Mo, 2016). For example, according to Mo (2016), GB firms lack adequate credit ratings, which largely affects their ability to secure green loans. This is because capital costs are a function of the borrower's credit rating, securities provided, leverage ratio, and aggregated project risk. Hence, a higher aggregated project risk leads to higher interest rates requested for loans or even complete denial by lenders such as banks (Arnold and Yildiz, 2015).

3.8.7 Sector Risks

Sector risks are GB-specific risks, such as lack of third-party evaluation of GB (Mo, 2016; Wang et al., 2019a), inadequate GB experience or qualifications, conflicts of interest with GB evaluation agencies who also provide GB consulting services (Mo, 2016), effectiveness of financed green projects (Agliardi and Agliardi, 2021), and greenwashing risks (Baldi and Pandimiglio, 2022; Esposito et al., 2022).

3.8.8 Gaps in Knowledge

From the literature reviewed, while several studies have addressed the risk factors associated with GF, limited attention has been paid to GF-in-GB risk factors. This section therefore examined the GF risks identified in the literature that can be adapted to the GB sector. To aid the development of a novel risk assessment model for GF-in-GB, this study evaluated the GF risk factors identified in the literature with a group of GF-in-GB experts using linguistic evaluation questionnaire surveys.

3.9 Strategies to promote Green Finance in Green Building

Because GB lacks the necessary finance, it is necessary to identify strategies to promote GF-in-GB. A comprehensive literature review was conducted to identify GF strategies that can be adapted to promote GF-in-GB. These strategies are intended to de-risk and overcome adoption barriers to GF-in-GB. According to Schmidt (2014), de-risking strategies are measures to decrease the downward risk of low-carbon investment and to reduce the likelihood of a negative event or a risk for investment. This is necessary to create attractive conditions, in most times, for private investors.

Komendantova et al. (2019) identified two kinds of de-risking strategies, financial and policy. Other studies identify technological strategies, market strategies, and behavioural strategies. A summary of the strategies for promoting GF is provided below.

3.9.1 Market Strategies

Market strategies such as capturing multiple GB benefits in valuation and accounting methods, creating markets for (local, urban) externalities, and integrating accounting and assessment methods into decision-making are key to promoting strategies for GF (Toxopeus and Polzin, 2021). In addition, the Bank of England (2018) proposed the need to identify and measure the financial risks from climate change. This requires strategic board oversight (Bank of England, 2018; Feridun and Güngör, 2020) and climate scenario analysis and stress testing (Bank of England, 2021, 2018). To resolve the gap issue between companies' reporting metrics and investors' growing expectation of what constitutes "green" (Goh, 2021), increased information disclosure and better transparency have been recommended (Brodie and Hong, 2018; Feridun and Güngör, 2020). Goh (2021) argues that the implementation of standardised metrics and transparent reporting frameworks are important determinants necessary to satisfy investors' growing expectations. External verification through certification by reputable third-party institutions is the key to promoting GF. For example, the Hong Kong Quality Assurance Agency (HKQAA) has developed a GF certification scheme to provide third-party conformity assessments to GF issuers with pre-issuance and post-issuance certifications (HKQAA, 2022). Other strategies include institutionalization and mechanisms for managing carbon trading for buildings (Rozenberg et al., 2013; Shalneva and Zinchenko, 2019; Woo et al., 2021), aggregating small- and medium-sized individual projects into a sufficient size to reduce transaction costs and facilitate investments (Agliardi, 2021), climate change considerations in risk management (Cheung et al., 2022; Komendantova et al., 2019), and developing new insurance underwriting products and innovations to de-risk GF (Coburn et al., 2011; Monasterolo, 2020).

3.9.2 Financial Strategies

Financial strategies (de-risking), such as insurance or guarantees of public stakeholders, transfer the financial impact of negative events to other parties (Schmidt, 2014). The identified financial de-risking strategies include government incentives such as green subsidies and spillover tax returns to increase the rate of return (Brodie and Hong, 2018; Shalneva and Zinchenko, 2019; Taghizadeh-Hesary and Yoshino, 2019). According to Taghizadeh-Hesary et al. (2021), GF subsidies in the early stages of project development could help solve the problem of high-upfront costs. It is argued that, in the long term, subsidies could be repaid through tax spillovers generated through increased employment and revenues associated with green projects. Additionally, access to targeted financial instruments such as government loans, equity investments, risk insurance, and public guarantees is key to increasing GF-in-GB levels. For instance, because of the many small- and medium-sized companies involved in green projects, credit guarantees can allow these firms to receive higher funding, as the public entity acts as a form of collateral (Taghizadeh-Hesary et al., 2021b). Additionally, green securitisation can influence the development of low-carbon and climate-resilient buildings (Brodie and Hong, 2018). According to Brodie and Hong (2018), green REITs (Real estate investment trusts) supported by GF are associated with a higher proportion of green properties, increased financial performance, information disclosure and better transparency. This characteristic nature of green REITs may be responsible for the increase in leasing market share and overall value of GB-traded assets in the market. Additionally, banks' role in facilitating access to capital markets through the securitisation of green projects and assets can support climate mitigation and adaptation (Bank of England, 2018). Finally, the public-private relationship is key to sharing risks. Hence, public actors (such as state investment banks) may adopt large high-risk portfolios to influence private sector involvement (Polzin, 2017; Toxopeus and Polzin, 2021).

3.9.3 Technological Strategies

Technological strategies are intended to leverage the development of technologies to promote GF access and efficiency. Developments in artificial intelligence and other technologies are key in promoting GF-in-GB (Debrah et al., 2022b, 2022a). New technology and disruptive business models are key to GF (Bank of England, 2018). As technology evolves and unit costs decrease, new disruptive business models may arise. Financial technology (fintech) is an emerging technology that can support the appropriate utilisation of resources gathered through GF, such as GF-in-GB (Bhutta et al., 2022). The wide capabilities of fintech from mobile payment platforms to high-frequency trading (HTF) to crowd funding and virtual currencies to blockchain technology (Kim, 2018), make it more suitable to adapted with changing technologies in the finance for efficient GF-in-GB.

3.9.4 Policy Strategies

Policy strategies (or de-risking) decrease the likelihood of risk by improving investment climate and local institutions (Komendantova et al., 2019). For example, improvements in permitting procedures decrease the likelihood of construction delays (Komendantova et al., 2019). Again, public-private sector coordination or partnerships could drive increased private sector participation in GF-in-GB (Toxopeus and Polzin, 2021). Others include co-investment into GF-in-GB research and development (Shalneva and Zinchenko, 2019; Toxopeus and Polzin, 2021), and improvements in climate-related policies and regulations to stimulate private sector investment (Bank of England, 2018; Toxopeus and Polzin, 2021). Regulatory developments could include new disclosure or reporting requirements introduced within the financial sector to address climate-related issues (Bank of England, 2018).

The shortlisted strategies are presented in Table 3.6.

Table 3.6 List of potential strategies to promote GF-in-GB

Attribute	Code	Criteria	Relevant literature
Market strategies	SC1	Improving access to capital for small-scale GB projects	[1]
	SC2	Encouraging climate scenario analysis by adopting existing guidelines such as TFCD (Task Force on Climate-Related Financial Disclosures)	[2-8]
	SC3	Capturing multiple GB benefits in valuation and accounting methods	[9]
	SC4	Increased information disclosure and better transparency	[10-13]
	SC5	Institutionalization and mechanisms for managing carbon emission trading for buildings	[14-16]
	SC6	Quality climate risks and other ESG data for investor (and customer) assessment	[2,15,17-18]
	SC7	Integrating climate risk exposure assessment into GF-in-GB projects	[13]
	SC8	Reputable third-party green certification and labels	[19]
	SC9	Harmonise GF-in-GB standards	[32,33]
Financial strategies	SC10	Continuous improvement of incentives policies for GF-in-GB (e.g., spillover-tax-returns to increase rate of return, green subsidies)	[10,14,20-22]
	SC11	Access to targeted GF instruments for GB (e.g., government loans, equity investments, risk insurance and public guarantees)	[18,20,23-26]
	SC12	Innovation of financial instruments that enable public/private risk sharing	[9]
Technological strategies	SC13	New technology and disruptive business models	[7]
	SC14	Innovative Fintech solutions for GF-in-GB (e.g., AI, blockchain, etc., integration)	[15,27-31]
Policy strategies	SC15	Simplification of administrative procedures linked with GB projects (e.g., permitting and licensing procedures)	[18,26]
	SC16	Increased R&D support for GF-in-GB	[9,14,27]
	SC17	Public-private partnerships to facilitate GF from the private sector	[9,15]
	SC18	Developments in climate-related policy and regulation to stimulate private investment	[7,9]
	SC19	Increased government participation as “leader by example”	[32,33]
	SC20	Ensuring compliance of both public and private actors to green standards	[33]

[1] = Agliardi (2021); [2] = Monasterolo (2020); [3] = NGFS (2020); [4] = Chenet et al. (2021); [5] = Chenet et al. (2015); [6] = Bank of England (2021); [7] = Bank of England (2018); [8] = Basel Committee on Banking Supervision (2015); [9] = Toxopeus and Polzin (2021); [10] = Brodie and Hong (2018); [11] = NGFS (2019); [12] = FSB (2022); [13] = Feridun and Güngör (2020); [14] = Shalneva and Zinchenko (2019); [15] = Kim (2018); [16] = Rozenberg et al. (2013); [17] = Cheung et al. (2022); [18] = Komendantova et al. (2019); [19] = Goh (2021); [20] = Taghizadeh-Hesary and Yoshino (2019); [21] = Taghizadeh-Hesary et al. (2021); [22] = Li et al. (2018); [23] = Matthäus and Mehling (2020); [24] = Hourcade et al. (2021); [25] = Carafa et al. (2016); [26] = Schmidt (2014); [27] = Chen (2018); [28] = Taghizadeh-Hesary and Yoshino (2020); [29] = Muganyi et al. (2021); [30] = Woo et al. (2021); [31] = Green Finance Taskforce (2018); [32] = Berensmann et al. (2017); [33] = Nedopil et al. (2021)

Fig. 3.7 provides a conceptual structure of the principal strategies for promoting GF-in-GB.

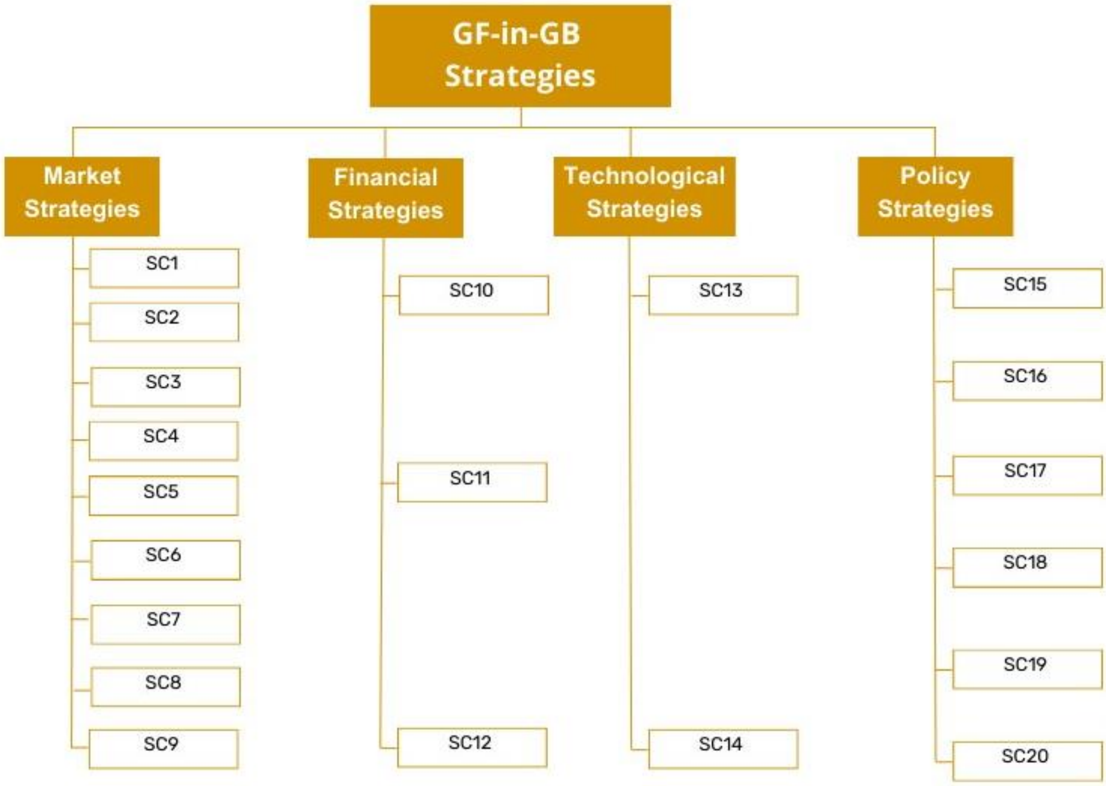

Fig. 3.7 Conceptual structure of the principal strategies to promote GF-in-GB
Source: Author's

3.9.5 Gaps in Knowledge

Following the comprehensive and careful literature review discussed above, this study identified 20 potential strategies to promote and de-risk GF-in-GB. The promotional strategies of GF-in-GB identified and shortlisted for analysis in the context of this research are based on the existing literature and in consultation with two experts, one in the industry and one from academia. The four major categories adopted are based on the literature: market strategies, financial strategies, technological strategies and policy strategies (Bank of England, 2021; Komendantova et al., 2019; Toxopeus and Polzin, 2021).

Existing studies on GF strategies are generic in nature and do not focus on a particular industry. The literature reveals that no earlier work has been conducted on identifying strategies to promote GF-in-GB. The literature also lacks research on the prioritisation and interrelationship between strategies.

The literature review above indicates that several studies have proposed different strategies to promote GF, with limited attention paid to the GF-in-GB sector. Therefore, this study examines the strategies identified in the literature on the GF-in-GB sector. Additionally, no study has assessed the interactions between strategies and their impact on each other. Therefore, this study evaluates the interdependencies of GF-in-GB strategies with a group of experts using the FDM and FDEMATEL methodologies.

3.10 Techno-economic Feasibility of Green Finance in Green Building Projects in Ghana: Framework Development

This section focuses on the technical-and-economic (techno-economic) feasibility of a GB office in Ghana. A techno-economic analysis provides the basis for assessing the factors that lead to variability in cost estimates (Abdul-Ganiyu et al., 2021). Feasibility studies are typically conducted to justify investments in infrastructure projects (Hyari and Kandil, 2009). This is an important aspect of any project in the pre-contact stage (Halil et al., 2016). A feasibility study details how a project can be completed, and accounts for factors such as technological, economic, legal, operational, and scheduling activities that may affect the progress of a project (Mukherjee and Roy, 2017). Generally, feasibility studies consider effective methodologies for strategically managing projects in various investment and economic activities under the least possible degree of uncertainty (risk) over a project's lifecycle (Heralova, 2017). This study considered the economic feasibility of GB projects in Ghana. Economic feasibility, an expression in the accounting and economic sciences, refers to the examination and review of different investment alternatives by calculating their benefits and costs (Ahmed et al., 2019). Generally, economic feasibility is carried out using standard measures of profitability, such as cost-benefit analysis (CBA) (Begum et al., 2006). Hence, economic and financial analyses are useful for assessing the capacity of GB projects to generate income and make financial projections for future years. This is usually achieved through discounted cash flow (Halil et al., 2016).

For GB projects, economic feasibility studies provide evidence to building owners or investors regarding the benefits and costs associated with green projects. According to Miraj et al. (2021), economic feasibility should be performed considering the building's LCC to show energy efficiency upgrades and CBA from GB adoption and movement. While several studies have investigated the CBA of GB in different economies internationally, there are limited studies on the whole-building LCC of GB, especially in emerging and developing economies (Dwaikat and Ali, 2018; Miraj et al., 2021). A whole-building LCC considers the cost of GB over its life, from design and construction to its eventual demolition or replacement (University of Reading, 2023).

There is consensus in the literature that GB studies should be considered from a "local" context. Hence, owing to the specificities of different countries, economies, production processes, and legislation, numerous location-specific CBA for GB projects abound (Gabay et al., 2014). Additionally, while GB investment is more likely to be seen as profitable from a lifecycle perspective (Zhang et al., 2018), most CBA studies do not consider the whole building lifecycle in GB performance measurement (Miraj et al., 2021). This limitation in existing studies is attributed to limited data availability, insufficient support from the national construction policy, lack of accurate assumptions, and a limited understanding of building owners and practitioners (Boussabaine and Kirkham, 2008).

To address these gaps, this study investigated the techno-economic feasibility of GB projects from a whole-building LCC perspective. Hence, the feasibility of a certified GB office is considered from the design and construction, O&M and deconstruction. To do so, the CBA of a GB office project was assessed in a developing country context using Ghana as a case study. This provides quantitative evidence of the attractiveness of GB that is necessary to increase green investments.

3.10.1 Review of Related Work and Knowledge Gaps

Techno-economic studies of GBs are critical for stimulating their design, construction, and use. It is necessary to assess the economic viability and profitability of GBs to inform policymaking and increase adoption. Few studies have investigated the costs and benefits of GBs from a lifecycle perspective (Dwaikat and Ali, 2016; Zhang et al., 2018). A seminal study by Kats (2003) suggests that, while GB comes with extra costs, it offers cost savings when examined through a LCC methodology. In this study, an extra GB construction cost of 2% yielded a lifecycle savings of 20% of the total construction cost. Several other studies have investigated the LCC of GBs using different methodologies and contexts. This is because the concept of sustainability is highly contextual (Jarrar and Al-Zoabi, 2008), and not all GBs need to be the same (Debrah and Owusu-Manu, 2021). Owing to distinct climatic conditions, unique cultures and traditions, diverse building types and ages, and wide-ranging environmental, economic, and social priorities of different economies, GBs have been approached differently in terms of design, construction, and O&M. As a result, various GB rating systems have been created worldwide, such as LEED, ENERGY STAR, and Green Globes in the US, BREEAM (UK), Green Star (Australia, South Africa), EDGE (IFC), and BEAM Plus (Hong Kong). Even so, these green rating systems have been criticised as not universally acceptable or applicable and require constant updating (Hopkins, 2016). This has necessitated the investigation of the costs and benefits of GBs in different contexts. Table 3.7 provides a summary of review studies of the economics of GBs.

Table 3.7 Summary of some review studies on the economics of GBs

Source	Focus of review	Number of studies included	Developed economies	Emerging and developing economies	Publication period	Incremental cost of GBs [a]	Gap identified
Hu and Skibniewski (2021)	GB construction cost surcharge	31	USA, UK, Australia, New Zealand, Israel, Singapore, Malaysia, Thailand, Taiwan	India, China	2000 - 2020	-18.33 to 18%	Ambiguity of construction cost calculation methods and databases
Hopkins (2016)	GB costs and benefits	13	USA	-	2004 - 2012	0 to 6%	Lack of studies from developing economies perspective
Dwaikat and Ali (2016)	GB cost premium	17	USA, UK, Australia, New Zealand	-	2000 - 2014	-0.4 to 21%	Lack of studies from developing economies perspective
Rehm and Ade (2013)	Construction costs comparison between “green” and conventional office buildings	19	USA, UK, Australia	-	2002 - 2010	-15 to 21%	Lack of transparent methodology used in majority of studies
Ade and Rehm (2020)	Green cost premium	10	USA, Singapore	China	2005 - 2018	-18 to 13.9%	Few studies focus on China, a developing country.
Zhang et al. (2018)	Economics of GBs	10	USA, UK, Australia, Hong Kong,	China	2003 - 2015	-0.4 to 11%	Lack of comprehensive and robust LCC and benefits of GBs.
Yasinta et al. (2020)	GB cost analysis	12 [b]	USA, UK, Australia, Singapore, Hong Kong, Malaysia, Italy	India, Sri Lanka	2013 - 2020	NR	Different analytical methods and data (i.e., quantitative and qualitative data) impact LCC of GBs.
Weerasinghe and Ramachandra (2018)	Economic sustainability of GBs	22	USA, New Zealand, Australia	-	2000 - 2014	-15 to 18%	Imprecise participants’ perception of LCC of GBs

[a] Results include actual cost data and participants’ perception or survey responses.
[b] Two studies were excluded since they did not focus on the CBA of GBs
NR – Not reported.

From the reviews, most studies have focused on advanced economies, particularly the USA. Only a few studies include emerging and developing economies, such as China, India, Sri Lanka, and Indonesia (Ade and Rehm, 2020; Hu and Skibniewski, 2021; Miraj et al., 2021; Yasinta et al., 2020; Zhang et al., 2018). The reviewed studies reveal regional, national, and local differences between GB premiums and cost-benefit results. For instance, Hu and Skibniewski (2021) found regional differences among green cost surcharges: the USA had the largest variation from -18.33% to 46% and Europe had the smallest variation, from 0% to 6.5%. Hence, it is imperative to conduct further studies from the perspective of emerging and developing economies. For instance, while the discount rate used in NPV calculations in previous studies focusing on advanced economies ranges from 2% to 6.1% (Lu et al., 2021), the cases of emerging and developing economies are different. Owing to issues such as unsustainable economic conditions, emerging and developing economies are characterized by high discount and interest rates. Therefore, it is necessary to develop a LCC model for GBs in emerging and developing economies. Additionally, few studies have been conducted from the whole-building lifecycle perspective of GBs (Dwaikat and Ali, 2016; Miraj et al., 2021). A summary of previous empirical models is presented in Table 3.8 and discussed below.

Table 3.8 Summary of related GB CBA and LCC empirical studies

Related studies	Country	Number of GBs	Certification type	Building type	Methodological focus	LCC savings of GB	CBR [a]
Weerasinghe and Ramachandra (2018)	Sri Lanka	2 GBs and 1 similar nurtured non-GB	LEED	Industrial buildings	LCC	21%	NR
Weerasinghe et al. (2021)	Sril Lanka	2 GBs and 1 similar nurtured non-GB	LEED	Industrial buildings	LCC	17%	NR
Ries et al. (2006)	USA	1 GB and old non-GB	LEED	Industrial building	CBA	NR	1.7
Kats (2003)	USA	30 GBs	LEED	School buildings	CBA	$71/ft^2	-
Miraj et al. (2021)	Indonesia	1 GB and non-GB	GBCI [b]	Office buildings	CBA	41.74%	2.35
Gabay et al. (2014)	Israel	6 GBs	Green Building Standard	Office buildings	CBA	NR	NR
Dwaikat and Ali (2018)	Malaysia	1 GB	Malaysian GBI [c]	Office buildings	LCC	$6266/m^2	NR
Li et al. (2020)	Singapore	44 GBs	Green Mark	Residential buildings	LCC	S$222.03/m^2/year [d]	NR

[a] CBR: Cost-benefit ratio
[b] GBCI: Green Building Council Indonesia
[c] GBI: Green Building Index
[d] S$: Singaporean Dollar

Table 3.8 reveals that previous studies have conducted LCC and CBA of GBs from the perspective of different countries with varying certifications. It can be observed that the majority of the GBs analysed were from developed countries with a large stock of GBs as compared to the few from developing countries. Again, most of the GB studies were LEED certified, with few studies on other certifications. As indicated earlier, the IFC EDGE certification has emerged and is being adopted in the majority of developing countries to certify GBs. Yet there are limited LCC/CBA studies on IFC EDGE certified GBs. It should be noted that studies that considered just the green cost premiums of GBs were not the focus of this thesis and, hence were excluded from the review (Dwaikat and Ali, 2016).

To close the gaps above, this section focuses on developing a whole-building LCC for GB from the perspective of emerging and developing economies. Hence, this study was focused on an IFC EDGE certified GB in a developing country context of GB. The findings of this study help eliminate the challenge of comparing the cost and benefits of GBs of similar size and function in different countries, regions, and localities. Such comparisons provide little help in understanding the costs of green design (Kats, 2003). To provide a meaningful assessment of the cost of building green, comparisons should be made between conventional and green designs of the same building (Kats, 2003). The existing literature adopts the incremental analysis method using a code-compliant building (of the same size and function, in the exact location) as a baseline to examine the incremental returns from incremental green investment (Zhang et al., 2018). Consequently, the GB features of the selected office building were removed and compared *head-to-head* with those of the GB concept (Miraj et al., 2021). Information for this study was collected through primary data on actual building costs and a broad literature review that provides up-to-date and well-linked compilations of important datasets related to GB costs and benefits (Dwaikat and Ali, 2016; Gabay et al., 2014; Guy, 2006; Kats, 2003; Miraj et al., 2021). The selected case study has the IFC-EDGE final certification.

3.10.2 Overview of Green Finance in Developing Countries

As noted, GBs are faced with the challenges of increased additional cost and lack of financing, hence the need for GF-in-GB. It is, therefore, critical to consider financing avenues in the LCC of GBs. Yet, existing CBA or LCC studies consider just the costs and benefits of GBs compared to non-GBs. While results of existing studies reveal that GBs are economically feasible and profitable over the lifecycle, little attention has been paid to evaluating the impact of GF on the feasibility and profitability of GBs (Caleb Debrah et al., 2022a, 2022c). So far, existing economic feasibility models of GF in green projects exist only in the energy sector. Taghizadeh-Hesary et al. (2022) studied the economic and financial feasibility analysis of hydrogen energy projects in China to identify appropriate GF solutions for them. A cost-benefit and sensitive analysis of three hydrogen projects revealed that diversifying financing channels with GF instead of just relying on bank loans is recommended to reduce the financing risk and capital cost of green projects. Hence, to close this gap in the buildings and construction sector, this study incorporates GF in the LCC of GBs to develop an LCC assessment model to evaluate the economic feasibility of GF-in-GB from a developing country perspective. An overview of GF in developed countries is provided below.

Green bonds and green loans have become significant pivots for GF's development in the global market. China has accounted for 60% of the emerging markets' green bonds since 2012. The top five emerging market issuers of green bonds since 2012 are China ($195 billion), India ($20 billion), Chile ($15 billion), Brazil ($13 billion), and Poland ($8 billion) (IFC, 2023). China alone has accounted for 73% of green bond issuances in developing countries since 2012.

Sub-Saharan Africa accounts for the least amount ($4 billion) of green bond issuance over the last decade, but it represents the highest percentage (18%) of GDP. This shows that GF is gaining popularity and acceptance among investors within the subregion. Consequently, this study considers GF issuances in sub-Saharan Africa as a case study for developing countries. Table 3.9 presents the GF (green bond and green loan) issuances in sub-Saharan Africa (2013 – 2023).

From Table 3.9, the green bond coupon rates ranged from 0.75 to 15.60 with an average tenor of seven years. Of the 23 GF issuances in sub-Saharan Africa, only four were allocated to GBs in Kenya, South Africa, and Cote D'Ivoire. The data show that GF-in-GB issuances within sub-Saharan Africa attract an average coupon rate of 6.97% and an average tenor of eight years. The data in Table 3.9 indicates that GF is still nascent and emerging in Africa.

Table 3.9 Summary of GF issuances in sub-Saharan Africa

SN	Issuer	Country	Issue Date	Coupon (%)	Amount issued (US$ million)	Tenor (years)	Instrument type	Sectors
1.	Emergence Plaza	Cote D'Ivoire	2018	7.5	18.10	8	Green bond	Green buildings
2.	Growthpoint	South Africa	2018	2.00	97.30	10	Green bond	Green buildings
3.	Acorn Project (Two) LLP	Kenya	2019	12.5	40.55	5	Green bond	Green buildings
4.	Standard Bank Group	South Africa	2020	5.87	200.00	10	Green bond	Water, Energy, Green buildings
5.	Federal Government of Nigeria	Nigeria	2017	13.48	29.70	5	Sovereign	Energy
6.	Federal Government of Nigeria	Nigeria	2019	14.5	41.40	7	Sovereign	Green projects [a]
7.	Access Bank of Nigeria Plc.	Nigeria	2019	15.50	41.80	5	Green bond	Green projects
8.	North South Power Company	Nigeria	2021	15.60	16.57	10	Green bond	Energy
9.	City of Johannesburg	South Africa	2014	10.18	137.80	10	Green bond	Energy, Transportation
10.	City of Cape Town	South Africa	2017	1.33	76.00	10	Green bond	Water
11.	Nedbank	South Africa	2019	1.23	68.00	5	Green bond	Energy
12.	ACWA Power Solar Reserve Redstone	South Africa	2019	NR	540.00	17	Green loan	Energy
13.	Nedbank	South Africa	2020	1.35	116.00	7	Green bond	Energy
14.	Bank of Windhoek	Namibia	2018	NR	4.74	NR	Green bond	Green projects
15.	Republic of Seychelles	Seychelles	2018	NR	15.00	10	Green bond	Conservation
16.	African Development Bank	Africa	2013	0.75	500.00	3	Green bond	Green projects
17.	African Development Bank	Africa	2014	1.75	89.79	5	Green bond	Green projects
18.	African Development Bank	Africa	2015	1.36	500.00	3	Green bond	Green projects
19.	African Development Bank	Africa	2022	6.90	10.69	1	Green bond	Energy, Water
20.	African Development Bank	Africa	2023	3.75	92.76	5	Green bond	Green projects
21.	African Development Bank	Africa	2023	5.00	32.21	5	Green bond	Green projects
22.	Africa Finance Corporation	Africa	2020	1.21	163.50	5	Green bond	Green projects
23.	West African Development Bank	West Africa	2021	2.75	909.00	12	Green bond	Green projects

[a] Green projects refer to projects related to renewable energy; energy efficiency; pollution prevention and control; environmentally sustainable management of living natural resources and land use; terrestrial and aquatic biodiversity; clean transportation; sustainable water and wastewater management; climate change adaptation; circular economy adapted products, production technologies and processes and/or certified eco-efficient products; and green buildings.
Not reported
Sources: (CBI, 2023; Taghizadeh-Hesary et al., 2022b; Tyson, 2021)

To date, there have been no green bond issuances in Ghana, whether sovereign or corporate. However, the government identifies GF, such as green bonds, as key to achieving Ghana's

NDCs, SDGs, and the National Development Plan. In particular, there is growing interest in exploring GF-in-GB, such as green mortgages, green loans for developers, and green bonds (FSD Africa, 2021). This has been identified as critical in solving Ghana's housing and social infrastructure deficits. Green loans and green mortgages for certified GB in Ghana are estimated at US$25.5 million (FSD Africa, 2021). To promote GF-in-GB in Ghana, this study assessed GF and the economic feasibility of GB. It is expected that the outcomes of this study will be useful to both green investors and green developers in mitigating GF-in-GB challenges, such as a lack of market understanding and pricing uncertainty. Additionally, the findings will be useful for developing and promoting a GF market for GBs in Ghana and other developing countries with conditions similar to those in Ghana.

3.11 Chapter Summary

Chapter 3 provided a review of relevant literature on the concepts and objectives of this study. This was necessary to identify the knowledge gaps, important factors of the various objectives as well as methodological gaps in the literature. In the end, proposed conceptual frameworks and a checklist of the principal drivers, barriers, risk factors, and strategies of GF-in-GB in Ghana were developed to aid the data collection from the experts. Finally, a review of previous cost-benefit studies and the development of GF in developing countries were provided, and the existing gaps were clearly defined. The next few chapters focus on objective-specific empirical results, data analysis, and findings and discussion of results.

CHAPTER 4 - ANALYSIS OF THE INTERRELATIONSHIP BETWEEN THE DRIVING FACTORS OF GREEN FINANCE IN GREEN BUILDING: THE CASE OF GHANA[5]

4.1 Introduction

The previous chapters focused on the introduction of this study, the research methodology adopted, and a review of relevant literature. In this chapter, partial findings from linguistic evaluation questionnaire surveys conducted in Ghana are reported. This chapter focuses on the interrelationships between the drivers of GF-in-GB in Ghana. To achieve the objectives of this chapter, a two-round linguistic evaluation questionnaire survey was conducted in Ghana, as described in Chapter 2. After a comprehensive literature review to identify the drivers of GF-in-GB, FDM, and FDEMATEL were used to screen out and model the relationship between the critical drivers, as described in the subsequent sections. The first section of this chapter presents the FDM results of the first round of the linguistic evaluation questionnaire survey. The second section focused on the FDEMATEL results from the second- and final-round linguistic evaluation questionnaire surveys. This chapter also discusses key findings, provides theoretical and practical implications as well as the study limitations. Finally, a summary of this chapter is provided.

A literature review indicates that few studies have attempted to analyse the factors driving GF-in-GB in developing countries (Akomea-Frimpong et al., 2022; Debrah et al., 2022a). In most cases, available studies identify and rank drivers without considering the interrelationship

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[5] This chapter is largely based upon:

Debrah, C., Chan, A.P.C., Darko, A., Ries R.J., Ohene, E. and Tetteh, M.O. (2024) Driving factors for the adoption of green finance in green building for sustainable development in developing countries: The case of Ghana. *Sustainable Development*. (Q1) between them. It is important to note that various drivers of GF-in-GB, albeit with varying degrees of criticality, do not act in isolation but establish complex interrelationships that shape the acceptance and implementation of GF. Without examining the interrelationships between these factors, if not impossible, it will be challenging to zero in on the most crucial ones and devise effective plans for implementing GF. The application of multi-criteria decision-making (MCDM) techniques has the capacity to analyse complicated interdependencies among factors. Novel methods were applied to identify the dependence relations between the drivers of GF-in-GB, which are currently lacking in the literature.

To this end, two specific research questions are addressed:

1. What are the critical drivers of GF-in-GB?
2. What is the cause-and-effect relationship between the drivers of GF-in-GB using MCDM techniques: FDM and FDEMATEL methods?

This study is important because it is the first to evaluate the interrelationship between GF-in-GB drivers using MCDM techniques. This study makes novel contributions by identifying important drivers based on the extant literature via expert inputs using FDM. It further applies the FDEMATEL method to prioritise the important drivers. The identification and prioritisation of drivers using the hybrid method provides a systematic way to analyse how to promote the most influential drivers. In addition, given the limited number of studies examining GF-in-GB in developing countries, the empirical findings add significantly to the existing GB and GF literature. Moreover, this study improves the understanding of the relevant drivers of GF-in-GB adoption and their interrelationships, which is necessary for guiding decision-making regarding GF-in-GB adoption by industrial practitioners and other stakeholders. The findings will also help policymakers and advocates to focus on and allocate resources to the most influential drivers that can be widely promoted to encourage the widespread adoption of GF-in-GB to meet Paris Agreement targets in their NDCs and ultimately achieve SDGs.

4.2 Results

Expert opinions were collected in FDM (round one) and FDEMATEL (round two). Sixteen criteria (Table 4.1) of the drivers of GF-in-GB were presented for FDM evaluation.

4.2.1 Fuzzy Delphi Results

Using Eqns. (2.1) and (2.2), the acceptance threshold is 0.521. The FDM results include the weights of the criteria and their thresholds. As presented in Table 4.1, all criteria with defuzzied weights below the threshold value were unacceptable and were removed.

Table 4.1 Drivers screening out – FDM (round one)

Criteria (Drivers)		Weights	Decision
DC1	Government participation and support for GF	0.515	Unaccepted
DC2	Regulatory incentives for GF	0.532	Accepted
DC3	Mandatory legislation, standards and climate-relative financial disclosures	0.514	Unaccepted
DC4	Favourable macroeconomic conditions and investment returns	0.532	Accepted
DC5	Improved access to and lower cost of capital	0.523	Accepted
DC6	Reduced business and financial risk	0.526	Accepted
DC7	Reasonable maturity/investment period	0.510	Unaccepted
DC8	Preferential capital requirements for low-carbon assets	0.524	Accepted
DC9	Improve corporate branding or reputation	0.513	Unaccepted
DC10	Institutional/peer pressure	0.513	Unaccepted
DC11	Management commitment	0.518	Unaccepted
DC12	Positive fundamentals or green credentials of issuer/developer	0.519	Unaccepted
DC13	Ecological and corporate social responsibility	0.505	Unaccepted
DC14	Climate commitment	0.525	Accepted
DC15	Promotion of responsible and ethical investment	0.534	Accepted
DC16	Increased awareness of GF models in GB	0.526	Accepted
	Threshold (α)	**0.521**	

4.2.2 Fuzzy DEMATEL Results

The interrelationship between the criteria (drivers) was evaluated by experts using a validated set of drivers, as listed in Table 4.1. The expert responses were defuzzied and normalised according to the following steps. The FDEMATEL process followed for the criteria is explained as follows. First, twelve 8x8 non-negative matrices were created, including:

1

E1 =

NE	H	L	VH	A	NE	A
NE	H	L	A	VH	A	NE
L	NE	A	H	L	H	H
H	VH	NE	H	A	L	NE
H	L	NE	NE	H	L	H
H	VH	A	H	NE	H	VH
L	A	H	VH	H	NE	L
H	L	A	V	H	L	NE

E2 =

NE	L	H	VH	H	A	H
L	NE	H	VH	H	A	H
H	H	NE	H	A	L	VH
VH	VH	H	NE	A	H	H
H	H	A	A	NE	VH	H
A	A	L	H	VH	NE	A
H	H	VH	H	H	A	NE
H	VH	H	VH	H	H	VH

E3 =

NE	A	H	H	H	H	A
A	NE	VH	H	H	A	H
H	VH	NE	H	H	H	H
H	H	H	NE	A	A	VH
H	H	H	A	NE	H	H
H	A	H	A	H	NE	VH
A	H	H	VH	H	VH	NE
H	H	H	VH	H	H	H

E4 =

NE	H	L	A	VH	A	NE
L	NE	A	H	L	H	H
H	VH	NE	H	A	L	NE
H	L	NE	NE	H	L	H
H	VH	A	H	NE	H	VH
L	A	H	VH	H	NE	L
H	L	A	V	H	L	NE
VH	A	L	H	H	L	H

E5 =

NE	H	L	A	VH	A	NE
L	NE	A	H	L	H	H
H	VH	NE	H	A	L	NE
H	L	NE	NE	H	L	H
H	VH	A	H	NE	H	VH
L	A	H	VH	H	NE	L
H	L	A	V	H	L	NE
VH	A	L	H	H	L	H

E6 =

NE	H	A	H	A	A	H
A	NE	H	H	H	A	H
H	H	NE	VH	H	A	H
H	H	H	NE	H	H	H
A	H	A	A	NE	H	H
H	A	H	H	H	NE	A
VH	H	H	H	H	H	NE
A	A	A	A	A	H	H

E7 =

NE	H	H	H	H	H	H
H	NE	H	H	H	H	H
H	H	NE	H	H	H	H
H	H	H	NE	H	H	H
H	H	H	H	NE	H	H
H	H	H	H	H	NE	H
H	H	H	H	H	H	NE
H	H	H	VH	H	H	H

E8 =

NE	A	A	A	H	H	VH
A	NE	VH	VH	VH	VH	VH
A	VH	NE	VH	VH	VH	VH
H	H	VH	NE	VH	VH	VH
H	H	H	VH	NE	H	VH
VH	VH	VH	H	H	NE	VH
VH	H	VH	H	H	VH	NE
VH	A	VH	H	VH	VH	VH

E9 =

NE	A	VH	H	A	VH	VH
A	NE	VH	VH	A	VH	H
H	H	NE	A	A	H	A
H	H	H	NE	A	VH	VH
A	A	A	A	NE	A	A
VH	H	VH	H	H	NE	VH
VH	VH	H	VH	A	H	NE
H	VH	VH	VH	A	VH	VH

E10 =

NE	VH	H	VH	VH	L	L
H	NE	VH	VH	VH	L	H
VH	VH	NE	VH	H	H	H
VH	VH	VH	NE	H	H	H
VH	VH	H	H	NE	VH	H
L	L	H	H	VH	NE	H
L	H	H	H	H	H	NE
VH	H	VH	VH	VH	VH	VH

E11 =

NE	VH	H	H	H	H	H
VH	NE	H	H	H	VH	H
H	H	NE	H	H	L	H
H	VH	H	NE	L	L	L
H	L	H	H	NE	H	H
L	L	H	L	H	NE	H
H	H	L	L	H	H	NE
L	L	H	L	L	L	L

E12 =

NE	H	L	A	VH	A	NE
L	NE	A	H	L	H	H
H	VH	NE	H	A	L	NE
H	L	NE	NE	H	L	H
H	VH	A	H	NE	H	VH
L	A	H	VH	H	NE	L
H	L	A	V	H	L	NE
VH	A	L	H	H	L	H

Second, the average matrix w was constructed following the steps outlined in Eqn. (2.3):

w =

0.0000	0.5257	0.4284	0.5251	0.6219	0.4600	0.3668	0.5446
0.3630	0.0000	0.5730	0.6393	0.4612	0.5416	0.5924	0.6307
0.5758	0.6864	0.0000	0.6070	0.4930	0.3797	0.3994	0.5846
0.6080	0.4933	0.4159	0.0000	0.5098	0.4281	0.5910	0.4859
0.5592	0.6059	0.4604	0.5260	0.0000	0.5918	0.6386	0.5213
0.3959	0.4110	0.5758	0.5900	0.6083	0.0000	0.4601	0.6159
0.5744	0.4620	0.5089	0.5752	0.5602	0.4607	0.0000	0.6642
0.6216	0.4759	0.4764	0.6056	0.5421	0.4604	0.6067	0.0000

Third, the normalised initial direct-relation matrix (D) is calculated using Eqns. (2.4) – (2.8):

$$U = w \times \frac{1}{\max\limits_{1 \le i \le 8} \sum_{j=1}^{8} a_{ij}}$$

0.0000	0.1347	0.1098	0.1345	0.1593	0.1178	0.0940	0.1395
0.0930	0.0000	0.1468	0.1638	0.1182	0.1388	0.1518	0.1616
0.1475	0.1759	0.0000	0.1555	0.1263	0.0973	0.1023	0.1498
0.1558	0.1264	0.1066	0.0000	0.1306	0.1097	0.1514	0.1245
0.1433	0.1552	0.1180	0.1348	0.0000	0.1516	0.1636	0.1335
0.1014	0.1053	0.1475	0.1512	0.1558	0.0000	0.1179	0.1578
0.1472	0.1184	0.1304	0.1474	0.1435	0.1180	0.0000	0.1702
0.1593	0.1219	0.1220	0.1552	0.1389	0.1180	0.1554	0.0000

Fourth, the total interrelationship matrix (T) was estimated using the following formula (Eqn. 2.9):

$$Y = U(I-U)^{-1} = \begin{vmatrix} 2.1820 & 2.2662 & 2.1149 & 2.4755 & 2.3560 & 2.0813 & 2.2495 & 2.4734 \\ 2.4499 & 2.3245 & 2.3146 & 2.6942 & 2.5072 & 2.2593 & 2.4732 & 2.6829 \\ 2.4453 & 2.4314 & 2.1432 & 2.6381 & 2.4666 & 2.1862 & 2.3890 & 2.6237 \\ 2.3460 & 2.2871 & 2.1412 & 2.3875 & 2.3633 & 2.0998 & 2.3209 & 2.4904 \\ 2.5415 & 2.5122 & 2.3426 & 2.7301 & 2.4576 & 2.3199 & 2.5353 & 2.7205 \\ 2.3787 & 2.3445 & 2.2420 & 2.5992 & 2.4572 & 2.0672 & 2.3693 & 2.5947 \\ 2.4918 & 2.4303 & 2.2997 & 2.6798 & 2.5270 & 2.2430 & 2.3398 & 2.6879 \\ 2.4888 & 2.4211 & 2.2822 & 2.6727 & 2.5115 & 2.2322 & 2.4622 & 2.5294 \end{vmatrix}$$

Table 4.2 presents the direct and indirect effects of the eight evaluated criteria. Finally, the threshold value (Eqn. 2.9) was computed to obtain the average of the elements in the matrix T, which was 2.4090. A diagraph of these eight criteria is shown in Fig. 4.1.

Table 4.2 The sum of influence given and received among the eight criteria

	Criteria	D + R	DEMATEL ranking of prominence/importance	D – R	Cause-effect ranking
DC14	Climate commitment	36.5418	8	1.5640	1
DC5	Improved access to and lower cost of capital	37.2040	7	1.4432	2
DC4	Favourable macroeconomic conditions and investment returns	38.7230	5	0.6887	3
DC15	Promotion of responsible and ethical investment	38.8386	4	0.5600	4
DC8	Preferential capital requirements for low-carbon assets	39.8058	2	0.5132	5
DC2	Regulatory incentives for GF	37.5227	6	-1.1252	6
DC16	Increased awareness of GF models in GB	40.4029	1	-1.2028	7
DC6	Reduced business and financial risk	39.3134	3	-2.4410	8

From Table 4.2, the prominence or importance of the eight criteria can be prioritised as DC16 > DC8 > DC6 > DC15 > DC4 > DC2 > DC5 > DC14 based on the $(D + R)$ values, where increased awareness of GF models in GB is the most important criterion with a value of 40.4029. In contrast, climate commitment (DC14), improved access to and lower cost of capital (DC5), favourable macroeconomic conditions and investment returns (DC4), promotion of responsible and ethical investment (DC15), and preferential capital requirements for low-carbon assets (DC8) are net causes, whereas regulatory incentives for GF (DC2), increased awareness of GF models in GB (DC16), and reduced business and financial risks (DC6) are net effects based on $(D - R)$ values. Table 4.3 summarises the drivers with the highest prominence and net cause-effect values.

Table 4.3 Drivers with the highest prominence and net cause-effect values.

	Criteria	Most prominent drivers	Key cause drivers
DC2	Regulatory incentives for GF		✓
DC4	Favourable macroeconomic conditions and investment returns	✓	
DC5	Improved access to and lower cost of capital	✓	
DC6	Reduced business and financial risk		✓
DC8	Preferential capital requirements for low-carbon assets	✓	
DC14	Climate commitments	✓	
DC15	Promotion of responsible and ethical investment	✓	
DC16	Increased awareness of GF models in GB		✓

Fig. 4.1 illustrates the causal relations among the eight GF-in-GB criteria. It shows that criterion DC5 (improved access to and lower cost of capital) is not affected by others but affects DC8 (preferential capital requirements for low-carbon assets) and DC2 (regulatory incentives for GF). Generally, pairs (DC4 and DC8) and (DC2 and DC16) are mutually influenced by each other. It was also observed that DC6 (reduced business and financial risk) had the greatest impact when most drivers were promoted. Finally, while criterion DC14 (climate commitment) had the highest net cause, it had a medium impact on DC6 and DC16.

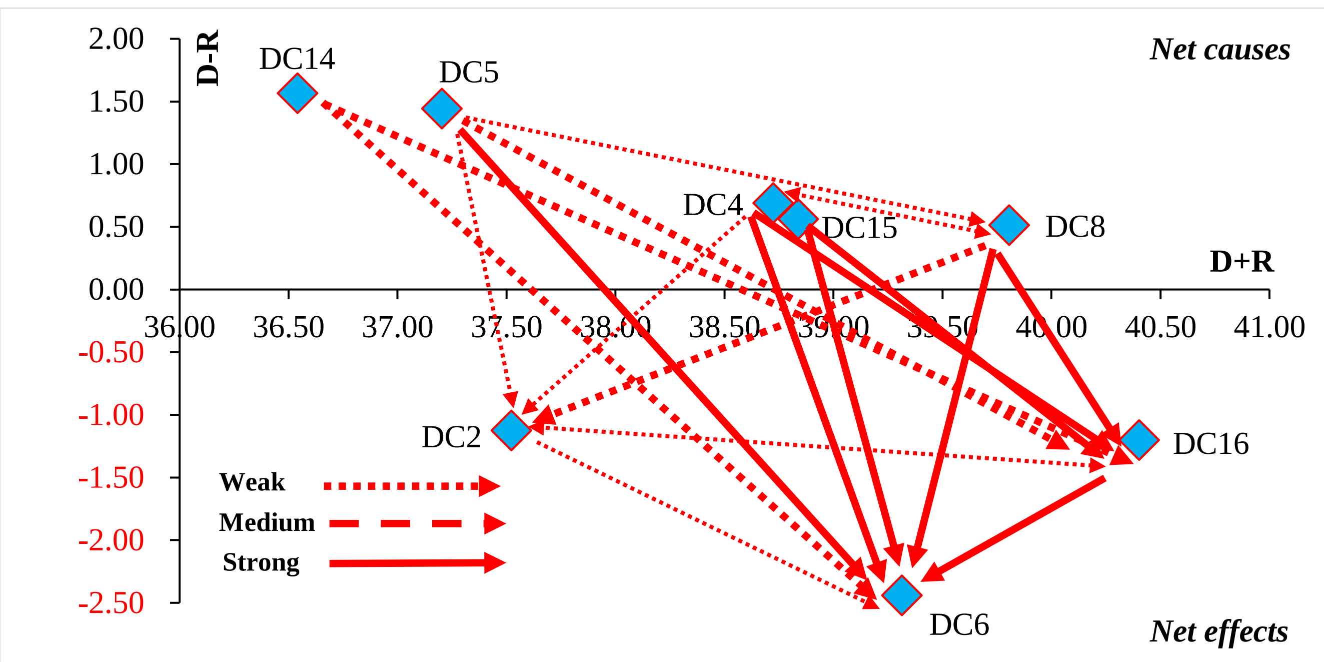

Fig. 4.1 The diagraph shows the causal relationships among these eight criteria
All double-headed arrows show two-way relationships or interdependence. For instance, weak relationships exist between these drivers: DC4 and DC8 and DC2 and DC16. This means that they exhibit the same effect on each other; therefore, focusing on either of the two yields the same results.

4.2.3 Summary of Findings

From Tables 4.1 and 4.2 and Fig. 4.1, drivers with the highest net cause (D – R) values had the greatest long-term impact on the entire system; therefore, they should receive more attention. Similarly, drivers with the highest prominence values have the potential to affect and/or be affected by other drivers; therefore, managers and policymakers should prioritise promoting or pursuing these drivers in the short term.

In summary, GF-in-GB actors and policymakers should focus more on five causes (DC14, DC5, DC4, DC15, and DC8) than on effect-group drivers (DC2, DC16, and DC6). DC5 (improved access to and lower cost of capital) is a key criterion because it is not affected by other criteria. Improving access to and lower cost of capital or GF promotes other drivers such as DC8 (preferential capital requirements for low-carbon assets), DC2 (regulatory incentives for GF), and DC6 (reduced business and financial risks). However, improved access to and lower cost of capital (DC5) ranks seventh in terms of importance. This may explain the weak impact of driver DC5 on DC8 and DC2 since they rank higher. On the contrary, while DC6 has higher prominence than DC5, DC5 is a stronger cause of driver DC6. As shown in Fig. 4.2, if most drivers are promoted, the business and financial risks associated with GF-in-GB are reduced. Therefore, it is not necessary to focus on reducing the business and financial risks of GF-in-GB because it is the major net receiver of the promotional results of the majority of the drivers of GF-in-GB. Preferential capital requirements for low-carbon assets (DC8) and favourable macroeconomic conditions and investment returns (DC4) rank second and fifth, respectively, in terms of prominence $(D + R)$. These two criteria are very important because they mutually have a strong effect on several drivers: DC2, DC6, and DC16.

4.3 Discussion of Key Findings

4.3.1 Managerial and Practical Implications

GF presents a great business opportunity for GB investors and developers to overcome several cost-related barriers, such as inadequate capital and higher investment costs (Debrah et al., 2022a). This is a way to allocate financial resources to the economy to support sustainable development and fight climate change in the built environment. GF can support efforts from countries to shift from conventional construction to GB and promote green retrofits, as outlined in the NDCs emerging from the Paris Agreement (Debrah et al., 2022d). Therefore, it is important to understand how different factors promote the growth of GF-in-GBs. Evaluating how these drivers interact with each other is critical to focusing on the most prominent drivers and understanding how to allocate constrained resources to influential drivers based on the cause-effect matrix using the fuzzy-Delphi-DEMATEL method (Farooque et al., 2020; Negash et al., 2021). The study results reveal that "improved access to and lower cost of capital" is a key criterion because it is not affected by other criteria. Consequently, improving access to and lowering the cost of capital or GF is very important for promoting other drivers, such as preferential capital requirements for low-carbon assets, regulatory incentives for GF, and reduced business and financial risks. This is because these drivers belong to the effect-group and are net receivers of the results of improving access to and lowering the cost of capital or GF. Previous studies argue that if stakeholders have increased access to GF with a lower cost of finance, the business and financial risk associated with investment may be reduced (Agliardi and Agliardi, 2021). Policymakers may, therefore, focus on promoting increased access to GF and lowering the cost of finance for GBs. Focusing more on this may drive acceptance of GF-in-GB in the built environment (Akomea-Frimpong et al., 2022). Actors who intend to reduce their business and financial risks may utilise GF to fund GB projects. Green banks involved in GF-in-GB can reduce non-performing loans and transaction costs, as well as increase their investment portfolio of low-carbon assets and reduce their carbon footprints (Cui et al., 2018; Debrah et al., 2022c). Small and medium GB firms that struggle to access finance because of their high collateral requirements would be reduced through access to GF (Debrah et al., 2022a; Zhang et al., 2021).

Moreover, drivers DC8 and DC4 (preferential capital requirements for low-carbon assets, favourable macroeconomic conditions, and investment returns) mutually affect several drivers: regulatory incentives for GF, reduced business and financial risk, and increased awareness of GF models in GB. Tolliver et al. (2020) revealed that macroeconomic factors such as trade openness, size of the economy or GDP, and stock market capitalisation positively influence GF issuance volumes. It is not surprising that "favourable macroeconomic conditions" are identified as highly prominent and influence other drivers. Again, the results of the present study demonstrate that preferential capital requirements for low-carbon assets influence other drivers of GF. Previous studies (Tolliver et al., 2020) have shown that institutional factors such as regulatory quality promote GF. To meet these climate goals, several governments have introduced penalising capital requirements for high-carbon assets and preferential capital treatment for low-carbon assets (Sangiorgi and Schopohl, 2021). Mandatory climate-relative financial disclosures included in GF indices, GF certification, and international credit ratings that integrate environmental risk analysis are known GF drivers (Sangiorgi and Schopohl, 2021). Similarly, due to the increasing investor preference for low-carbon investments amidst a favourable economic situation within a country, more awareness of GF models and products will be created. Awareness is critical for the promotion of GF-in-GBs (Akomea-Frimpong et al., 2022). The results showed that climate commitment has a high net cause and is highly influential in the GF-in-GB system. This suggests that climate commitment to achieving the Paris Agreement Goals and SDGs in the built environment should be pursued intensively. Research has shown that the world will face much danger if emissions are not rapidly reduced, according to the Paris Agreement. The recent wildfire destruction of forests, homes, and lives has made climate commitments even more urgent (UNEP, 2022). Climate commitment also creates new business opportunities (Agyekum et al., 2021). For instance, using the NDCs of countries, Debrah et al. (2022d) explained the potential of GF-in-GB in the global economy and available investment opportunities. In addition, Tolliver et al. (2019, 2020) demonstrated that NDCs to the Paris Agreement have the largest impact on GF drivers. Therefore, public and private participation in realising climate commitment is likely to strongly influence GF-in-GB's other driving factors.

4.3.2 Theoretical Implications

This study has several theoretical implications for sustainability research. First, financial, regulatory, organisational, environmental, and social drivers interact to drive GF-in-GB adoption and implementation. It was found that unique GF drivers, such as climate commitment, had the highest net cause and could exert a strong influence on GB investment. Other drivers, such as improved access to and lower cost of capital, favourable macroeconomic conditions and investment returns, promotion of responsible and ethical investment, and preferential capital requirements for low-carbon assets, are net causes, whereas regulatory incentives for GF, increased awareness of GF models in GB, and reduced business and financial risks belong to the effect-group and are net receivers. This study makes novel contributions by identifying the most prominent drivers using the FDM and FDEMATEL. The identification and prioritisation of drivers using the MCDM method provides a systematic way to analyse how to promote the most influential drivers. As one of the few empirical studies to present the major driving factors and their interrelationships in a developing country, the findings will add significantly to the existing GB and GF literature.

4.4 Chapter Summary, Contributions, and Limitations

In this chapter, the relationship between the critical drivers of GF-in-GB is presented. The identified drivers were validated using FDM. FDEMATEL was applied to identify the interdependence of the eight driver criteria. The FDEMATEL method is based on FDM results. The findings show that increased awareness of GF models in GB is the most important criterion, with a value of 40.4029. In contrast to the importance criteria, climate commitments, improved access to and lower cost of capital, favourable macroeconomic conditions and investment returns, promotion of responsible and ethical investment, and preferential capital requirements for low-carbon assets are net causes, whereas regulatory incentives for GF, increased awareness of GF models in GB, and reduced business and financial risks belong to the effect-group and are net receivers. Drivers with the highest prominence values have the potential to affect and/or be affected by other drivers, and therefore, managers and policymakers should prioritise promoting or pursuing these in the short term. Similarly, drivers with the highest net cause values have the greatest long-term impact on the entire system; therefore, they should receive more attention than equal attention.

Despite its contributions, this study had several limitations. Given the novelty of GF applications in GB research and practice, the analysis presented in this study was based on the results of 12 experts with GF and GB experience in Ghana. Future research should consider a larger scale in terms of the number of respondents. This study can be extended to other developing and developed countries. Future research incorporating distinct perspectives of different stakeholders of GF-in-GB, such as issuers, investors, developers, governments, and non-governmental organisations, may provide a further understanding of how different stakeholders perceive different drivers. Forecasting the effects of drivers in a GF-in-GB system can be achieved using neural networks and adaptive fuzzy-inference systems. Intelligent models can be applied to explain how the identified influential GF-in-GB drivers can be optimized amidst constraints for maximum impact.

CHAPTER 5 - ANALYSIS OF THE INTERRELATIONSHIP BETWEEN THE CRITICAL BARRIERS TO GREEN FINANCE IN GREEN BUILDING IN DEVELOPING COUNTRIES: THE CASE OF GHANA

5.1 Introduction

The previous chapter focused on the analysis and discussion of the interrelationship between the drivers of GF-in-GB. This chapter presents the findings of the linguistic evaluation questionnaire surveys on the interrelationships between barriers to GF-in-GB in Ghana. To achieve the objectives of this chapter, a two-round linguistic evaluation questionnaire survey was conducted in Ghana, as described in Chapter 2. After a comprehensive literature review to identify the barriers to GF-in-GB, FDM, and FDEMATEL were used to screen out and model the relationship between the critical barriers, as described in the subsequent sections. The first section of this chapter presents the FDM results of the first round of the survey. The second section focused on the FDEMATEL results from the second and final-round questionnaire surveys. This chapter also discusses key findings, provides theoretical and practical implications, and the study’s limitations. Finally, a summary of this chapter is provided.

The findings of this chapter are critical for addressing the gap in the lack of studies that consider the influences and relationships between the barriers of GF-in-GB under fuzzy environments. This study quantitatively and objectively assessed the interactions between barriers to GF-in-GB via two-step FDEMATEL. The findings of this study are crucial to understanding the most important barriers and their causal effects.

5.2 Results

5.2.1 Fuzzy Delphi Method

FDM was used to assess 22 criteria of barriers to GF-in-GB (see Table 5.1). Based on Eqns. 2.1 and 2.2, the acceptance threshold was 0.525. As presented in Appendix B.1, the FDM results comprise criteria weights and thresholds. All criteria with defuzzied weights less than the acceptable threshold were excluded. Table 5.1 presents the 16 accepted barrier criteria and aggregated fuzzy weights.

Table 5.1 FDM of identified barriers to GF-in-GB in Ghana

Barriers	Criteria		Weights
Financial barriers (B1)	BC1	Split incentives	0.527
	BC4	Capital adequacy & liquidity issues	0.531
	BC6	Economic instability	0.555
Regulatory barriers (B2)	BC7	Policy & regulatory uncertainty	0.530
	BC9	Regulatory requirement	0.525
Organisational barriers (B3)	BC10	Greenwashing	0.526
	BC11	Inadequate management support	0.525
	BC12	Inadequate private investment	0.539
Technical barriers (B4)	BC15	Technological uncertainty	0.526
Structural barriers (B5)	BC16	Limited green projects	0.534
	BC17	Lack of harmonised global standards & guidelines	0.528
	BC18	Risks perception	0.531
	BC19	Lack of universal definition for “green projects”	0.526
	BC20	Inadequate transparency and consistency with GF	0.542
	BC21	Information asymmetry	0.534
	BC22	Lack of quality historical data	0.538

The interactions among the barriers were evaluated by experts using a linguistic scale based on the validated barriers and criteria. The qualitative data of the experts were translated into matching TFNs. Expert responses were normalised, left and right values were approximated, and overall crisp values were computed using Eqns. 2.3-2.4.

5.2.2 Fuzzy DEMATEL

Appendix B.2 – B.3 provide the results obtained by, for example, Expert 1 and the defuzzification process. The IDRM (Table 5.2) was derived using Eqns. 2.7 by averaging the crisp values from all 12 respondents.

Table 5.2 Initial direct relation matrix

	B1	B2	B3	B4	B5	Sum
B1	0.000	0.703	0.616	0.745	0.656	2.724
B2	0.659	0.000	0.967	0.701	0.716	3.042
B3	0.457	0.748	0.000	0.620	0.590	2.415
B4	0.423	0.575	0.664	0.000	0.748	2.410
B5	0.494	0.796	0.787	0.664	0.000	2.742
					Max	3.042

Eqns. 2.8-2.11 were then used to create the total interrelationship matrix of the barriers and their driving and dependence power. Tables 5.3 and 5.4 present the causal interrelationships between the barriers.

Table 5.3 Total interrelationship matrix of GF-in-GB barriers

	B1	B2	B3	B4	B5	D
B1	(0.150)	0.078	0.020	0.103	0.062	0.114
B2	0.099	(0.233)	0.163	0.061	0.070	0.159
B3	0.037	0.122	(0.203)	0.068	0.054	0.077
B4	0.025	0.039	0.067	(0.176)	0.129	0.084
B5	0.037	0.119	0.095	0.066	(0.201)	0.116
R	0.048	0.125	0.141	0.122	0.115	0.022

Table 5.4 Driving and dependence powers of GF-in-GB barriers

	D	R	D+R	D-R
B1	0.114	0.048	0.162	0.066
B2	0.159	0.125	0.284	0.034
B3	0.077	0.141	0.218	(0.063)
B4	0.084	0.122	0.206	(0.038)
B5	0.116	0.115	0.230	0.001
Max			0.284	0.066
Min			0.162	(0.063)
Average			0.220	0.000

The barriers are divided into causal group barriers on the positive side of the (D-R) axis: financial barriers (B1), regulatory barriers (B2), and structural barriers (B5). Technical barriers (B4) and organisational barriers (B3) belong to the effect group. As shown in Table 5.3 and Fig. 5.1, regulatory barriers (B2) were the most significant barriers and can cause or prevent other GF-in-GB barriers. Regulatory barriers had the highest score (0.284) among all barriers. This implies that it has the most significant influence on the entire GF-in-GB system. This was followed by structural barriers (0.230), organisational barriers (0.218), and technical barriers (0.206). Financial barriers (0.162) had the least important index. Financial barriers had the highest cause index (0.066) among all barriers. Technical barriers (-0.038) and organisational barriers (-0.063) belong to the effect group because of their negative cause index. Fig. 5.1 presents the causal interactions among the GF-in-GB barriers.

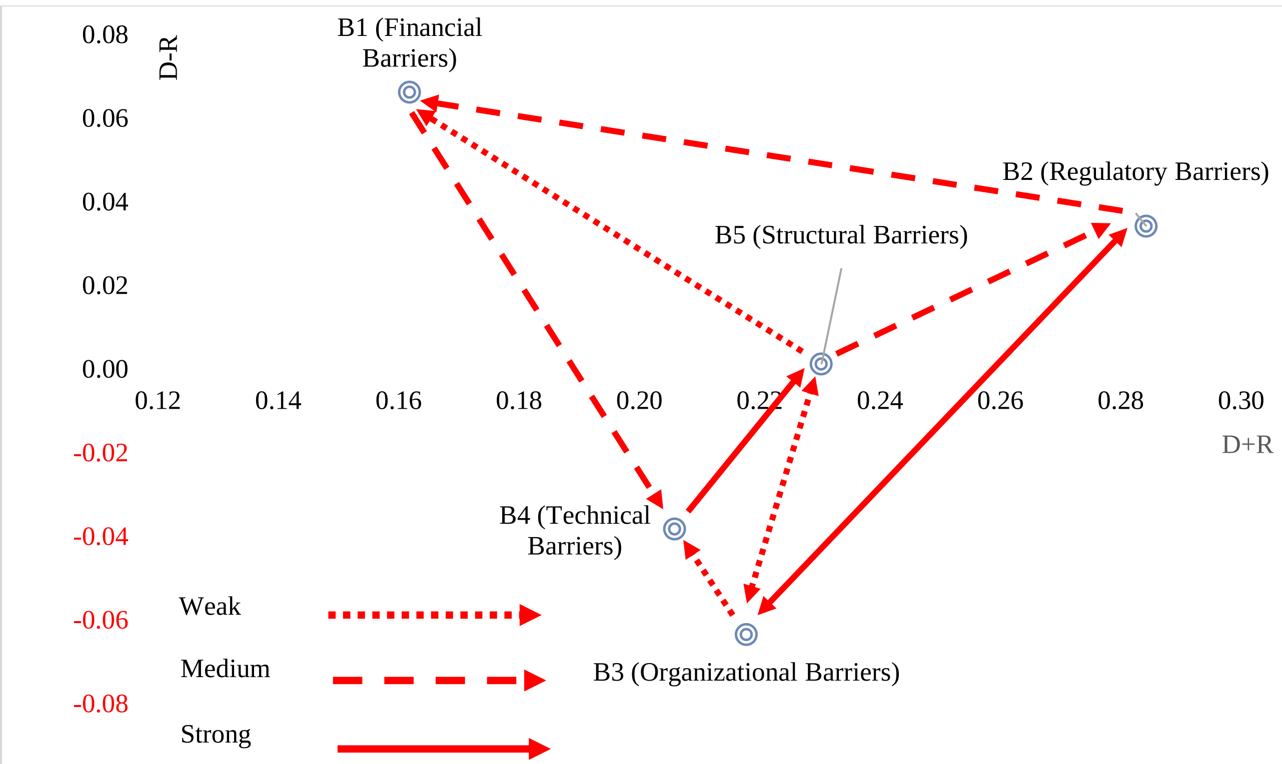

Fig. 5.1 Causal interrelationship diagram among barriers.

The literature (Addae et al., 2019; Lin et al., 2018) shows that two-step FDEMATEL thrives on the concept that barriers found in the "cause groups" (those with positive cause index), tend to affect the whole system and give rise to other barriers. Such barriers are critical because they can impact those in the "effect group."

To obtain the total interrelationship matrix of the barrier criteria and the importance and cause index of the criteria, Eqns. 2.8-2.11 were repeated, and the results are presented in Tables 5.4 and

5.5. Among these, risk perception (BC18) had the highest global importance index (48.980). Considerable attention must be paid to this barrier when implementing GF-in-GBs because the results show it is the most important barrier in the entire GF-in-GB system. In addition, greenwashing (BC10) had the lowest global importance score of 43.808, indicating that it has the lowest potential to influence the GF-in-GB barrier system among all the criteria; therefore, devoting too much attention to this criterion is unnecessary. Comparatively, the structural barriers criteria had higher importance indexes, followed by organisational barriers, financial barriers, and regulatory barriers. The global importance index, as shown in Fig. 5.2, integrates the importance scores of each criterion.

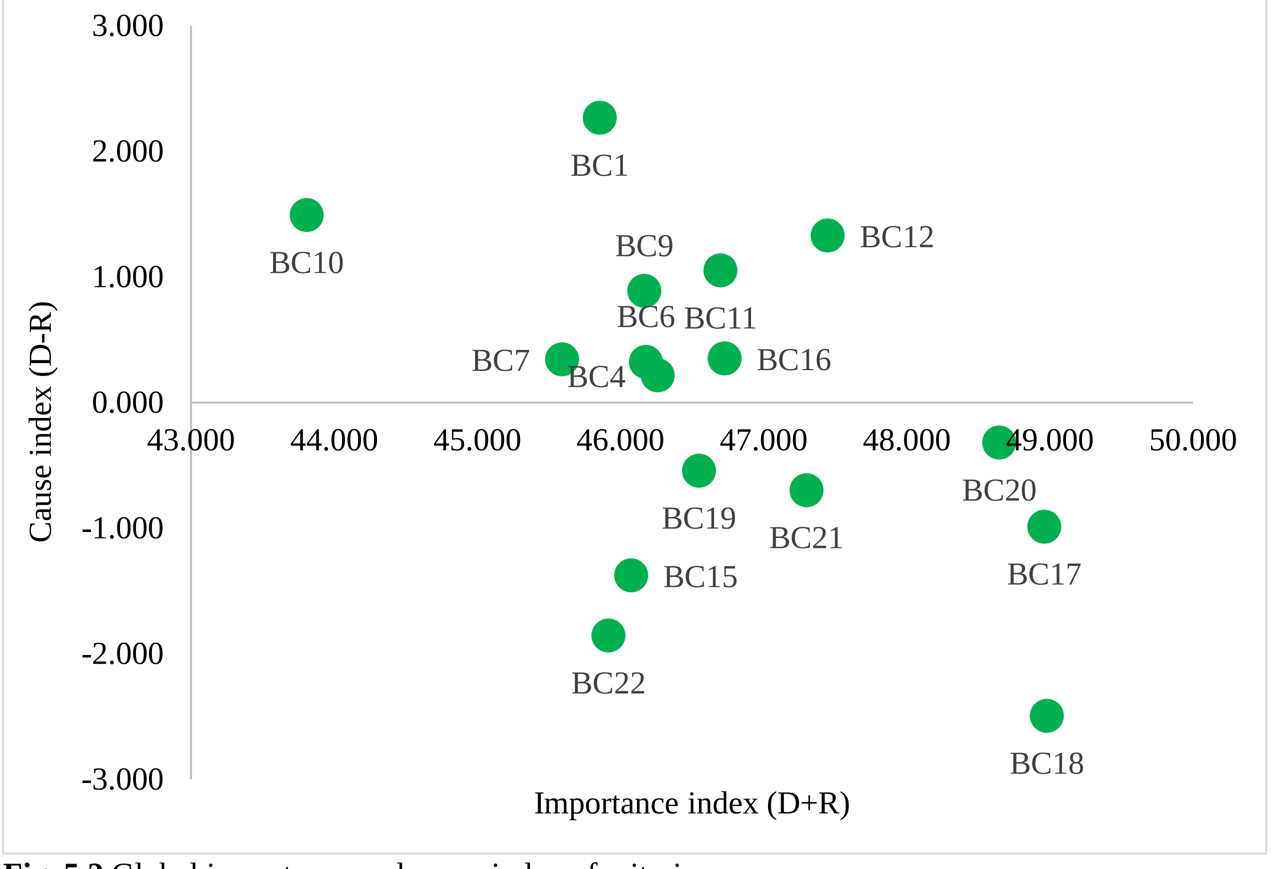

Fig. 5.2 Global importance and cause index of criteria.

Table 5.5 Total interrelationship matrix of criteria

	BC1	BC4	BC6	BC7	BC9	BC10	BC11	BC12	BC15	BC16	BC17	BC18	BC19	BC20	BC21	BC22	D
BC1	1.345	1.493	1.485	1.472	1.472	1.373	1.463	1.498	1.532	1.498	1.586	1.667	1.519	1.592	1.527	1.541	24.062
BC4	1.358	1.372	1.438	1.411	1.411	1.318	1.429	1.434	1.480	1.446	1.545	1.602	1.476	1.530	1.497	1.491	23.239
BC6	1.381	1.455	1.368	1.416	1.416	1.315	1.425	1.437	1.490	1.445	1.554	1.591	1.464	1.518	1.486	1.491	23.251
BC7	1.357	1.445	1.425	1.370	1.386	1.308	1.419	1.442	1.456	1.452	1.563	1.634	1.454	1.456	1.458	1.346	22.969
BC9	1.375	1.449	1.452	1.372	1.372	1.330	1.447	1.453	1.499	1.476	1.579	1.638	1.489	1.550	1.523	1.524	23.528
BC10	1.321	1.384	1.386	1.370	1.370	1.231	1.398	1.403	1.439	1.402	1.520	1.549	1.433	1.501	1.476	1.469	22.651
BC11	1.396	1.480	1.468	1.452	1.452	1.347	1.398	1.471	1.518	1.484	1.607	1.648	1.505	1.577	1.528	1.545	23.876
BC12	1.439	1.501	1.493	1.486	1.486	1.377	1.491	1.442	1.557	1.518	1.628	1.677	1.541	1.608	1.575	1.571	24.389
BC15	1.308	1.373	1.383	1.350	1.350	1.268	1.367	1.390	1.362	1.393	1.502	1.550	1.419	1.468	1.436	1.429	22.349
BC16	1.385	1.451	1.454	1.434	1.434	1.329	1.433	1.469	1.492	1.400	1.573	1.614	1.500	1.542	1.516	1.513	23.540
BC17	1.388	1.486	1.475	1.445	1.445	1.382	1.470	1.477	1.536	1.481	1.538	1.663	1.520	1.591	1.554	1.535	23.987
BC18	1.350	1.441	1.436	1.420	1.420	1.309	1.424	1.441	1.481	1.436	1.564	1.532	1.456	1.530	1.497	1.504	23.243
BC19	1.336	1.412	1.420	1.405	1.405	1.297	1.410	1.416	1.468	1.441	1.538	1.590	1.389	1.512	1.482	1.480	23.004
BC20	1.417	1.495	1.480	1.458	1.458	1.377	1.473	1.492	1.537	1.510	1.628	1.662	1.523	1.523	1.565	1.566	24.164
BC21	1.358	1.424	1.413	1.411	1.411	1.343	1.433	1.445	1.486	1.444	1.567	1.606	1.461	1.538	1.438	1.522	23.302
BC22	1.279	1.361	1.349	1.351	1.351	1.255	1.344	1.347	1.393	1.364	1.483	1.513	1.396	1.446	1.442	1.358	22.031
R	21.794	23.022	22.927	22.624	22.639	21.158	22.824	23.060	23.726	23.189	24.974	25.737	23.545	24.483	23.998	23.886	1.459

Table 5.6 Total interrelationship matrix of GF-in-GB barriers

	BC1	BC4	BC6	BC7	BC9	BC10	BC11	BC12	BC15	BC16	BC17	BC18	BC19	BC20	BC21	BC22
D	24.062	23.239	23.251	22.969	23.528	22.651	23.876	24.389	22.349	23.540	23.987	23.243	23.004	24.164	23.302	22.031
R	21.794	23.022	22.927	22.624	22.639	21.158	22.824	23.060	23.726	23.189	24.974	25.737	23.545	24.483	23.998	23.886
D+R	45.856	46.261	46.178	45.593	46.167	43.808	46.700	47.448	46.075	46.728	48.961	48.980	46.549	48.647	47.300	45.917
D-R	2.268	0.216	0.325	0.345	0.889	1.493	1.052	1.329	(1.377)	0.351	(0.987)	(2.493)	(0.541)	(0.319)	(0.697)	(1.854)

5.3 Discussion of Key Findings

This section elucidates the key findings of the study. Here, the barriers with higher global importance indexes are discussed. Then, the barriers that belong to the cause-effect group are expounded. Finally, the criteria that showed highly important and causal indexes are discussed.

5.3.1 Barriers with Higher Global Importance Index

Regulatory barriers emerged as barriers with the highest global importance index among all the barriers. This implies that it has the most significant influence on the entire GF-in-GB system. Regulations impact the adoption of sustainability in construction (Negash et al., 2021), and GF-in-GB is the major source of other barriers, such as organisational and technical barriers. The lack of existing guidelines and regulations has been stressed as a key constraint on GF in Ghana. In addition, the lack of requirement for credit risk ratings in Ghana remains a challenge to the issuance of GF products, such as green bonds in the country (FSD Africa, 2021). Agyekum et al. (2020) also identified changing government policy as a key obstacle to GB project financing in Ghana. These regulatory barriers lead to policy uncertainty (Nelson and Pierpont, 2013). Such uncertainties restrain private sector participation in GF. Addressing regulatory barriers, such as the lack of existing guidelines or regulations (FSD Africa, 2021) and changing government policies (Nelson and Pierpont, 2013), can effectively remove organisational and technical barriers. The government and other stakeholders must assess how regulations and policies can positively impact the development of GF-in-GB. In doing so, the development of local guidelines and regulations for GF is key, particularly for GBs. Thus, the government must actively regulate the green capital market. Considering the current economic conditions, best practices from other developed countries and those in the sub-region can be adapted to the peculiar case in Ghana. As a result, the uncertainties characterised by the implementation of GF in a novel Ghanaian capital market will be lessened, and eventually, investors will be more confident.

The second most important barrier was the structural barriers. They include limited green projects (Deschryver and De Mariz, 2020; FSD Africa, 2021), lack of harmonised global standards & guidelines (FSD Africa, 2021; Taghizadeh-Hesary et al., 2022b), risks perception (Agyekum et al., 2020), lack of universal definition for "green projects" (Akomea-Frimpong et al., 2022; Paranque and Revelli, 2019), inadequate transparency and consistency with GF, information asymmetry (Cheung et al., 2022; Schuetze, 2020), and lack of quality historical data (Agyekum et al., 2020). For instance, Ghana lacks a pipeline developed for eligible green projects (Deschryver and De Mariz, 2020; FSD Africa, 2021). In addition, Agyekum et al. (2020) stress barriers such as the lack of credible historical information or databases on green projects and the various risk perceptions associated with green project financing in Ghana. Since these structural (also known as market) barriers prevent new entrants to the GF market in Ghana, addressing them is critical for promoting GF-in-GB. For example, the results suggest that GF-in-GB is hindered by a lack of quality historical databases, which may further lead to information asymmetry among GF investors and suppliers. To overcome this, the Ghana government could create a public repository or database to track future sovereign green bonds to finance GBs and their performance. With such transparency from the government, commercial developers, non-private building owners, corporate building owners, and private green banks could also be encouraged to share data on their corporate green bonds for GBs with the database to increase access to information on GF. The proposed Ghana GF-in-GB database could be a comprehensive resource on GB and GF costs, including cost breakdowns for GB, indices, location-adjustment factors, and GF data (such as issuer, size, tenor, financing costs, verifier and/or external review reports, green certification reports, use of and management of proceeds, etc.).

The third most important barrier was the organisational barriers. The identified organisational barriers include greenwashing (Berensmann and Lindenberg, 2016; Deschryver and De Mariz, 2020; Taghizadeh-Hesary et al., 2022), inadequate management support (FSD Africa, 2021), and inadequate private investment (Clark et al., 2018; Dmuchowski et al., 2021; Kann, 2009). Taghizadeh-Hesary et al. (2022) noted that there are emerging concerns about how the majority of GF issued revealed no positive environmental impact; hence, a lot of greenwashing exists. Again, there is evidence of very low and insufficient private sector participation in GF to meet growing global needs (Clark et al., 2018). To overcome this challenge, the government should provide leadership by engaging the private sector and sensitising market participants to GF opportunities in the country, as well as providing green incentives (FSD Africa, 2021). For example, the government of Ghana could provide financial incentives, such as tax breaks, tax credits, government grants, and guarantees, to motivate the adoption of GF-in-GB. Others could be in the form of non-financial incentives such as discounted development application fees and expedited permitting (Debrah et al., 2022a). These financial and non-financial green incentives could serve as motivators for increased private sector participation and management support for GF-in-GB. As a result, there would be no incentive for greenwashing.

Regarding criteria, as presented in Table 5.5, risk perception (BC18) emerged as the criterion with the highest global importance index. This was followed by “lack of harmonised global standards & guidelines” (BC17), “inadequate transparency and consistency with GF” (BC20), “inadequate private investment” (BC12), and “information asymmetry” (BC21), respectively. These criteria are the top five barriers with the highest global importance indices. In comparison, it is observed that structural barriers criteria have higher importance indexes followed by organisational barriers, financial barriers, and regulatory barriers.

5.3.2 Cause-Effect Barriers

The second category included barriers that belonged to the cause-effect group. The cause group barriers are those with positive cause indexes that tend to affect the entire GF-in-GB system, thereby leading to other barriers (Addae et al., 2019; Lin et al., 2018). Barriers with negative cause indexes belong to the effect group. The cause barriers are deemed critical because of their potential influence on the effect barriers. As indicated in Table 5.6, financial, regulatory, and structural barriers were found in cause group barriers. Hence, they have the potential to give rise to additional barriers such as technical and organisational barriers. Among the cause group barriers, financial barriers had the highest cause index. This implies that it had the greatest impact on the entire GF-in-GB barrier system. These barriers arise when the high costs make it difficult to afford green activities.

Consequently, financial difficulties impede the implementation of GB. GF highly depends on favourable macroeconomic conditions, such as stable inflation and foreign exchange rates (Akomea-Frimpong et al., 2022; Kats, 2003; Tolliver et al., 2020). In addition, the perception of uncertain GB benefits (Agyekum et al., 2020) creates a mismatch between issuers' and investors' expectations (FSD Africa, 2021). This could be addressed by structuring GF products through a certification process that shows the tangible benefits of GF-in-GB (Shishlov et al., 2016; Yamahaki et al., 2020). Issues such as green bond pricing premiums are achievable through corporate green bonds and long-term institutional investors (Wang et al., 2020). In the long term, developing countries may experience pricing benefits enjoyed by highly rated issuers in developed countries. The inability of institutional investors in Ghana to identify and quantify credit and market risks associated with investments in debt instruments (FSD Africa, 2021) can be improved through GF workshops. The government must take the initiative of organising training for government officials and finance and investment experts to increase the awareness and knowledge of GF. Successful green bond issuances from sub-Saharan African countries such as Nigeria, Kenya, Namibia, and South Africa (FSD Africa, 2021; Taghizadeh-Hesary et al., 2022b) are pivotal to developing the Ghanaian GF market and training experts. In doing so, regulations must consider the collateral and liquidity requirements and the ability of SMEs in Ghana to participate in the GF market. Increasing green loans, which are usually smaller in volume and done privately (IFC, 2021), and green securitisation could be the starting point. For instance, green securitisation is now required to access debt capital market financing for small-scale low-carbon, and climate-resilient assets, particularly GBs (CBI, 2018). They provide avenues for increasing access to capital and decreasing capital costs for SMEs. From the results (Table 5.6), financial barriers belong to the cause group and can lead to effect-group barriers, such as technical and organisational barriers. As explained above, adopting the above strategies to eliminate the identified financial barriers would address the underlying cause and lead to the reduction of barriers such as inadequate private investment (organisational barriers) and technological uncertainty (technical barriers).

Regulatory barriers were the second most important cause group barriers. This means that they have a powerful influence on the entire GF-in-GB system and, to some extent, drive technical and organisational barriers. As noted, regulations affect the adoption of sustainability in construction, and GF-in-GB is the major source of other barriers, such as organisational and technical barriers. Addressing regulatory barriers, such as a lack of existing guidelines or regulations (FSD Africa, 2021) and changing government policies (Nelson and Pierpont, 2013), is critical to eliminating other barriers in the GF-in-GB system. For instance, literature shows that the local issuance of guidelines for GF products, such as green bonds, provides additional information to the local market. Providing such a regulatory environment helps to avoid organisational barriers, such as greenwashing. This provides further data on private sector engagement and participation in the GF market. Hence, addressing regulatory barriers such as “policy and regulatory uncertainty” and “regulatory requirements” is necessary to develop a nascent GF-in-GB market, especially in developing countries such as Ghana. Therefore, the government should adopt a holistic approach to develop GF guidelines to provide more information and clarity to potential green investors.

5.3.3 Criteria with High Importance and Cause Indexes

The third category of barriers that require special attention are those that show both high importance and cause indexes. The following criteria met the requirements and required critical attention: “split incentives” (BC1), “inadequate private investment” (BC12), “inadequate management support” (BC11), and “limited green projects” (BC16). The uncertain benefits of GB (Agyekum et al., 2020) create a mismatch between issuer and investor expectations (FSD Africa, 2021). This may hinder adequate private investment owing to the uncertainties associated with pricing benefits (FSD Africa, 2021; Taghizadeh-Hesary et al., 2022). Similarly, there is inadequate management support, owing to the lack of urgency to embrace green practices (Akomea-Frimpong et al., 2022). This could be attributed to fear of loss of investment and uncertainty about the returns of GB (Akomea-Frimpong et al., 2022), lack of building and finance models (Porumb et al., 2020), and technological uncertainty (Agyekum et al., 2020; FSD Africa, 2021). Engagement with investors is crucial in developing an appetite for GF (FSD Africa, 2021). Increasing investors’ appetite for GF-in-GB will lead to the development of a pipeline for eligible green projects. Addressing these barriers with both high importance and cause indexes is very critical to addressing effect criteria, such as inadequate transparency and consistency with GF (BC20), lack of universal definition for “green projects” (BC19), information asymmetry (BC21), lack of harmonised global standards and guidelines (BC17), technological uncertainty (BC15), lack of quality historical data (BC22), and risk perception (BC18). For example, the government of Ghana could champion GF-in-GB through demonstration projects. These green-financed projects could be helpful in assessing the performance of GF-in-GB in the novel Ghanaian market. Lessons from the demonstration projects can be shared with the private sector. Again, the experience gathered from such green-financed projects could serve as a basis for training other professionals and private developers.

The success stories of green-financed demonstration GB projects could motivate the private sector to explore the concept and adopt GF to promote sustainability in the built environment.

5.4 Chapter Summary, Contributions, and Limitations

This chapter identifies and prioritises the critical barriers to GF-in-GB in Ghana. To do so, a valid set of barriers and criteria were developed from the literature to ascertain the interactions among them. A two-step FDEMATEL was a suitable method to assess the interrelationship between the barriers. In the first round, 16 out of 22 barriers were identified by experts as critical barriers using FDM. Based on FDEMATEL in the second round, the experts established interrelationships and prioritised barriers. The results revealed regulatory barriers to be the most significant barrier and had the most powerful influence on the entire GF-in-GB system. It was also a major source of other barriers, such as organisational and technical barriers. In terms of criteria, the results showed that split incentives, inadequate private investment, inadequate management support, and limited green projects deserved critical attention because they showed high importance and cause indexes. The findings identified the most significant barriers that might be useful in the development of GF-in-GB policies and regulations. Again, this method helps all stakeholders be more resource-efficient by prioritising solutions. This is achievable by focusing on barriers with high importance and cause index, as these other barriers arise from such barriers (effect group barriers).

The contributions of this study are twofold: theoretical and practical. First, theoretically, the findings contribute to filling the knowledge gap concerning the interrelationship between barriers to GF-in-GB and could serve as a useful reference for future research in similar areas. This study adds to the literature by highlighting the guidelines for advancing GF-in-GB by identifying critical barriers. The insights presented in this chapter might be useful to researchers, policy advisers, and decision-makers in shaping actions that governments can take to improve GF-in-GB. Practically, the findings can be a useful guide in decision-making for policymakers and stakeholders who want to reduce barriers by concentrating on the most influential ones. Through the method adopted in this chapter, the uncertainties and complexities associated with the barriers are addressed. Again, the most influential and important barriers could be prioritised and removed. For instance, developing strategies to address regulatory barriers will lead to the elimination of organisational barriers such as low private sector engagement and participation in GF-in-GB. The outcomes of the study could be applicable to developing countries seeking to promote GF-in-GB because of the systematic nature of identifying and prioritising barriers using two-step FDEMATEL.

Despite the contributions of this study, it has some limitations. The number of experts who assessed these barriers was limited. Data were collected from twelve experts in Ghana. This is because GF-in-GB is a novel concept in the country, with only a few professionals actively involved. As Ghana intends to adopt GF to achieve the majority of its NDCs in the Paris Agreement and SDGs, future studies should consider more experts and stakeholders, including government officials, to develop conclusions from diverse perspectives. To expand this study, future research should consider additional barriers and criteria.

CHAPTER 6 - FUZZY MODELLING OF THE INTERRELATIONSHIP AMONG THE RISK FACTORS OF GREEN FINANCE IN GREEN BUILDING: THE CASE OF GHANA

6.1 Introduction

The previous chapters analysed and discussed the interrelationship between critical barriers to GF-in-GB. This chapter reports partial findings from the linguistic evaluation questionnaire surveys conducted in Ghana. This chapter focuses on developing a fuzzy model of risk factors for GF-in-GB in Ghana. To achieve the objectives of this chapter, a two-round questionnaire survey was conducted in Ghana, as described in Chapter 2. After a comprehensive literature review to identify the barriers to GF-in-GB, FDM and FDEMATEL were used to screen out and model the relationship between the critical risk factors, as described in the subsequent sections. The first section of this chapter presents the FDM results of the first round of the survey. The second section focused on the FDEMATEL results from the second and final-round surveys. This chapter also discusses key findings and provides theoretical and practical implications and the study's limitations. A summary is provided at the end of the chapter.

The findings of this chapter are critical to addressing the gap in the lack of studies that consider the influences and relationships between the risk factors of GF-in-GB under uncertainty. Previous studies that investigate GF risk factors are generic, focusing on the impact of GF risk factors on financial market performance and sustainable projects in general (Esposito et al., 2019; Febi et al., 2018; Schmidt, 2014; Venturini, 2022; Wang et al., 2019). In addition, most studies have focused on advanced economies. A literature review reveals that more sector-specific research is needed, particularly from the perspective of emerging economies. Without industry case studies of the specific risk factors faced in GF projects in each sector, it would be more challenging to implement specific strategies and policies for the GF market to flourish. Hence, this study fills the gap of lack of studies on the risk factors of GF-in-GB projects. Therefore, this study quantitatively and objectively assessed the interactions between the risk factors of GF-in-GB via a two-step FDEMATEL. The findings of this study are key to understanding the most prominent and influential risk factors and the causal-effect relationships among them.

6.2 Results

A set of 25 risk factor criteria for GF-in-GB (Table 6.1) was evaluated using FDM. By applying Eqns. 2.1 and 2.2 in Chapter 2, the acceptance threshold was established at 0.535. The FDM outcomes encompassing criteria weights and thresholds are presented in Table 6.1.

Table 6.1 Risk factors of GF-in-GB

	Risk factors screening out	Weights	Decision
RC1	Compensation for climate-related losses or damages	0.540	Accepted
RC2	Judicial decisions and sanctions imposed by laws	0.519	Unaccepted
RC3	Regulatory pressures and policy risks (e.g., prohibitions, environmental taxes, carbon pricing)	0.539	Accepted
RC4	Technological innovation risk	0.542	Accepted
RC5	Reputation risk due to shifting consumer and investor preferences	0.532	Unaccepted
RC6	Risks associated with the occurrence of climate- and weather-related events leading to property damage	0.539	Accepted
RC7	Low adaptation capabilities of GB and GF firms	0.512	Unaccepted
RC8	Mismatch between the short-term financial decision-making and long-term impacts of climate change	0.528	Unaccepted
RC9	Sluggish demand for high-rated GBs	0.531	Unaccepted
RC10	Long payback period for GBs	0.537	Accepted
RC11	Uncertain market value for GBs	0.533	Unaccepted
RC12	Uncertain macroeconomic factors	0.546	Accepted
RC13	High income tax rates	0.517	Unaccepted
RC14	Inadequate credit rating of GB firms	0.522	Unaccepted
RC15	Breach of contract due to change of property owners	0.531	Unaccepted
RC16	Green level promised by real estate developers for GBs did not materialize	0.539	Accepted
RC17	Default risk of GBs	0.534	Unaccepted
RC18	Insufficient cash flow of GBs firms	0.540	Accepted
RC19	Up-front risks or capital-intensive nature of GBs	0.535	Accepted
RC20	Construction delays owing to complicated permitting processes	0.547	Accepted
RC21	Lack of third-party evaluation of GBs	0.546	Accepted
RC22	Increased competition with conventional building	0.551	Accepted
RC23	Greenwashing risks	0.535	Accepted
RC24	Inadequate green experience or qualification	0.523	Unaccepted
RC25	Lack of transparency reporting of GB project	0.547	Accepted
	Threshold (α)	**0.535**	

Criteria with defuzzied weights below the designated acceptance threshold are omitted. Table 6.1 consequently presents the 14 retained criteria, along with their aggregated fuzzy weights. The outcomes derived from the FDEMATEL procedure enabled the identification of cause-effect relationships among the risk factors. The findings are summarised in Table 6.2, which presents the net-cause effect values and prominence of the major categories.

Table 6.2 Cause/effect of major categories of risk factors of GF-in-GB

Categories	D*i*	R*i*	D*i* + R*i*	D*i* – R*i*
Liability risks	0.1075	0.0833	0.1909	0.0242
Climate transition risks	0.0999	0.0878	0.1877	0.0121
Climate physical risks	0.0836	0.0738	0.1574	0.0097
Market risks	0.1151	0.0820	0.1971	0.0331
Credit risks	0.0812	0.1070	0.1883	–0.0258
Liquidity risks	0.0796	0.0868	0.1664	–0.0071
Sector risks	0.0700	0.1162	0.1862	–0.0462
Max			0.1971	0.0331
Min			0.1574	–0.0462
Average			0.1820	0.0000

Fig. 6.1 illustrates the graphical depiction of the causal relationships among the attributes in the context of GF-in-GB.

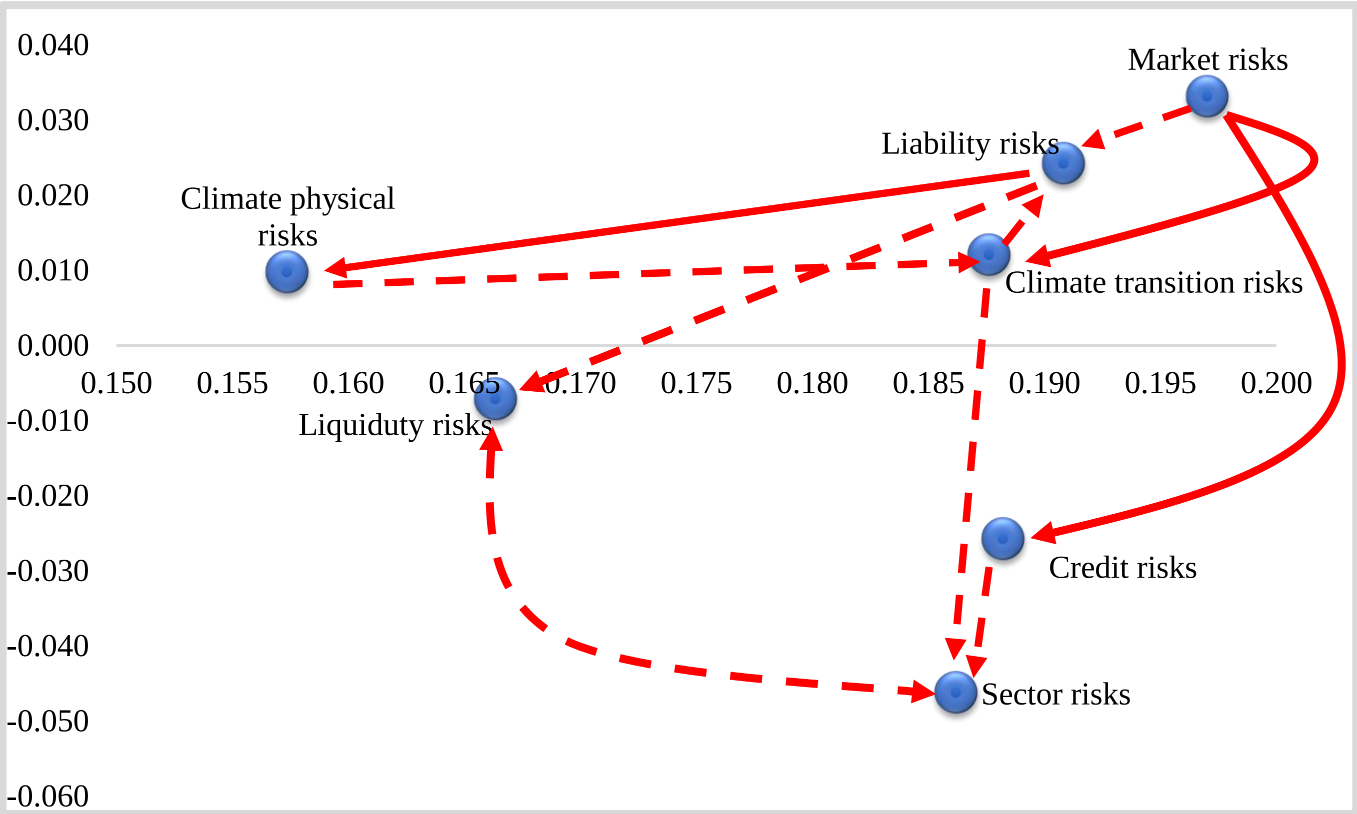

Fig. 6.1 Causal interrelationship diagram among categories

Table 6.3 displays the net-cause effect values and prominence of the GF-in-GB risk factors.

Table 6.3 Cause/effect of risk factors of GF-in-GB

Criteria	D*i*	R*i*	D*i* + R*i*	D*i* – R*i*
RC1	8.6207	7.3510	15.9717	1.2696
RC3	8.7743	7.8818	16.6560	0.8925
RC4	7.4269	8.3376	15.7645	–0.9107
RC6	9.2970	8.7140	18.0111	0.5830
RC10	7.8109	8.6316	16.4424	–0.8207
RC12	8.5506	8.3983	16.9489	0.1523
RC16	8.1001	8.6239	16.7240	–0.5237
RC18	8.6691	8.8950	17.5641	–0.2259
RC19	8.8838	8.3844	17.2682	0.4993
RC20	8.9495	7.8980	16.8475	1.0515
RC21	8.0992	8.1754	16.2745	–0.0762
RC22	7.8155	8.7410	16.5565	–0.9256
RC23	8.9115	8.6584	17.5699	0.2531
RC25	7.3188	8.5375	15.8563	–1.2187
Max			18.0111	1.2696
Min			15.7645	–1.2187
Average			16.7468	0.0000

A diagrammatic representation of the causal relationships among the criteria is shown in Fig. 6.2.

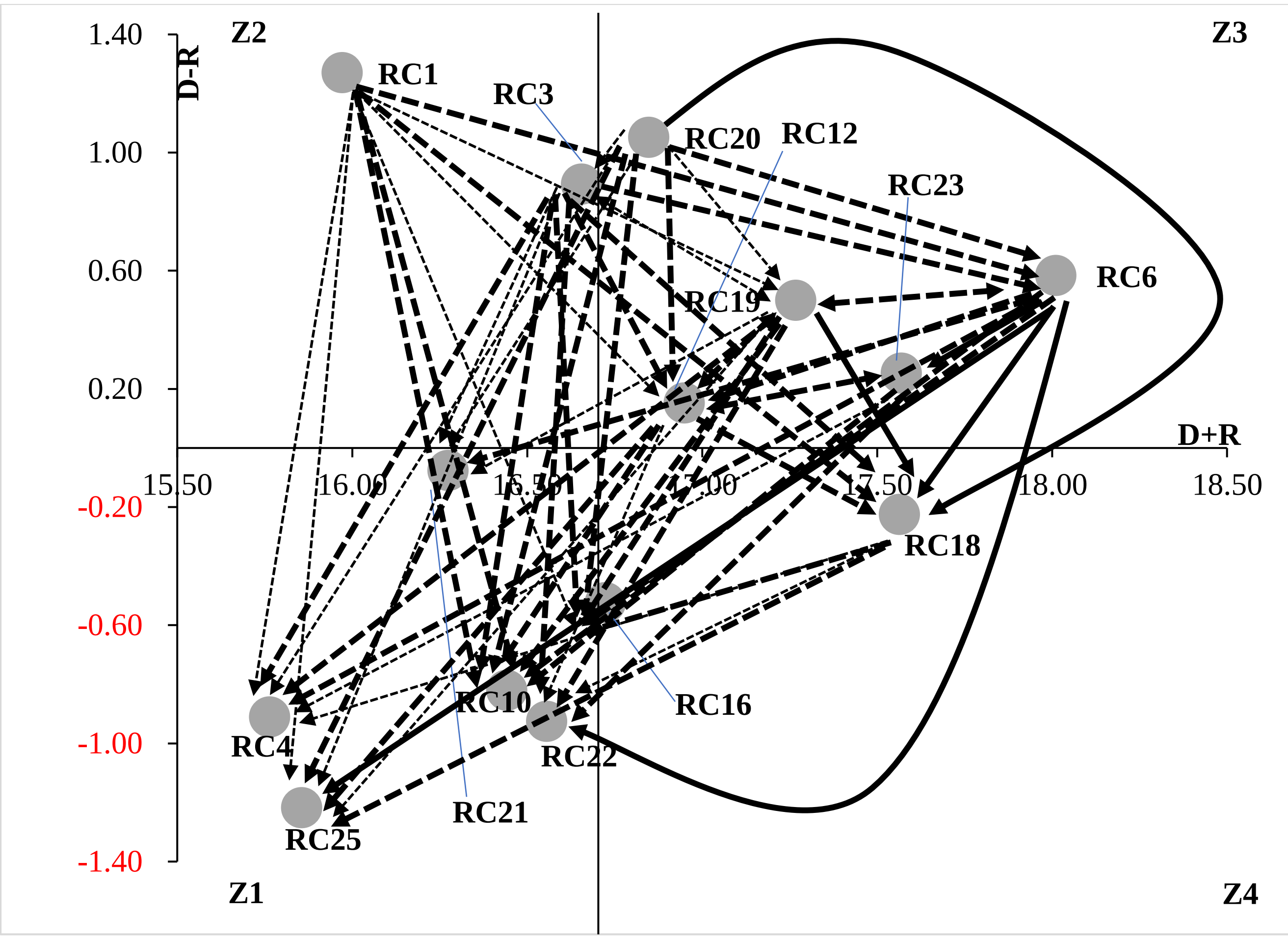

Fig. 6.2 Causal relationships among the criteria (risk factors) of GF-in-GB.

The criteria of risk factors can be primarily categorised into two groups based on the net effect value $(d_i - r_j)$:

(i) Cause group: where the $(d_i - r_j)$, value > 0.

(ii) Effect group: where the $(d_i - r_j)$, value < 0.

6.2.1 Cause Group

Within this classification, certain risk factors exhibited a strong influence, significantly affecting others within the group. Based on the calculated $(d_i - r_j)$ value, it becomes evident that "market risks", "liability risks", "climate transition risks" and "climate physical risks" fall under the category of causal factors. In terms of specific criteria, the risk factors demonstrating high causal influence include the following:

1. Compensation for climate-related losses or damages (RC1)
2. Construction delays owing to complicated permitting processes (RC20)
3. Regulatory pressures & policy risks (e.g., prohibitions, environmental taxes, carbon pricing) (RC3)
4. Risks associated with the occurrence of climate- & weather-related events leading to property damage (RC6)
5. Up-front risks or capital-intensive nature of GBs (RC19)
6. Greenwashing risks (RC23)
7. Uncertain macroeconomic factors (RC12)

Consequently, the risk factors belonging to the cause group can be ranked in the following order: RC1 > RC20 > RC3 > RC6 > RC19 > RC23 > RC12 (Table 6.4).

Table 6.4 Final evaluation of risk factors with ranking

Criteria	Rank	
	Cause group	Prominence
RC1	1	12
RC20	2	6
RC3	3	8
RC6	4	1
RC19	5	4
RC23	6	2
RC12	7	5
	Effect group	
RC21	1	11
RC18	2	3
RC16	3	7
RC10	4	10
RC4	5	13
RC22	6	9
RC25	7	14

6.2.2 Effects Group

The effect group risk factors, categorised by those mostly affected by other risk factors with a $(d_i - r_j)$ value < 0, are ranked as follows:

1. Lack of third-party evaluation of GBs (RC21)
2. Insufficient cash flow of GBs firms (RC18)
3. Green level promised by real estate developers for GBs did not materialize (RC16)
4. Long payback period for GBs (RC10)
5. Technological innovation risk (RC4)
6. Increased competition with conventional building (RC22)
7. Lack of transparency reporting of GB project (RC25)

These rankings were based on their susceptibility to the influence of other risk factors and their degree of impact within the effect group.

6.2.3 Correlation among the Risk Factors

According to the $(d_i + r_j)$ values, the risk factors can be ranked as follows: RC6 > RC23 > RC18 > RC19 > RC12 > RC20 > RC16 > RC3 > RC22 > RC10 > RC21 > RC1 > RC4 > RC25. This ranking reflects the degree of correlation and influence of each criterion with other risk factor criteria within the cause-and-effect network (Table 6.4). The risk factors falling within the different quadrants in Fig. 6.3 indicate their significance and interrelations. Critical, driving, independent, and impact risk factors are categorised based on their importance and interdependence, which enhances the understanding of their contributions within the overall network. The exact ranking and interpretation may vary depending on the specific context and data used in the analysis. For instance, the strong correlation observed between the risk factors linked to climate- and weather-related incidents causing property damage (RC6) and other risk factors can be attributed to the substantial financial implications homeowners face owing to the effects of shifting and extreme weather conditions, such as wildfires and floods (Bank of England, 2018). These events can result in considerable losses for property owners, leading to challenges, such as difficulties in repaying loans on properties that have suffered damage or experienced a decrease in value. In instances of such catastrophic events, homeowners may be unable to meet loan obligations for properties that have been compromised or are now appraised at lower values.

In this study, it was perceived that each risk factor was directly influenced by other risk factors. In Fig. 6.3, the risk factors located above the *x*-axis have the greatest influence on the network and are indicated as *causal* group risk factors. The other risk factors, which are located under the line, were indicated as *effect-group* risk factors. These risk factors can be further divided into four regions to accurately analyse their influence on other risk factors. Zone 1 represents *the effect group* of risk factors with the least influence on other risk factors with low potential importance. In this research, "*lack of third-party evaluation of GBs* (RC21)", "*long payback period for GBs* (RC10)", "*technological innovation risk* (RC4)", "*increased competition with conventional building* (RC22)", and "*lack of transparency reporting of GB project* (RC25)" belong to this group. Zone 2 also represents the causal relationships among risk factors that have a low influence on GF-in-GB implementation. "*Compensation for* *climate-related losses or damages* (RC1)", and "*regulatory pressures and policy risks* (*e.g., prohibitions, environmental taxes, carbon pricing*) (RC3)" are the risk factors in this zone. Zone 3 represented the risk factors with the highest significance. These risk factors are in the causal group and should be considered in GF-in-GB implementation. These risk factors can help managers and other stakeholders undertake proactive and reactive steps in adopting GF practices in GB. Included in Zone 3 are risk factors of "*construction delays owing to complicated permitting processes* (RC20)", "*risks associated with the occurrence of climate- and weather-related events leading to property damage* (RC6)", "*up-front risks or capital-intensive nature of GBs* (RC19)", "*greenwashing risks* (RC23)", and "*uncertain macroeconomic factors* (RC12)". Zone 4 indicates the risk factors that have high significance but are in the *effect* group. In this zone, "*insufficient cash flow of GBs firms* (RC18)" and "*green level promised by real estate developers for GBs did not materialize* (RC16)" seem to be the most significant risk factors that have received a high effect from other causal risk factors during GF-in-GB implementation. The ranking of the importance of risk factors for both cause-and-effect groups is shown in Table 6.4.

6.3 Discussion of Key Findings

Based on the above, it is observed that the risk factors in Zone 3 have the highest influence on GF-in-GB implementation. The causal risk factor group can influence the occurrence of other risk factors; hence, proactive and reactive strategies to mitigate or overcome them are necessary. These critical risk factors are discussed below, along with mitigation strategies.

First, the results reveal that "*construction delays owing to complicated permitting processes* (RC20)" was the *most influential* causal risk factor for GF-in-GB implementation. Schmidt (2014) considered this a policy risk factor. In this study, this risk was categorised into operational and sector risk groups. This risk is influenced by the inability of local institutions to approve construction permits on time or the bottlenecks developers or investors deal with during GB permit approvals. Therefore, this finding suggests that removing this risk factor could influence green investments in GB. For instance, responsible local institutions could be improved by streamlining permitting processes to reduce the likelihood of construction delays (Schmidt, 2014). However, well-performing approval systems are necessary to smoothen the permitting processes without compromising the quality of approved GB designs. The literature (Nawari and Ravindran, 2019) suggests that blockchain technology can be integrated with building information models to automate the building permitting process using smart contracts and Hyperledger fabric. This can reduce the time and resources required to issue building permits.

Next, "*risks associated with the occurrence of climate-and-weather-related events leading to property damage* (RC6)" received the second most priority in the causal group. This climate physical risk is due to climate change and should be considered additional financial market risks (Venturini, 2022). The occurrence of extreme climate and weather-related events, such as floods, wildfires, hurricanes, and heatwaves, can negatively impact the operations of GB firms, green supply chains, and society. The recent recurring floods in Ghana and the increasing heat in buildings could explain why experts consider this acute physical risk important. Other risks, such as rising sea levels, changes in precipitation patterns, and rising temperatures, are chronic climate physical risks. According to Esposito et al. (2019), an insurance approach can be used to manage this risk appropriately. In this context, promoting GB insurance in Ghana would effectively address the climate physical risks associated with climate-and-weather-related events that may lead to property damage.

Our findings indicate that "*up-front risks or capital-intensive nature of GBs* (RC19)" was the third most influential risk factor that can significantly influence other effect group risk factors. This perception of risk is reflected in financing costs or the cost of capital. With higher investment risks, banks raise the interest rate (cost of debt), and equity investors raise the expectation of return (cost of equity) (Schmidt, 2014). This investment risk and related financing costs are more significant for low-carbon projects such as GBs, which are more capital-intensive than their non-GB counterparts. This is due to the incremental cost of going "green" (Zhang et al., 2018). Hence, the advantages of GF, such as low interest rates and long tenures, could be used to offset the investment risks associated with GBs, as perceived by investors.

"*Greenwashing risks* (RC23)" identified as a fourth-ranked causal risk factor that may act as a significant causal factor of GF-in-GB. Current research reveals that the recent concern of investors of "greenwashing" may cause liquidity shortages and lead to higher risk premiums (Wang et al., 2019). The results of this study are consistent with those of previous studies (Baldi and Pandimiglio, 2022; Lau et al., 2022), which revealed a positive relationship between the risk of greenwashing practices by the issuer and the yield-to-maturity of GF. This indicates that when developers fail to prove the positive impact and performance savings or benefits of GB, they may affect the investment returns. This is because customers may be unwilling to pay for green because of their inability to prove green benefits, especially beyond green design preliminary certifications, leading to greenwashing. Hence, the likelihood of deceptively announcing, but not effectively implementing, green practices renders green-financed GB projects risky. To overcome this risk, GF-in-GB investors can monitor any potential deceptive greenwashing activity post-issuance during the construction process. Hence, any impactful GB features announced in the pre-issuance stage should be monitored and assessed post-issuance, particularly during operational and maintenance periods. In addition, policymakers should devote more time and effort to detecting greenwashing practices, thus promoting new regulations aimed at mitigating the potentially deceptive behaviour of both public and corporate issuers and developers when green financing and developing GB projects (Baldi and Pandimiglio, 2022).

Finally, "*uncertain macroeconomic factors* (RC12)" were the fifth most important risk factors in the causal group. An unstable macroeconomic environment negatively impacts GF market development (Yamahaki et al., 2020). This is because GF is highly dependent on favourable macroeconomic conditions, such as stable inflation and foreign exchange rates (Akomea-Frimpong et al., 2022; Kats, 2003; Tolliver et al., 2020). Stable macroeconomic factors can further lessen the fear or perception of the uncertain benefits associated with GF projects.

Previous studies that investigate GF risk factors are generic, focusing on the impact of GF risk factors on financial market performance and sustainable projects in general (Esposito et al., 2019; Febi et al., 2018; Schmidt, 2014; Venturini, 2022; Wang et al., 2019). In addition, most studies have focused on advanced economies. Based on a literature review, more sector-specific research is needed, particularly from the perspective of emerging economies. Without industry case studies of the specific risk factors faced in GF projects in each sector, it would be more challenging to implement specific strategies and policies for the GF market to flourish. Hence, this study fills the gap of lack of studies on the risk factors of GF-in-GB projects.

6.4 Chapter Summary, Contributions and Limitations

This Chapter presented the relationship between critical risk factors for GF-in-GB. The risk factors identified in the literature review were validated using the FDM. FDEMATEL was used to identify the interdependence of 14 criteria of risk factors. The FDEMATEL method is based on FDM results.

The results showed that the attributes (categories) and criteria (risk factors) of GF-in-GB are interrelated and could belong to either the cause or effect group. Causal group risk factors have the highest significance and should be considered in GF-in-GB implementation. These risk factors can help managers and other stakeholders undertake proactive and reactive steps in adopting GF practices in GB. Prominent among them were "*construction delays owing to complicated permitting processes*", "*risks associated with the occurrence of climate- and weather-related events leading to property damage*", "*up-front risks or capital-intensive nature of GBs*", "*greenwashing risks*", and "*uncertain macroeconomic factors*". These five risk factors identified under the cause group have a direct impact on the implementation of GF-in-GB and demand a high priority. Giving priority to the cause group by managers in decision-making will facilitate better results by stabilising the risk factors in the effect group.

This study makes novel contributions to the literature by identifying the most prominent risk factors using FDM and FDEMATEL. Practically, the identified and prioritised risk factors that could contribute to the failure of GF-in-GB projects. Such knowledge will help managers define the risk factors that need greater attention within the sector and identify those that are less important. Cause-effect rankings could assist managers and decision-makers in devising policy strategies during GF-in-GB implementation. Theoretically, this study established a generic checklist of critical risk factors for green-financed projects. These findings may form the basis of future GF-in-GB research.

Despite the contributions of this study, it has some limitations. First, future research should consider additional risk factors and assess their impact on the results. In addition, while the data were collected from 12 experts in Ghana, GF-in-GB is an emerging concept in the country, and a few experts are directly related to this field. It should be noted that the bias of the experts to some of the risk factors may have impacted the results. Future studies should consider more experts and stakeholders, including government officials, to develop conclusions from diverse perspectives.

Furthermore, since the results are based on the perspectives of experts in the Ghanaian case, the generalizability of the findings may be affected. However, the established risk framework for GF-in-GB can be adapted to any context. Future comparative studies are needed to unravel these differences. In addition, no real case studies were used to validate the identified and prioritised risk factors and may be considered in future research. Future research should collect more data to quantify the impact of risk factors and model their interactions in other countries. Finally, the GF-in-GB risk factors identified in this research are quite generic and, with a few modifications, can be employed in different sectors. Other statistical methods may be employed to validate the results.

CHAPTER 7 - MODELLING THE INTERRELATIONSHIP AMONG STRATEGIES TO PROMOTE GREEN FINANCE IN GREEN BUILDING

7.1 Introduction

The previous chapters focused on developing an assessment model for the relationship between the critical risk factors of GF-in-GB. This chapter focuses on evaluating the interrelationship between strategies to promote GF-in-GB based on the linguistic evaluation questionnaire surveys conducted in Ghana. To achieve the objectives of this chapter, a two-round survey was conducted in Ghana, as described in Chapter 2. After a comprehensive literature review to identify the strategies to promote GF-in-GB, FDM, and FDEMATEL were used to screen out and model the interrelationship between the strategies, as described in the subsequent sections. The first section of this chapter presents the FDM results of the first round of the questionnaire survey. The second section focused on the FDEMATEL results from the second and final-round surveys. This chapter also discusses key findings and provides theoretical and practical implications and the study's limitations. A summary of this chapter is provided at the end of the chapter.

The findings of this chapter are critical to addressing the gap in the lack of studies that consider the influences and relationships between the promotional strategies of GF-in-GB. Although the literature review reveals various strategies to promote GF, little research has been done on developing a model and framework for assessing the critical strategies to promote the adoption and effective implementation of GF, particularly for the buildings and construction sector. This study intends to fill this research gap by proposing a conceptual framework that reveals the relationships among critical strategies for the adoption and effective implementation of GF-in-GB. The FDM and FDEMATEL methodologies were used to analyse the strategies and identify the interrelationship and cause-effect parameters.

7.2 Results

Twenty criteria (see Table 7.1) of GF-in-GB strategies were evaluated using FDM. Based on Eqns. 2.1 and 2.2 (see Chapter 2), the acceptance threshold was 0.536. As presented in Table 3, the FDM results comprise the criteria weights and thresholds. All the criteria with defuzzied weights below the acceptable threshold were excluded. Table 7.1 presents the 12 accepted criteria and the aggregated fuzzy weights.

Table 7.1 FDM – Strategies screening out

	Significant strategies	**Weights**	**Decision**
SC1	Improving access to capital for small-scale green building projects	0.545	Accepted
SC2	Encouraging climate scenario analysis by adopting existing guidelines such as TFCD (Task Force on Climate-Related Financial Disclosures)	0.531	Unaccepted
SC3	Capturing multiple green building benefits in valuation and accounting methods	0.533	Unaccepted
SC4	Better quality information (Increased information disclosure and better transparency)	0.542	Accepted
SC5	Institutionalization and mechanisms for managing carbon emission trading for buildings	0.531	Unaccepted
SC6	Enhancing data for climate-related risk assessment	0.542	Accepted
SC7	Integrating climate risk exposure assessment into green finance in green building projects	0.519	Unaccepted
SC8	Reputable third-party green certification and labels	0.535	Unaccepted
SC9	Harmonise green finance in green building standards	0.543	Accepted
SC10	Continuous improvement of incentive policies for green finance in green building	0.541	Accepted
SC11	Access to targeted green financial instruments for green building	0.537	Accepted
SC12	Innovation of financial instruments that enable public/private risk sharing	0.542	Accepted
SC13	New technology and disruptive business models for green finance in green building	0.515	Unaccepted
SC14	Innovative Fintech solutions for green finance in green building	0.524	Unaccepted
SC15	Simplification of administrative procedures linked with green building projects (e.g., permitting and licensing procedures)	0.528	Unaccepted
SC16	Increased R&D support for green finance in green building	0.538	Accepted
SC17	Public-private partnerships to facilitate green finance from the private sector	0.537	Accepted
SC18	Developments in climate-related policy and regulation to stimulate private investment	0.543	Accepted
SC19	Increased government participation as "leader by example"	0.541	Accepted
SC20	Ensuring compliance of both public and private actors to green standards	0.547	Accepted
	Threshold (α)	**0.536**	

The defuzzification process, initial direct relation matrix of criteria, normalised direct relation matrix of criteria, and total interrelation matrix of criteria and attributes of strategies are presented in Appendices B.4 – B.5. Based on the results obtained from the FDEMATEL, the cause-effect relationship among the strategies is identified. Table 7.2 reveals the net-cause effect values and prominence of the attributes (categories).

Table 7.2 Cause/effect strategies (categories) for GF-in-GB

Categories	D*i*	R*i*	D*i* + R*i*	D*i* – R*i*
Market strategies	13.8206	15.1402	28.9608	– 1.3197
Financial strategies	15.0115	14.1532	29.1647	0.8583
Technological strategies	15.4701	14.7152	30.1853	0.7550
Policy strategies	14.5935	14.8872	29.4807	– 0.2937
Max			30.1853	0.8583
Min			28.9608	– 1.3197
Average			29.4479	0.0000

A diagrammatic representation of the causal relationships between the attributes is shown in Fig. 7.1.

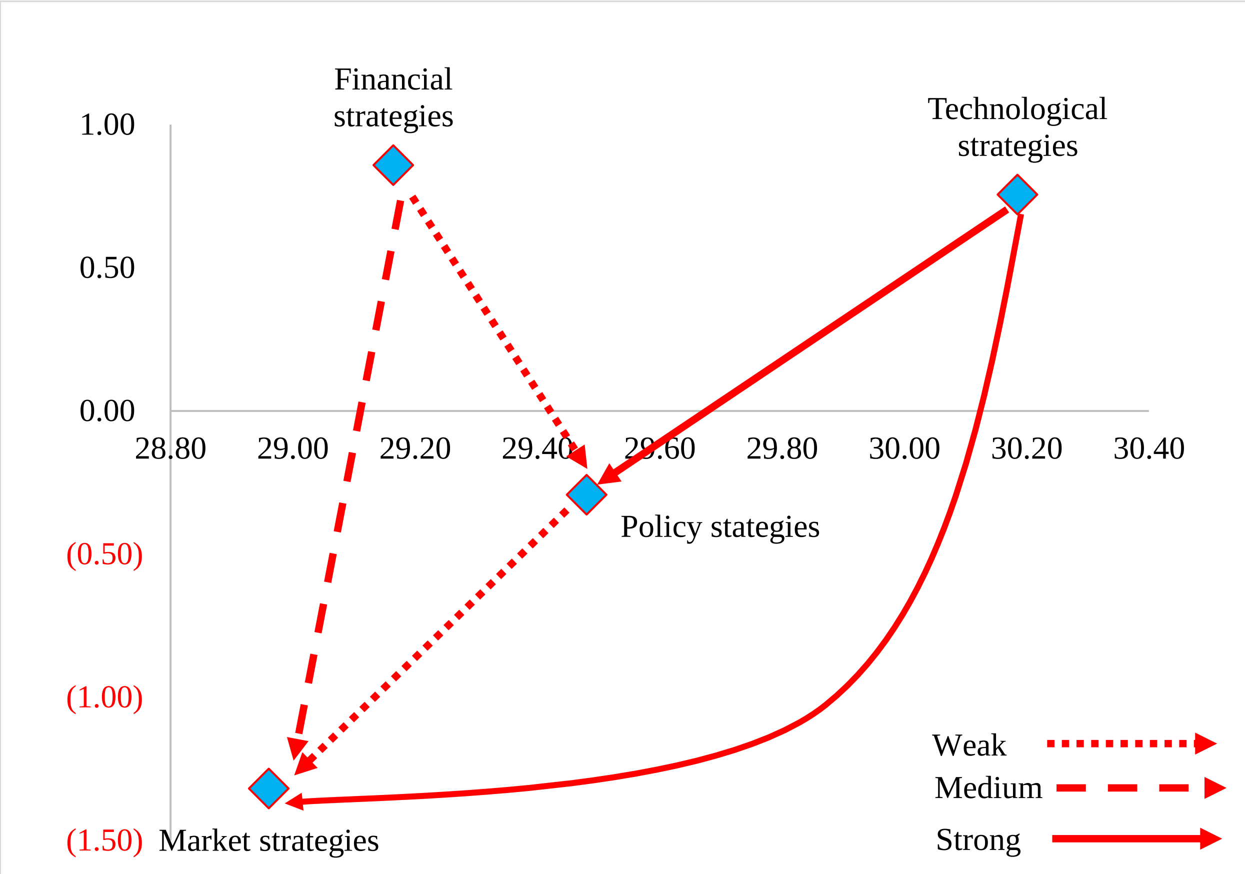

Fig. 7.1 Causal interrelationship diagram among category of strategies.

Table 7.3 reveals the net-cause effect values and prominence for the criteria (strategies) of GF-in-GB.

Table 7.3 Cause/effect promotional strategies for GF-in-GB

Criteria	D*i*	R*i*	D*i* + R*i*	D*i* – R*i*
SC1	18.1809	18.2379	36.4187	– 0.0570
SC4	19.3466	18.7229	38.0695	0.6236
SC6	17.3632	17.6631	35.0263	– 0.2999
SC9	18.2970	18.4484	36.7454	– 0.1514
SC10	19.2571	19.4538	38.7109	– 0.1967
SC11	19.0980	19.1736	38.2716	– 0.0757
SC12	19.7858	20.7173	40.5032	– 0.9315
SC16	19.3350	18.9849	38.3199	0.3501
SC17	19.4279	18.6675	38.0954	0.7604
SC18	19.1800	18.5842	37.7642	0.5958
SC19	18.9622	17.8625	36.8247	1.0996
SC20	17.8748	19.5921	37.4669	– 1.7173
Max			40.5032	1.0996
Min			35.0263	– 1.7173
Average			37.6847	0.0000

A diagrammatic representation of the causal relationships among the criteria is shown in Fig. 7.2.

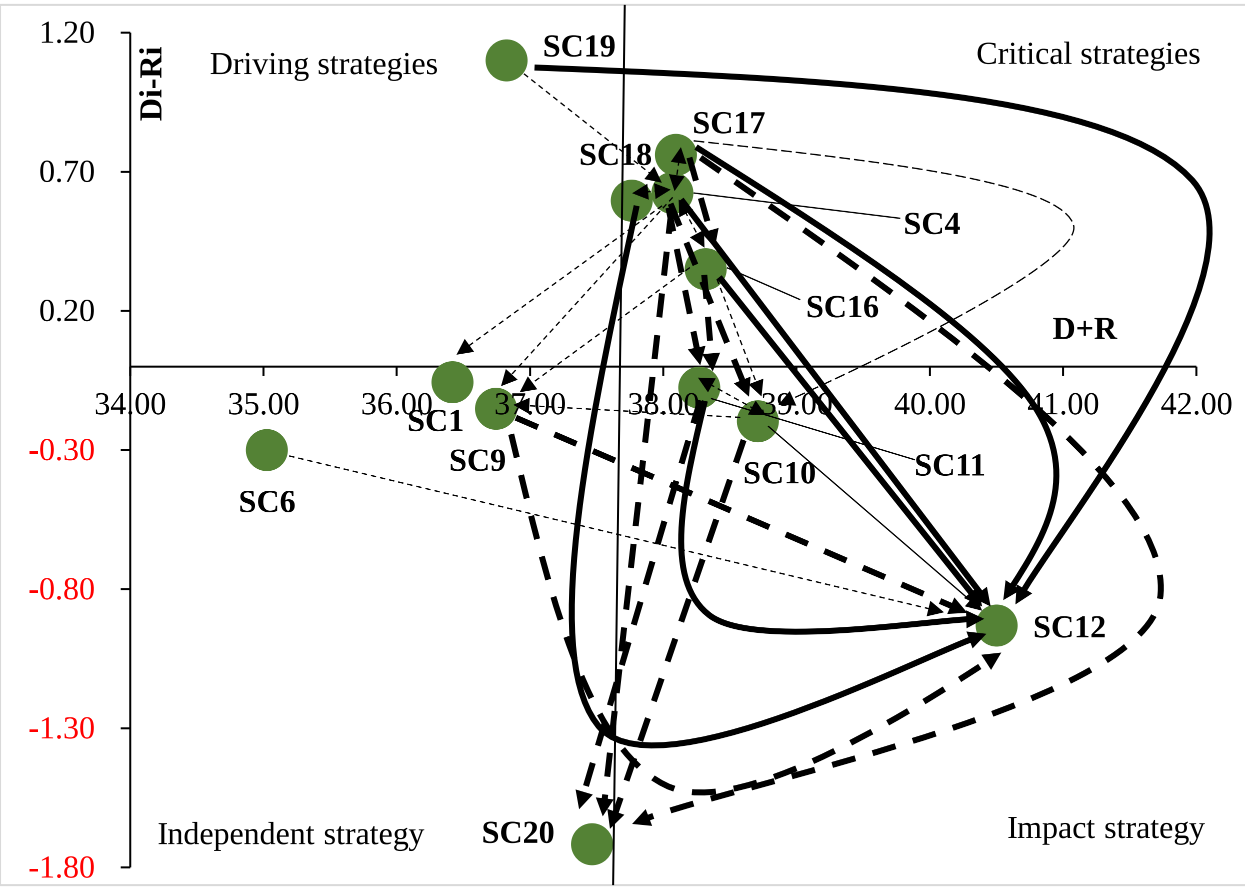

Fig. 7.2 Diagram showing the causal relationships among the criteria (strategies) for GF-in-GB

According to the value of net effect $(d_i - r_j)$, the strategies can be divided mainly into two groups:

(i) Cause group: where the $d_i - r_j)$, value > 0.

(ii) Effect group: where the $(d_i - r_j)$, value < 0.

7.2.1 Cause Group

In this group, strategies that have a high influence and affect other strategies significantly are categorised. According to $(d_i - r_j)$ value, it is found “financial strategies”, and “technological strategies” are the categories that belong to the cause group category. For the criteria, increased information disclosure and better transparency (SC4), increased R&D support for GF-in-GB (SC16), PPPs to facilitate GF from the private sector (SC17), developments in climate-related policy and regulation to stimulate private investment (SC18), and increased government participation as “leader by example” (SC19) are the strategies that belong to the causal group. Accordingly, the cause group strategies were ranked as follows: SC17>SC4>SC18>SC16>SC19 (Table 7.4).

Table 7.4 Final evaluation of strategies with ranking

Criteria	Rank	
	Cause group	Prominence
SC17	1	5
SC4	2	6
SC18	3	7
SC16	4	3
SC19	5	9
	Effect group	
SC1	1	11
SC11	2	4
SC12	3	1
SC9	4	10
SC20	5	8
SC10	6	2
SC6	7	12

7.2.2 Effects Group

This includes strategies that are primarily affected by other strategies. The strategies where the $(d_i - r_j)$ value < 0 are categorised under the effects group. Improving access to capital for small-scale GB projects (SC1), quality climate risks, and other ESG data for the investor (and customer) assessment (SC6), harmonise GF-in-GB standards (SC9), continuous improvement of incentives policies for GF-in-GB (e.g., spillover-tax-returns to increase rate of return, green subsidies) (SC10), access to targeted GF instruments for GB (e.g., government loans, equity investments, risk insurance, and public guarantees) (SC11), Innovation of financial instruments that enable public/private risk sharing (SC12), and ensuring compliance of both public and private actors to green standards (SC20) are the criteria (strategies) that belong to the effects group. Accordingly, the effect group strategies were ranked as follows: SC1>SC11>SC12>SC9>SC20>SC10>SC6 (Table 7.4).

7.2.3 Correlation among the Strategies

According to $(d_i + r_j)$, the strategies can be ranked as: SC12>SC10>SC16>SC11>SC17>SC4>SC18>SC20>SC19>SC9>SC1>SC6. The innovation of financial instruments that enable public/private risk-sharing (SC12) seems to have the highest correlation with other strategies. This could be due to the higher perception of risks/insufficient risk management associated with GF (Setyowati, 2020a). According to Wells et al. (2013), the balance between cost and risk plays a major role in investment decisions. Additionally, risk assessment and risk management are critical to the financial feasibility of green projects such as GB (Arnold and Yildiz, 2015).

In this study, it was perceived that each strategy was directly influenced by other strategies. In Fig. 7.2, the strategies located above the *x*-axis have the greatest influence over the network and are indicated as causal group strategies. The strategies in Fig. 7.2 can be divided into four regions for an accurate analysis of their influences. In Fig. 7.2, the strategies falling in the first quadrant are critical strategies. These strategies have causal features and are of higher importance, namely SC4, SC16, SC17, and SC18. Only one strategy (SC19) falls within the second quadrant, which contains driving strategies with causal functions but lower importance. The third quadrant consists of strategies that are less important and independent, namely SC1, SC6, and SC9. Core or impact strategies were mapped into quadrant four, indicating higher importance. The core strategies rely on driving and critical strategies and are unable to have a major impact because they experience the effects of other promotional strategies. The ranking of the prominence of the strategies for both cause-and-effect groups is presented in Table 7.4.

7.3 Discussions of Key Findings

7.3.1 Increased R&D support for GF-in-GB (SC16)

Enhancing GF-in-GB can be traced to increased R&D. This was the most effective strategy for promoting GF-in-GB. Investment in R&D is an effective strategy for reducing carbon emissions, improving innovation capabilities, and promoting sustainable development (Zhang et al., 2022). Additionally, public and private investments in R&D have enormous potential to stimulate green economic growth and alleviate poverty (Feng et al., 2022). For instance, increased government spending on education may accelerate the transition to decarbonising buildings and the construction of net-zero buildings by 2050. Some countries, such as Hong Kong, have established green technology funds to promote R&D projects focused on decarbonisation and environmental protection (Debrah et al., 2022d). Additionally, R&D investments will encourage society to accept and implement cleaner GB technologies and renewable energy resources in buildings and construction projects (Martínez-Moya et al., 2019). With this, more GF will be required to meet the needs of society in the green transition.

7.3.2 Public-Private Partnerships to facilitate GF from the Private Sector (SC17)

Next, *PPPs to facilitate GF from the private sector* received the second-highest priority in the causal group. PPPs are enduring agreements between a government entity and a private party. These partnerships are forged to advance initiatives at both national and international levels aimed at addressing socioeconomic challenges, providing public assets or services, and fostering the sustainable development of economies and civil societies (World Bank, 2017).

PPPs are instrumental in harnessing the strengths of both the public and private sectors to achieve common goals and benefit society. These partnerships between the public and private sectors, as well as collaborations among private entities, are instrumental in driving progress toward achieving SDGs.

Consequently, governments must establish robust partnerships with the private sector to secure the GF required for critical GB projects and other sustainability initiatives across various sectors (UN, 2022). Such collaboration is pivotal for addressing the complex challenges posed by sustainable development and climate change. Furthermore, PPPs have the potential to stimulate green entrepreneurship and facilitate the creation of networks that foster innovation. These collaborations play a crucial role in addressing externalities and unlocking the value of numerous green investments, often with the assistance of Green Investment Banks (Vassileva, 2022). Hence, dedicated GF institutions can be strategically employed to mobilise private capital and bridge the funding gap for low-carbon building investments, particularly in developing nations. Such institutions can be instrumental in accelerating the transition towards investments in sustainable and environmentally responsible construction. In the aftermath of the pandemic, investments are increasingly being characterized as green-aligned. Governments and corporations actively seek sustainability-focused financial instruments for significant projects. Consequently, there is a growing appeal among institutional investors to engage with GF initiatives linked to PPP projects (Vassileva, 2022). This trend reflects heightened awareness of the importance of sustainability and environmental responsibility in shaping post-pandemic investments.

7.3.3 Better Quality Information (Increased Information Disclosure and Transparency) (SC4)

The findings indicate that *better quality information* (*increased information disclosure and better transparency*) was the third most influential strategy that could significantly influence other effect group strategies. Transparency refers to the availability and accuracy of specific information provided to a firm's stakeholders and is a vital corporate governance technique aimed at reducing information asymmetry (Xia et al., 2023). High-level transparency is essential to attract stakeholders, while companies that fail to maintain transparency risk face noncompliance penalties (Schnackenberg and Tomlinson, 2016). Notably, improving information transparency not only reduces information asymmetry but also fosters green innovation (Xia et al., 2023). According to Gabor et al. (2019), firms must disclose the climate impact and risks associated with their activities. These disclosures should focus on assessing the environmental friendliness of financial assets held by corporations, as well as the transition and physical climate risks they encounter. Such disclosures should be based on established Green Public Taxonomies or methodologies such as those developed by the Task Force on Climate-Related Financial Disclosures (TFCD) and the Network of Central Banks and Supervisors for Greening the Financial System (NGFS). In line with the findings of Steuer and Tröger (2022), disclosure-centred regulatory intervention can influence the demand for "green" assets. This implies that disclosure and transparency can activate market discipline, prompting the decarbonisation of economic activities. However, it is important to note that significant countervailing forces may hinder the achievement of social optima in the long run. The authors suggest that relying on *information-centred green financial regulation*, considered the first-best regulatory strategy, yields better results than comprehensive *mandatory green disclosure obligations*. Nevertheless, the challenges posed by climate change justify pursuing disclosure-centred GF interventions as the second-best regulatory strategy.

7.3.4 Developments in Climate-Related Policy and Regulation to stimulate Private Investment (SC18)

GF policies should be coordinated with other climate policies (green fiscal, industrial) to minimise emissions reduction and the economic disruptions caused by decarbonisation (Gabor et al., 2019). Hence, the development of climate-related policies and regulations is necessary to stimulate green investment from the private sector. Policies must provide the right incentives for the financial sector to direct or reallocate financing to support the green transition towards decarbonising buildings. To facilitate GF-in-GB and effectively promote sustainable investments, it is imperative to provide comprehensive guidance on the pricing of externalities (World Bank, 2021). This guidance should include clear frameworks for pricing externalities, such as carbon pricing instruments and feed-in tariffs for surplus renewable energy generated from sources such as solar PVs.

Furthermore, it is vital to develop a National GF Strategy. This strategy should describe how various sectors can adapt and align their practices with the GF strategy, thereby fostering increased investments and sustainable development. Such measures must demonstrate commitment to the low-carbon transition and provide investors and relevant stakeholders with the certainty needed to make informed decisions and actively participate in sustainable investments (World Bank, 2021). The impetus for stimulating green private investments lies firmly within the domain of governmental climate policies and regulations. Therefore, it is incumbent upon governments to not only formulate comprehensive climate plans and strategies but also to translate these into concrete actions. These action-oriented policies and regulations are essential for creating a supportive environment that encourages and facilitates private investment in green and sustainable initiatives, fostering a transition to a low-carbon and environmentally responsible future.

7.3.5 Increased Government Participation as 'Leader by Example' (SC19)

The fifth most important strategy in the causal group is *to increase government participation as* a '*leader by example*.' This aligns with existing literature that highlights the positive impacts of government expenditure on the green economy, including carbon emissions reduction, the development of green projects, resource efficiency improvements, and the preservation of ecosystems and scarce natural resources (Feng et al., 2022). Public and domestic finance and resources are pivotal in advancing mitigation and adaptation efforts, particularly within the built environment sector. These resources can manifest in various forms, such as government annual budgetary allocations, new climate-related taxes or levies, carbon pricing mechanisms, government grants, subsidies, and interest-free loans (Debrah et al., 2022a; Feng et al., 2022). Although public funding alone may be insufficient to meet climate goals, it serves as a critical catalyst for attracting more private GF investments.

Additionally, central banks, such as the Bank of Ghana, which oversees banking and financing operations within a country, have the potential to align their monetary policy operations with climate objectives. One potential adjustment involves revising the collateral framework to align it with climate goals. For instance, introducing climate-related criteria for collateral could prevent biases in capital allocation towards carbon-intensive activities and create more favourable financing conditions for green initiatives. This may entail excluding "super-brown" loans or securities and applying different terms to green and brown assets (Gabor et al., 2019).

7.4 Chapter Summary, Contributions and Limitations

In this chapter, we propose a structural model for the adoption and implementation of GF-in-GB by analysing strategies that will improve its effectiveness. Owing to the increasing importance of GF to GBs, this study provides a framework to assist managers in identifying the causal group strategies that influence the effect group strategies. A hybrid approach based on the FDM and FDEMATEL methodologies was used to identify the critical strategies and show the cause-effect relationship among GF-in-GB strategies.

The results showed that the attributes (categories) and criteria (strategies) of GF-in-GB are interrelated and could belong to either the cause or effect group. Five strategies were identified in the cause group: increased information disclosure and better transparency; increased R&D support for GF-in-GB; PPPs to facilitate GF from the private sector; developments in climate-related policy and regulation to stimulate private investment; and increased government participation as "leader by example". These strategies, also known as driving and critical strategies, have a direct impact on the GF-in-GB system and demand a high priority. Prioritising the cause group strategies will direct the impact on the effect group, leading to positive results. Thus, focusing on the causal group by stakeholders will facilitate better results by stabilizing the strategies in the effect group.

Therefore, this study makes novel contributions by identifying the most prominent strategies in the context of emerging economies using FDM and FDEMATEL. The identification and prioritisation of strategies using multi-criteria decision-making methods provide a systematic way to analyse how to promote the most influential strategies. The results show that identifying the most influential strategies is necessary to promote GF-in-GB. Hence, this study contributes to stakeholder theory, which facilitates stakeholders' minimisation of negative environmental, social, and economic impacts to promote a sustainable built environment through GF.

Despite the contributions of this study, it has some limitations. Future research should consider additional strategies and assess their impact on the results. Other statistical methods may be employed to validate the results. Data were collected from twelve experts in Ghana. GF-in-GB is an emerging concept in the country, and few studies have been directly related to this field. Therefore, the results were based on the perspectives of experts in the Ghanaian case. It should be noted that the biases of the experts towards some of the strategies may have impacted the results. Future studies should consider more experts and stakeholders, including government officials, to develop conclusions from diverse perspectives. Finally, the GF-in-GB strategies identified in this research are generic and, with a few modifications, can be employed in different sectors.

CHAPTER 8 - TECHNO-ECONOMIC ANALYSIS OF GREEN OFFICE BUILDING WITH COST-BENEFIT CONSIDERATIONS IN EMERGING AND DEVELOPING ECONOMIES

8.1 Introduction

The previous four chapters focused on developing assessment models for the interrelationship between critical drivers, critical barriers, critical risk factors, and strategies to promote GF-in-GB. FDM and FDEMATEL were used to screen out and model the interrelationship between the identified factors from the literature. In this chapter, a whole-building LCC of GB from the perspective of a typical emerging and developing economy, Ghana, is presented. The CBA of a case study was evaluated using a 50-year lifecycle (i.e., from design and deconstruction). Information for this study was collected through primary data on actual building costs and a broad literature review that provides up-to-date and well-linked compilations of important datasets related to GB costs and benefits. The data were analysed using the discounted NPV method. To achieve the objectives of this chapter, the data collection and analysis methods for CBA are discussed in Chapter 2. Chapter 3 presented a comprehensive literature review of GB building cost studies. This chapter also discusses key findings, theoretical and practical implications, and the study's limitations. A summary of this chapter is provided at the end of the chapter.

The findings of this chapter are critical to addressing the gap of a few studies addressing the subject from a whole-building lifecycle perspective. Additionally, previous studies have focused on advanced economies against the perspective of emerging economies. Consequently, this study adds to GB literature by providing new evidence on the business case of GBs from a whole-building lifecycle perspective in the context of emerging and developing economies. Therefore, it can form the primary basis for developers and investors in such economies to evaluate the expected costs and associated benefits of GB. This initial assessment can also be adopted in future evaluations of GB costs and benefits when the inventory of such buildings becomes sufficiently large for direct and comparative evaluations.

8.2 Results

8.2.1 Design and Construction Cost

The primary cost elements of the building's LCC are the design and construction costs, which began in 2014 and was completed in 2019. The building has been in operation since 2020. Table 8.1 compares the design and construction costs of non-GB and GB.

Table 8.1 Cost comparison of non-GB and GB (US$)

Components	Non-GB	% of cost	GB	% of cost
Non-construction cost [a]		***9.88***		***8.72***
Design & planning [b]	2,737,000.00	9.88	2,737,000.00	8.72
Construction cost [a]		***70.18***		***61.92***
Substructure	1,438,552.89	5.19	1,438,552.89	4.58
Superstructure	7,505,478.26	27.10	7,505,478.26	23.91
Finishes	1,013,333.33	3.66	1,013,333.33	3.23
Fittings & equipment	675,555.55	2.44	675,555.55	2.15
MEP	7,214,012.00	26.05	7,214,012.00	22.98
External works	1,589,597.82	5.74	1,589,597.82	5.06
GB cost				***11.76***
GB features [c]			3,681,864.83	11.73
Green certification			8,800.00	0.03
Other cost	5,523,132.92	19.94	5,523,132.92	17.60
Total cost	**27,696,662.77**	100.00	**31,387,327.60**	100.00

[a] This case study assumes the same non-construction and construction costs for both GB and non-GB.
[b] Design and planning costs include costs for supervision and construction management.
[c] GB features cost includes the cost of GB consultancy.

The total design and construction cost of the GB corresponded to US$31,387,327.60, while non-GBs are US$27,696,662.77. Overall, minor differences in the total design and construction costs were identified between the GB and non-GB. Construction costs in both GB and non-GB areas accounted for more than 80% of the costs. The superstructure and MEP were the highest-cost components of the structure. Other cost components, such as the substructure, finishes, fittings, equipment, and external works, account for <15% of the total design and construction costs. GB features, consultancy, and certification accounted for 11.76% of design and construction costs. While research on the incremental cost for buildings certified as green remains inconclusive, research findings from various sources reveal that actual design and construction costs range from -0.4-12.5% (WorldGBC, 2013).

As presented in Table 8.1, GB in Ghana, estimated at US$1,171.17/m^{2,} falls within the average cost of GB per square meter worldwide. Similar studies have shown that GBs in Malaysia, Indonesia, and Israel cost US$1,361/m^2, US$1,184.59/m^2, and US$1,096/m^2, respectively (Dwaikat and Ali, 2018; Miraj et al., 2021). As more GBs are constructed in Ghana, developers and professionals are expected to find novel ways to decrease the extra cost incurred for building green.

8.2.2 Building Operation Cost

The International Organisation for Standardisation (2020) states that building operating costs may include rent, utility, insurance, recurrent regulatory costs, taxes, and other operating costs. In this study, only utility costs (energy and water consumption bills) were considered, and the LCC were estimated as follows:

8.2.2.1 Energy Cost

The total building energy use (kWh/year) and electricity price tariff (US$/kWh) data were used to estimate the building's energy LCC. Based on the design assessment report for green certification, the estimated energy savings for the selected building was 36%. It should be noted that the energy use intensity (EUI), which represents the energy use of a building over its size within a period, may vary for different building types and countries. For example, it is estimated that the EUI of residential buildings in Ghana ranges 136-138kWh/m^2/year (Ohene et al., 2022). With the average EUI of typical office buildings in Accra or similar tropical climatic zones being 270kWh/m^2/year (CPCS, 2016), the resulting target EUI of the building is 173kWh/m^2/year. As the total floor space of the case study is 26,800m^2, the total predicted energy consumption for the GB equals 4,631,040kWh/year.

The Public Utilities Regulatory Commission (PURC) regulates electricity tariffs in Ghana. The tariffs are periodically reviewed to reflect the costs of power generation, transmission, and distribution. While electricity tariffs in Ghana are charged based on power usage, they are affected by factors such as the GH₵/US$ exchange rate, inflation rate, crude oil and natural gas prices, and the thermal-hydro generation mix (PURC, 2022a). According to the PURC, Ghana's end-users of electricity are grouped into six primary categories: residential, non-residential, special load tariff (SLT)-low voltage customers, SLT-medium voltage customers, SLT-high voltage customers, and SLT-high voltage (mines) customers. Non-residential tariffs that refer to commercial entities are applied to four consumption classes: (0-100, 100-300, 301-600, and 601+) kWh. The tariffs for the four non-residential consumption classes that were effective in 2020 (PURC, 2019) at the start of the building operation phase were as follows:

- 0.141US$/kWh for monthly consumption of 0-300kWh.
- 0.150US$/kWh for monthly consumption of 301-600kWh.
- 0.236US$/kWh for an overall monthly consumption of more than 600kWh.

Based on the above information, the total annual building energy cost was calculated for the case study, starting from the base year 2020. The annual energy cost for the base year is calculated using Eqn. (8.1):

$$Total\ annual\ energy\ cost\ (GB) = [300kWh/month\ x\ 12months\ x\ 0.141/kWh] + [300kWh/month\ x\ 12months\ x\ 0.150/kWh] + \left[\left(4{,}631{,}040 - (600kWh\ x\ 12months)\right) x\ 0.236/kWh\right] = \mathbf{1{,}092{,}273.84/year} \quad (8.1)$$

From Table 8.2, the annual energy cost of GB is 36% lower than that of non-GB, at US$1,092,273.84. This is slightly lower than the annual energy savings of GBs in Indonesia, which is estimated at 38% (Miraj et al., 2021). With the total annual building energy consumption, electricity tariffs and average inflation rate for electricity in Ghana being 17.14% (Fig. 2.4), the total lifecycle budget for energy was projected over the operational period of analysis (2020-2063) using Eqn. (2.15).

Table 8.2 Cost comparison of operating cost between non-GB and GB

Components	Shared unit	Non-GB	GB
Energy cost			
EUI (kWh/m^2)		270	173
GIFA (m^2)	26,800		
Energy usage (kWh/year)		7,236,000.00	4,631,040.00
Tariff (US$/kWh)	See Eqn. (8.1)		
Electricity cost (US$/year)		**1,707,044.40**	**1,092,273.84**
Water cost			
Occupants (persons)	1,787		
Water consumption (m^3/year)		61,640.00	27,122.00
Water tariff (US$/m^3)	1.63		
Water cost (US$/year)		**100,345.90**	**44,152.19**
Cleaning (US$/year)	**13,227.51**		
Management, security & health (US$/year)	**8,112.87**		
Operating cost in base year (US$) – 2020		**1,828,730.68**	**1,157,766.41**
Total operating cost at end-of life (US$) – 2063		**11,239,747,103.50**	**7,115,865,553.99**

8.2.2.2 Water Cost

Two types of data, total water usage (m^3/year) and water tariff (US$/m^3) were key to estimating the total water LCC for the building. Owing to the lack of data on the building's overall water use, some assumptions related to water usage calculation were adapted from the literature (Miraj et al., 2021). First, based on the green certification design assessment report, it is expected that water consumption in the building can be minimised by 56%. In addition, the gross average area of offices for general administrative purposes can be calculated based on Ghana's zoning guidelines and planning standards of 15m^2/person (Town and Country Planning Department, 2011). Contingent on the 26,800m^2 floor space, the building is expected to accommodate approximately 1,787 employees. The Town and Country Planning Department (2011) estimated the water consumption of private non-industrial business buildings to range between 69-138 litres/person/day. Based on the above considerations, the water consumption in the case study was 27,122.00m^3 per 250 working days.

For commercial users, Ghana's water tariff is estimated at US$1.63/m3. Water tariffs in Ghana are reviewed based on the cost of electricity, increase in volume/cost of chemicals to treat raw water, the GH₵/US$ exchange rate, inflation, infrastructure upgrade/expansion, and O&M of service delivery, as well as the financial viability of Ghana Water Company Limited (PURC, 2019). From Table 8.2, the annual water cost for GB is estimated at US$44,152.19m^3, which is 56% lower than that of non-GBs. Using Eqn. (2.15), the total lifecycle budget for water in Ghana was projected over the operational period of the analysis, considering an average escalation rate of 17.14% for water (Fig. 2.4).

8.2.2.3 Other Operation Cost

In addition to the water and energy costs, as outlined in Table 8.2, three operational cost components (cleaning, security, health, and management costs) were derived from the primary data through interviews with building management.

8.2.2.4 Building Maintenance Cost

Building maintenance refers to the corrective, responsive, and preventative maintenance of buildings and their components. This comprises all associated management, cleaning, servicing, repainting, repairing, and replacing parts required to allow the building to be used for its intended purposes (ISO 15686-5, 2017). While preventative maintenance concerns the routine maintenance of a building, corrective/reactive maintenance is undertaken to correct failures or breakdowns. Responsive/proactive maintenance relates to the planned inspection of building components to ensure optimum building performance over the life cycle (Dwaikat and Ali, 2018; Miraj et al., 2021).

Building maintenance costs include maintenance management, adaptation or refurbishment of the building, minor repair and replacement costs, major systems or component replacement costs, cleaning, ground maintenance, and redecoration tax on maintenance goods and services (ISO 15686-5, 2017). The present study adapted Miraj et al.'s (2021) building maintenance cost categories, as presented in Table 8.3, and estimated costs based on cost planning and related maintenance information supplied by building management. The theoretical basis for cost breakdowns in CBA studies can vary from a practical perspective (Miraj et al., 2021). However, estimates of building maintenance in Ghana are not well documented because of the lack of maintenance cost databases and benchmarks.

Based on the primary data, the maintenance cost for the main building, plumbing and sanitary, electrical installation, HVAC, lift, fire protection, and others are estimated. Due to a lack of data, estimates for the maintenance of GB features were based on a review of secondary data as well as international and domestic standards (Abdul-Ganiyu et al., 2021; Dwaikat and Ali, 2018; Miraj et al., 2021). As detailed in Table 8.3, compared with the total maintenance cost of US$220,433.30, GB features contribute an annual maintenance cost of <5% being US$10,238.89. The main building (building envelope, frameworks, fittings and furniture, paints, windows, and doors) and lift contributed to <65% of the maintenance cost. The maintenance cost of subsequent years considers the historical annual average general inflation rate of 12.05%. Overall, the LCC analysis found that GB required an additional maintenance cost of 4.87% (US$12,602,873.39) compared to non-GB.

Table 8.3 Cost comparison of maintenance cost between GB and non-GB (US$)

Components	Non-GB	GB
Main building	67,509.11	67,509.11
Plumbing & sanitary	4,374.24	4,374.24
Electrical installation	19,319.56	19,319.56
HVAC	22,393.68	22,393.68
Lift	75,334.14	75,334.14
Communication	15,188.34	15,188.34
Fire protection	6,075.33	6,075.33
Green building*		
Rainwater harvesting		565.02
High-performance HVAC		160.75
High-efficient lighting system		234.06
Landscaping and gardening		9,279.06
Maintenance cost in base year (US$) – 2020	210,194.41	220,433.30
Total maintenance cost at end-of life (US$) – 2063	**258,724,619.37**	**271,327,492.77**

*****Estimates based on a review of secondary data and local/international standards due to lack of primary data.

8.2.3 Integration of Renewable Resources

This section focuses on how GB with renewable resources (GB-RE), such as solar PVs and underground water harvesting, reduces the LCC of the GB.

8.2.3.1 Solar Photovoltaics

Recent studies have revealed that with renewables, building energy use will be less impacted by fossil price volatility and reduce building energy-use emissions (UNEP, 2022). The case study uses a standard solar PV panel with high-efficiency mono-Si-HIP-215NKHA5 PV with a conversion efficiency of 17.1%, manufactured by Sanyo (Kebede, 2015). Covering 47.5% of the roof space was covered (Ohene et al., 2022), 12,730m^2 of PV installation was estimated. Using the module unit area of 1.6m^2, the total number of PV panels was estimated to be 7,858. The total initial cost of the PV power system is US$ 2,931,235.46, while the annual O&M costs were estimated to be US$ 58,345.65/year. The annual average daily solar radiation of Accra is 4.49 kWh/m^2/day, and the climate of the city has enormous potential for solar generation (Asumadu-Sarkodie and Owusu, 2016). Table 8.4 presents details of the financial input parameters used for the PV cost analysis.

Table 8.4 Summary of solar PV energy generation cost

Item	Parameters	Reference/remarks
Initial costs		
Power capacity	0.32kW/unit	(Asumadu-Sarkodie and Owusu, 2016)
PV module (area)	US$297/module (1.6m^2)	(Asumadu-Sarkodie and Owusu, 2016; Ohene et al., 2022)
Balance of system cost	22% of module cost	(Asumadu-Sarkodie and Owusu, 2016; Kebede, 2015)
Feasibility study, development, and engineering cost	0.6% of module cost	(Asumadu-Sarkodie and Owusu, 2016; Kebede, 2015)
Miscellaneous/contingency fund	3% of module	(Asumadu-Sarkodie and Owusu, 2016; Kebede, 2015)
Periodic costs		
Inverter replacement costs	US$102,565/10 years	(Asumadu-Sarkodie and Owusu, 2016; Kebede, 2015)
O&M cost	5% of module/initial cost	(Abdul-Ganiyu et al., 2021)
Other assumptions/parameters		
Annual daily solar radiation (Accra)	4.49kWh/m^2/day	(Asumadu-Sarkodie and Owusu, 2016)
Life expectancy of PV	25 years	(Abdul-Ganiyu et al., 2021)
Project lifecycle	50 years	
Life expectancy of inverter	10 years	(Abdul-Ganiyu et al., 2021)
Module efficiency	17.1%	(Kebede, 2015)
Transmission and distribution losses	18%	(IEA, 2014)

Based on the above parameters, the case study generated 2,925,348.23kWh/year of energy from solar PV. In effect, only 37% (1,705,691.77kWh/year) of the energy is annually sourced from the national grid to complement the solar energy used. The annual energy cost sourced from the national grid was reduced to US$401,891.66. The annual O&M cost of solar PV is US$401,891.66. Using Eqn. (2.15), the total lifecycle budget for the O&M of solar PVs in Ghana was projected over the operational period of the analysis, considering a national average inflation rate of 12.05% (Fig. 2.4). Based on Abdul-Ganiyu et al. (2021), the life expectancy of solar PV is assumed to be 25 years. In the event of replacement, the average national inflation rate of 12.05% was used as an indicator to estimate the future replacement cost of PV.

In addition, to assess the economic viability of PV applications for GBs, the levelised cost of energy (LCOE) approach was used. Using Eqn. 8.2, the net economic value of unit electric energy delivered by generation resources can be used to estimate the financial implications of solar PVs.

$$NV = P - LCOE \tag{8.2}$$

$$LCOE = \frac{A(CAPEX) + A(OM) + A(F) + A(T)}{A(E)}$$

where NV denotes the net value of a unit of electric energy, P is the annual average electric price, $A(CAPEX)$ represents the annual levelised capital expenditure, $A(OM)$ is the annual O&M costs, $A(F)$ is the annual fuel costs and $A(T)$ is the expected annual value of electricity (on-grid). Simply, the LCOE was calculated using Eqn. 8.3:

$$LCOE = \frac{Total\ Annualised\ Cost\ (TAC)}{Annual\ Electricity\ Generation\ (E_{load})} \tag{8.3}$$

where (TAC) represents the total annualised cost ($/year), the annualised cost of the energy generation. The estimated LCOE of the PV over the project lifecycle is US$ 0.033/kWh (in comparison to the average national tariff of US$ 0.236/kWh).

Further, the payback period for just the PV system was assessed using Eqn. 8.4

$$Payback\ period = \frac{Total\ investment}{Net\ cash\ flow} \tag{8.4}$$

where $initial\ investment$ is the total cost of installing the PV system, and the $net\ cash\ flow$ is the annual actual/projected electricity tariffs saved by using PVs. The payback period of just the PV is nine years. This means investors can recoup their initial investment within the first ten years of PV installation. This is consistent with Ohene et al. (2022) and Asumadu-Sarkodie and Owusu's (2016) studies, where the PV payback period in Ghana ranged between 6 and 12 years.

Due to a lack of data, this study did not consider technological advancement, possibly making PV panels cheaper over time. In addition, this was outside the scope of the current study. Future studies may consider the effect of technological advancements on the replacement costs of PVs in LCC studies.

8.2.3.2 Underground Water Harvesting

The building utilises only harvested rainwater and underground water for all water consumption requirements as an alternative measure. From the primary data, the installation cost of the underground water system was US$ 17,636.68 (2020). The O&M cost of the water pumps for the system was US$5,291.01/year in the base year. This study assumed an equal O&M cost, considering the historical annual average general inflation rate of 12.05%. Due to a lack of data, this study did not consider a separate life expectancy for the water harvesting system. Except for the solar PV cost estimations, this study considered a 50-year lifecycle for all the green features of the GB understudy.

8.2.4 End of Lifecycle Cost

The building's ground floor space of 26,800m2 is expected to generate a waste volume of approximately 33,972.44m3 based on a waste factor of 1.2676 m^3/m^2, as Solís-Guzmán et al. (2009) proposed. In Ghana, construction debris is usually used for land reclamation, disposal at landfill sites, or as backfilling material at construction sites (Asah, 2019). Using a rate of US$8/$m^3$ for transporting waste material to a recycling plant or landfill sites at a distance of up to 60km (Solís-Guzmán et al., 2009)), the overall cost of the waste and transport components is US$271,773.44. Similarly, Guy (2006) estimated that around 0.06h/m2 is the required labour effort for deconstruction. Approximately 1,608 labour hours at a rate of US$2.21 per hour are needed for building deconstruction, estimated at US$3,553.68. With an additional 10% of the total cost of US$27,532.71 to account for all indirect costs, the total deconstruction budget is estimated at US$302,859.83, based on 2020 prices. To determine the nominal future value when the deconstruction cost is expected to occur, the average general historical inflation rate in Ghana is used in Eqn. (2.15) to determine the future value in 2063, representing the expected endpoint of the building lifecycle. Table 8.5 summarises the deconstruction budget; note that the salvage value was not calculated because of the scarcity of data.

Table 8.5 Building deconstruction cost estimate

Description	Area (m^2)	Unit rate	Quantity	Unit cost	Total cost (US$)
Site clearing and waste transport	26,800	1.2676m^3/m^2	33,972m^3	8US$/$m^3$	271,773.44
Labour cost	26,800	0.06h/m^2	1,608h	2.21US$/h	3,553.68
Indirect cost (10%)					27,532.71
Cost in 2020 prices					302,859.83
Cost in 2063 prices					45,223,435.62

Note: The construction all-in (skilled) labour rate in Ghana was GHC100.00 (US$17.64) per 8-hour daily labour as of 2020.

8.2.5 Total Lifecycle Cost of Green Building

The above analysis of the lifecycle components and budget describes the LCC baseline for the GB. This baseline considers the construction and operational stages by tracking costs at the end of the GB cycle. This cost is projected based on the inflation and/or discount rates (Dwaikat and Ali, 2018; Miraj et al., 2021). In Ghana, an average discount rate of 17.14% was adopted for housing, water, and electricity.

Generally, the LCC is estimated using the time-phased budgeting of all components to determine the annual sum of costs. While Dwaikat and Ali (2018) acknowledge that the design and construction costs are best distributed over project planning and construction duration, Miraj et al. (2021) indicate that a one-time investment cost is preferable when data scarcity exists. Hence, due to data limitations, this study used a one-time investment cost for the analysis.

The investment, O&M, and deconstruction costs comprise the total LCC of the building. The total LCC budget of GB was 35.50% lower than that of non-GB. The analysis revealed that the investment and maintenance costs of the GB concept increased at premium costs of 13.33% and 4.87%, respectively. For GB-RE, in addition to the renewal costs, the investment costs increased by 23.97%, while the maintenance costs increased by 33.89%. However, GB and GB-RE delivered 36.69% and 73.52% more efficient building operations, respectively. This justifies the increase in the investment and maintenance costs of GB and GB-RE. In effect, GB yielded a lower cost per square meter than non-GB, from US$431,768.35 to US$278,500.14, throughout the project's lifecycle of 50 years. For GB-RE, the cost was lesser, US$127,471.70/$m^2$. The details of the total LCC budget of the case study are presented in Table 8.6. They are graphically depicted in Fig. 8.1 as a cumulative curve showing the corresponding cumulative LCC value by the end of each year.

Table 8.6 Total LCC of GB vs non-GB

Description	Non-GB (US$)	Weight	GB (US$)	Weight	GB-RE	Weight
Design & construction cost	27,696,662.77	0.24%	31,387,327.60	0.42%	34,336,249.74	1.27%
O&M cost						
Operation cost	11,239,747,103.50	97.13%	7,115,865,553.99	95.34%	2,976,133,255.76	87.12%
Maintenance cost	258,724,619.37	2.24%	271,327,492.77	3.64%	346,400,434.53	10.14%
Renewals	-	-	-	-	14,148,169.93	0.41%
Deconstruction cost	45,223,435.62	0.39%	45,223,435.62	0.60%	45,223,435.62	1.32%
Total cost	11,682,995,677.19	100.00%	7,565,200,520.64	100.00%	3,416,241,545.58	100.00%
Cost/m^2	431,768.35		278,500.14		127,471.70	

From Fig. 8.1, the one-time investment cost is evident because there was no noticeable change in the curve from 2014 to 2019. Starting in 2020, during the O&M period, the LCC curve rises steadily over time. This is because LCC moderately accumulates the costs incurred in the O&M phase at lower rates. According to the literature (Dwaikat and Ali, 2018), the exponential effect of price inflation explains the LCC curve curvature. A comparison of the LCC curves of GB and non-GB reveals that the small additional investment cost in GB features yields long-term cost savings over the lifetime of the GB.

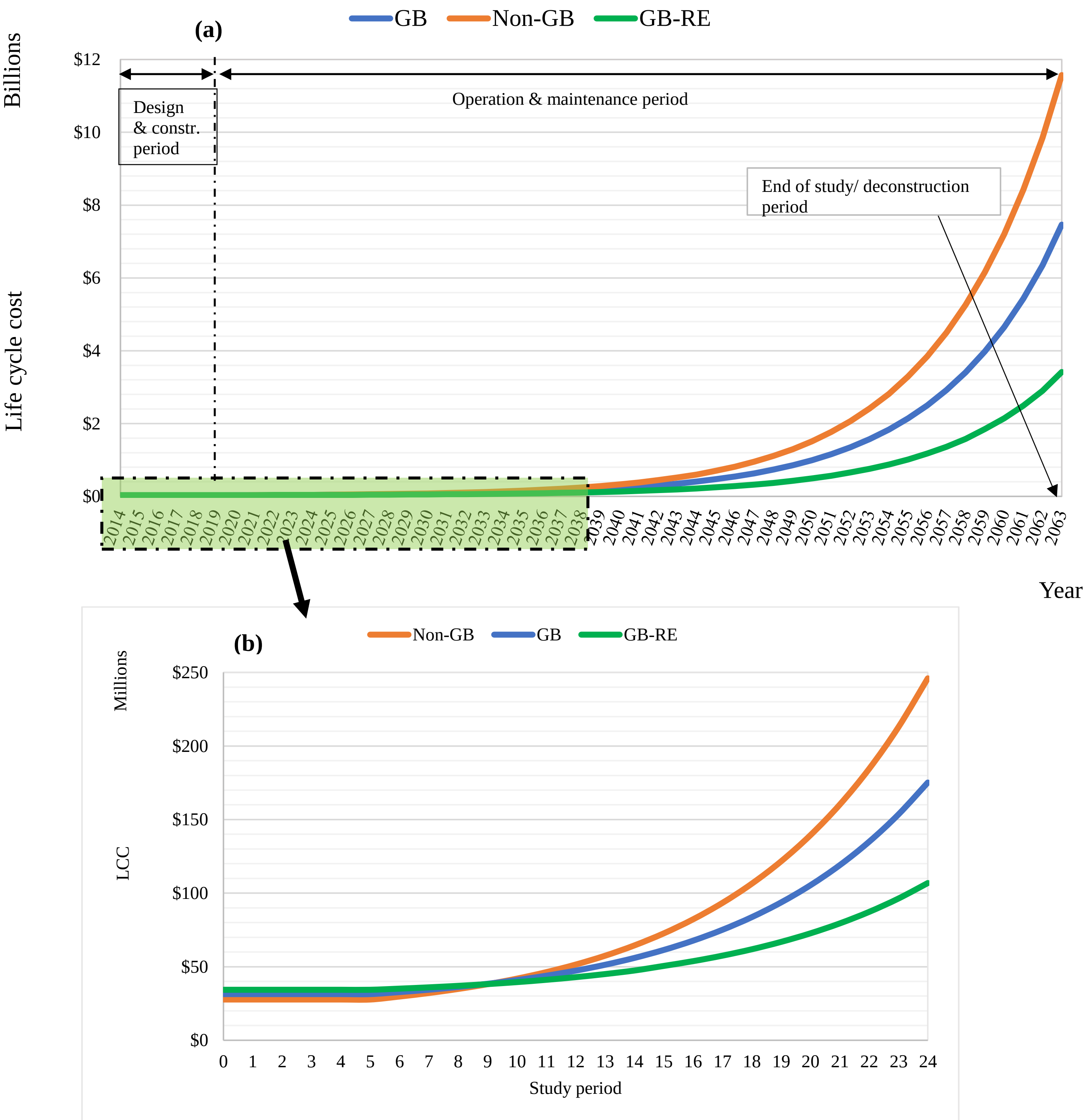

Fig. 8.1 Lifecycle cost baseline

Fig. (8.1a) presents the total LCC for the 50-year study period. **Fig. (8.1b)** expands the cumulative LCC for the first 25 years, from 2014 to 2038.

8.2.6 Cost-Benefit Analysis

A CBA identifies, measures, and compares the benefits and costs of an investment project or programme. It is used to appraise the efficiency of private or public projects from the perspective of the public interest to inform the decision-making process (Campbell and Brown, 2015). GB projects are a worthwhile economic investment if the total benefits throughout the building's lifecycle exceed the additional costs incurred (Gabay et al., 2014). The economic impact of GB may be based on a building's physical or environmental costs. Environmental costs may exist in the form of green space, emission reduction, urban heat islands, and occupant-related issues such as comfort and health. On the other hand, physical impacts are related to construction costs, O&M costs, energy and water efficiency benefits, and indoor environment quality (Miraj et al., 2021; Ries et al., 2006).

For CBA, this study considered four components: energy costs, water consumption, carbon emissions, and productivity increase. While the other components listed above may be relevant for economic evaluation, they were not considered in this study because of inadequacy or lack of data. The savings from GB features, compared with the additional costs throughout the lifecycle of the building, were used to evaluate the benefits of GB. Using Eqn. (8.5), the energy savings were estimated using the present-value approach:

$$PV\ (A) = \frac{A[(1+r)^n - 1]}{[(1+r)^n x\ r]} \tag{8.5}$$

PV – present value (US$); A – annual cost savings (US$/year); r – annual discount rate (%); n – building lifecycle (years).

Generally, non-GBs in Ghana consume a higher energy of 270kWh/m^2/year or an annual energy consumption of 7,236,000.00kWh. The energy efficiency measures in GB save

2,604,960kWh worth of energy. This translates to cost savings of US$614,770.56 per year using Eqn. (2.15), and as shown in Table 8.2.

Regarding water consumption, as discussed above, non-GBs consume more water. GBs usually use water-efficient measures, such as a dual flush for the water closet system, low-flow faucets in bathrooms, motion-sensor taps, and a grey water treatment and recycling system. The occupant capacity of 1,787 employees was based on the statutory requirement of 15m^2 of space per person for offices in Ghana. With a daily water consumption of 138 litres/person for offices, non-GB requires 61,640m^3 of water for 250 working days. As presented in Table 8.2, owing to the efficiency measures, GB consumes 56% less water for the same period, at 27,122m^3 per year, for US$1.63/m^3. This translates to water cost savings of US$ 56,193.70/year.

In terms of CO_2 emissions, this study used Eqn. (8.6) from the Intergovernmental Panel on Climate Change (IPCC) (World Bank, 1998). Table 8.7 outlines the parameters and results of the annual carbon efficiency estimation of the case study based on the standards and energy consumption calculations above.

$$CO_2\ emission\ \left(\frac{tCO_2}{year}\right) = \ Energy\ consumption\ (toe)\ \times\ Carbon\ emision\ factor\ \left(\frac{tCO_2}{toe}\right) \times\ Combustion\ efficiency\ (\%)\ \times \left(\frac{44}{12}\right) \quad (8.6)$$

Table 8.7 Annual CO_2 emissions for the case study

Parameters	Value [a]	Reference
Energy efficiency of GB (toe/year) [b]	224.03	Table 8.2
Grid emission factor for Ghana (tCO_2/toe)	0.413	Energy Commission of Ghana (2022)
Combustion efficiency (%)	99	World Bank (1998)
CO_2 emissions savings (tCO_2/year)	325.29	Authors' estimation
Carbon price (EU ETS) – US$/$tCO_2$	28.55 [c]	European Emission Allowances
Annual carbon savings (US$/year)	9,286.93	Authors' estimation

[a] Any slight difference in the estimated values may be due to rounding errors.
[b] 1 MWh = 0.086 toe (equivalent to electricity consumption).

[c] This study adopted the average 2020 closing spot price of European Emission Allowances at €25/tCO_2 (Statista, 2022).

Regarding the proposed PV's emission reduction, the study adapted Eqn. 8.7 from Kebede's (2015) study for simplicity.

$$Annual\ \ GHG\ emissions\ reduction\ (tCO_2) = \left(Base\ case\ GHG\ emission\ factor\ \left(\frac{tCO_2}{MWh}\right) - Proposed\ case\ GHG\ emission\ factor\ \left(\frac{tCO_2}{MWh}\right)\right) \times End\ use\ of\ energy\ delivered\ (MWh) \tag{8.7}$$

The GHG emission factor of the baseline electricity mix in Ghana is 0.413tCO_2/MWh.

First, based on the energy efficiency measures of the GB, 1,076 tCO_2 are avoided, which translates to US$30,719.80/year (see Eqn. 2.15 and Table 8.2). In addition, the PV system utilised in the case study could avoid 1,208 tCO_2/year. Additionally, it is observed that using solar energy in the case study avoids 2,925,348.25kWh/year worth of energy sourced from the national grid. This equals annual emission savings of US$34,493.24 (see Table 8.7). A total emissions savings of US$65,213.04/year is realised from the GB by integrating solar PVs. Besides, since the GB project is operational for 250 working days, an additional 801.47 MWh of electricity is generated that can be fed into the grid. As a result, the net emission reduction based on the feed-in-tariff system would be 331 tCO_2. This implies that 129,339 litres of gasoline are avoided.

On the other hand, the operational cost for the water pumps in GB-RE was estimated at US$2645.50/year at the base year, leading to water cost savings of US$97,700.40/year. In addition, US$2645.50/year annual maintenance cost was incurred for the pumps.

The GB concept increases productivity and health benefits due to indoor environment quality. This increase is estimated to range from 1% to 20% (Gabay et al., 2014; Kats, 2003). For instance, Kats (2003) estimated that a 1% increase in productivity is equivalent to approximately five minutes per working day per employee per year. This study adopted a modest 3% increase in daily productivity based on 250 working days. This translates to approximately 7.8 working days of productivity increase per employee annually. Using Ghana's 2020 daily minimum wage of US$2.16 (Ministry of Trade and Industry, Ghana, 2020), annual productivity savings of GB amount to US$16.88/employee. Consequently, the annual productivity savings from the case study with 1,787 occupants were US$30,155.63 or US$1.13/m^2.

The energy savings, water-use efficiency, reductions in carbon emissions, and productivity increase of GB compared with non-GB were used in estimating the CBA for this study. The benefits and costs of the case study under LCC parameters consider the inflation rate to estimate the value of GB over a project lifecycle of 50 years. NPV equations (Eqn. 8.2) were used to estimate the project's costs and benefits while considering the cash flow for the lifecycle (50 years), and Based on the Bank of Ghana's average monthly interest rate equivalent from 2011 to 2020, Ghana's average discount rate was estimated at 17.68% (Bank of Ghana, 2023). The total benefits plus salvage value are divided by the total cost of producing the cost-benefit ratio. Due to the lack of data, this study did not consider the salvage value of the case study. The results presented in Table 8.8 reveal that the net benefits of GB and GB-RE are higher than their net costs; thus, the economic impacts of GB and GB-RE remain positive. The results remain valid and positive even when changes in worker productivity and carbon emission savings are ignored.

Table 8.8 Cost-benefit analysis of GB and GB-RE (US$)

GB costs and benefits	GB	GB-RE
Additional GB cost		
GB features and consultancy cost	3,681,864.83	6,630,786.97
Green certification	8,800.00	8,800.00
Renewal costs	-	14,148,169.93
Annual maintenance cost	10,238.89	71,230.05
Total additional GB cost	**3,700,903.72**	**20,858,986.95**
Annual savings		
Energy savings	614,770.56	1,304,501.14
Water savings	56,193.70	97,700.40
Annual carbon savings	30,719.80	65,213.04
Productivity and health savings	30,155.63	30,155.63
Feed-in tariffs		84,153.85
Total annual GB savings	**731,839.69**	**1,581,724.06**
Present value of additional green cost	3,723,123.07	7,293,753.06
Present value of annual green savings	4,867,431.15	10,519,971.89
Cost-benefit ratio	**1.31**	**1.44**

The 50-year NPV over the project life of GB was US$42.70/m^2. While integrating renewable resources increases the additional green cost per square meter by almost 98% over the lifespan, it increases the NPV benefit by over 120%, justifying the additional green investment cost in RE. Table 8.9 compares the financial costs and benefits of GB and GB-RE per square meter.

Table 8.9 Financial costs-and-benefits of GB and GB-RE (US$/m^2)

Category	GB (US$/m^2)	GB-RE (US$/m^2)
Energy savings	152.57	323.74
Water savings	13.95	24.25
Emissions savings	7.62	16.18
Productivity and health savings	7.48	7.48
Sub-total of savings	**181.62**	**371.65**
Average additional cost of GB	(137.71)	(247.75)
Additional maintenance cost	(1.21)	(17.68)
Additional renewal cost	-	(9.01)
Sub-total of additional costs	**(138.92)**	**(274.44)**
Total 50-year NPV Benefit/m^2	**42.70**	**97.21**

8.3 Discussion of Key Findings

In this study, the costs of GB were compared with the benefits accrued over a lifecycle of 50 years through a CBA, demonstrating that it is economically worthwhile. The LCC findings of this study of approximately 6% excess investment and maintenance cost of GB are comparable to those in other countries, ranging from -0.4% to 12% (Dwaikat and Ali, 2016; Zhang et al., 2018). Justifying the rise in investment and maintenance costs of GB is the ability to deliver more efficient building operations owing to energy and water cost savings of up to 37%. While GB-RE requires 24% additional investment cost, it provides up to 74% operational cost savings.

The LCC cost and CBA used in this study considered the average inflation rates to measure GB feasibility. The total LCC budget of GB per square meter was 36% lower than that of non-GB. Comparing the present value of GB excess costs with the benefits obtained through savings from energy, water, carbon emissions, and productivity during the project lifecycle led to a cost-benefit ratio of 1.31. GB-RE has a higher cost-benefit ratio of 1.44, an increase of 10% in profitability. A score of >1 indicates that the benefits outweigh the building's costs and are expected to deliver a positive return on investment. The NPV of GB benefits over the project lifecycle was US$42.70/m^2. Emergent findings have revealed that reducing energy consumption is an influential factor in reducing the total LCC budget. For instance, integrating renewable resources such as solar PVs and underground water harvesting into the GB increased the NPV to US$97.21/m^2. The resultant cost-benefit ratio increased to 1.44. This remarkable decrease in the LCC of the GB and GB-RE by approximately 36% and 78%, respectively, compared to non-GBs in Ghana, proves the need to invest in the construction of GB and using renewable resources such as solar PVs.

This study illustrates that GB costs and benefits can be measured even with little actual data and a low inventory of GBs. The results of the study were comparable with those from other countries, with even larger GB inventories for direct cost-benefit evaluation. While this study provides the first comparison of the costs and benefits of GB and non-GB in Ghana, the results serve as preliminary evidence for entrepreneurs to assess the direct economic, social, and environmental benefits of their green investment. This study can also serve as a policy assessment guide to develop the GB market in Ghana and other emerging and developing economies. In addition, building energy codes and standards that promote GB development can further promote building energy efficiency in the country.

8.3.1 Sensitivity Analysis

Sensitivity analyses are therefore performed to determine "what happens when certain assumptions do not hold" (Gabay et al., 2014). In this study, sensitivity analysis refers to the process of establishing the sensitivity of CBA in response to changes in the assumptions made regarding the values of the selected variables involved in the analysis (Campbell and Brown, 2015). For instance, some assumptions were made in this study to forecast future changes in inflation (of the general economy as well as water and energy). An average increase of 17.14% in electricity was assumed. Similarly, a constant general inflation rate and discount/interest rate of 12.05% and 17.68%, respectively, are assumed in this study. However, these assumptions may vary over time. For instance, the review of electricity tariffs in 2018 resulted in a 30% reduction for non-residential consumers, while it was reviewed upward by an average of 27.15% for end users from 2022-2025 (PURC, 2022b). This study followed Kneifel and Webb's (2022) recommendation of simply increasing uncertain input values by a certain percentage to identify the critical inputs for the sensitivity analysis. This study adopted a 10% increase in the input values and recalculated LCC. The results showed that the inputs critical to the economic outcomes were electricity and maintenance costs. Knowing that the electricity cost has the most significant impact on LCC, the CBA was re-examined with variations in electricity tariffs (0.18-0.30US$/kWh) and varying discount rates.

Sensitivity analysis revealed that changes in electricity tariffs affect entrepreneurs' profits. GB produces a high cost-benefit ratio, even with an average annual reduction/increase in electricity (Fig. 8.2). Similar results were achieved in all the sensitivity analyses performed with an average decrease/rise in the inflation rate.

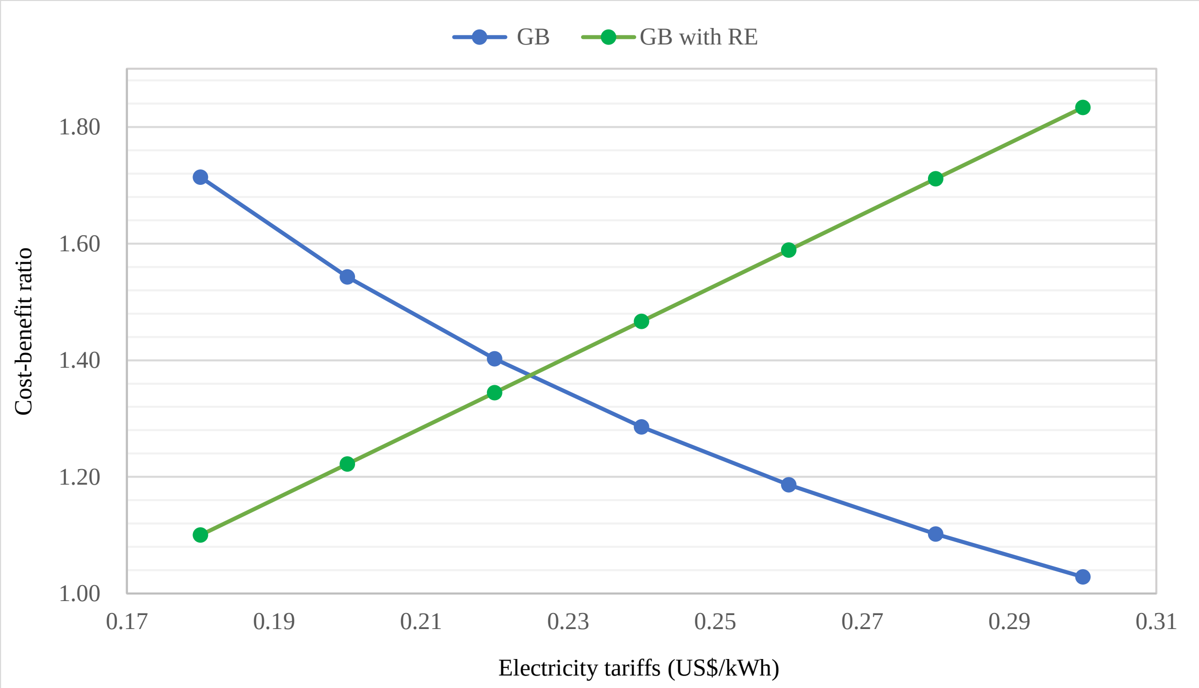

Fig. 8.2 Cost-benefit ratio from electricity tariffs variation.

GB and GB-RE had internal rates of return (IRR) of 24% and 29%, respectively. The IRR is the discount rate at which the NPV becomes zero (Campbell and Brown, 2015). The NPV/m^2 values for both GB and GB-RE remained positive when the discount rates did not exceed the IRR (Fig. 8.3). With an IRR of 29% for GB-RE, investments remain profitable at a slightly higher discount rate.

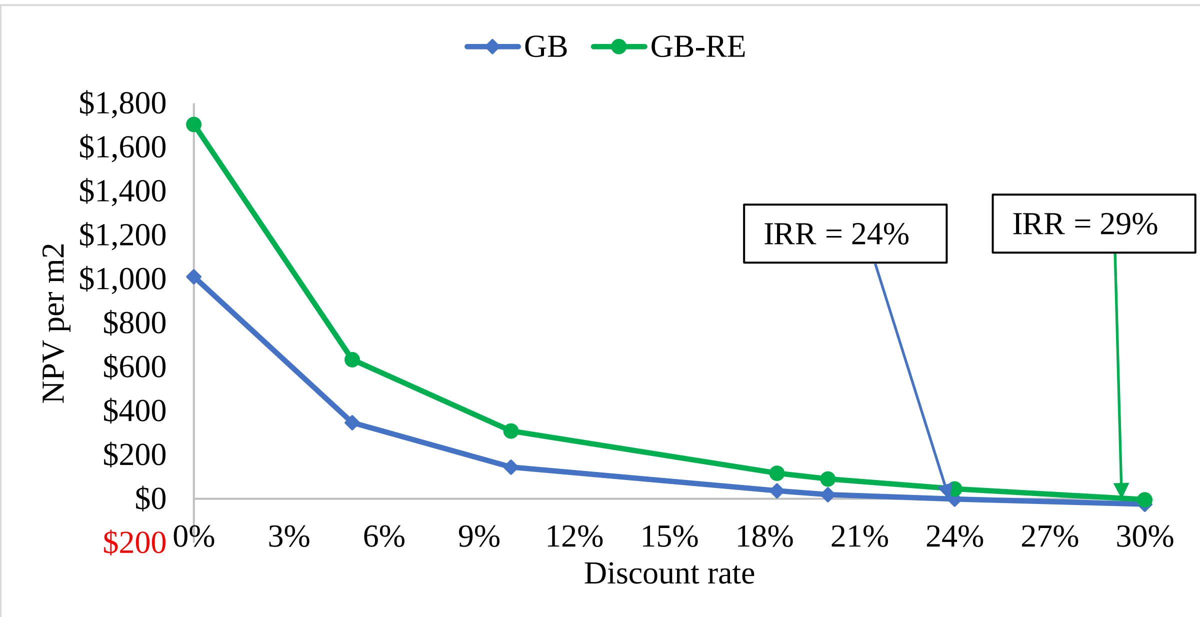

Fig. 8.3 NPV/m^2 for GB and GB-RE depending on the variation in discount rates.

8.3.2 Monte Carlo Simulation and Risk Analysis

To overcome the limitations of the sensitivity analysis, a Monte Carlo simulation was used to estimate the expected NPV and analyse the risks. From the simulations, the probability distribution for the NPV was generated, including the probability that the project failed (negative NPV) and the expected NPV (Belli, 2001). An annual discount rate of 17.68% was used for the project lifespan (n=50). Table 8.10 presents the key probability distributions, key assumptions, and outcomes.

Table 8.10 Key probability distributions, assumptions, and outcomes for Monte Carlo simulation for GB

Variable	Distribution	Minimum (US$)	Mode (US$)	Maximum (US$)	Mean (US$)	Standard deviation (US$)
Additional investment costs	Normal	n.a.	n.a.	n.a.	3,000,000	900,000
Additional maintenance cost	Normal	n.a.	n.a.	n.a.	10,000	5,000
Annual energy savings	Triangular	400,000	1,000,000	1,400,000	n.a.	n.a.

n.a. – Not applicable

Sources: Belli (2001) and Author’s estimation

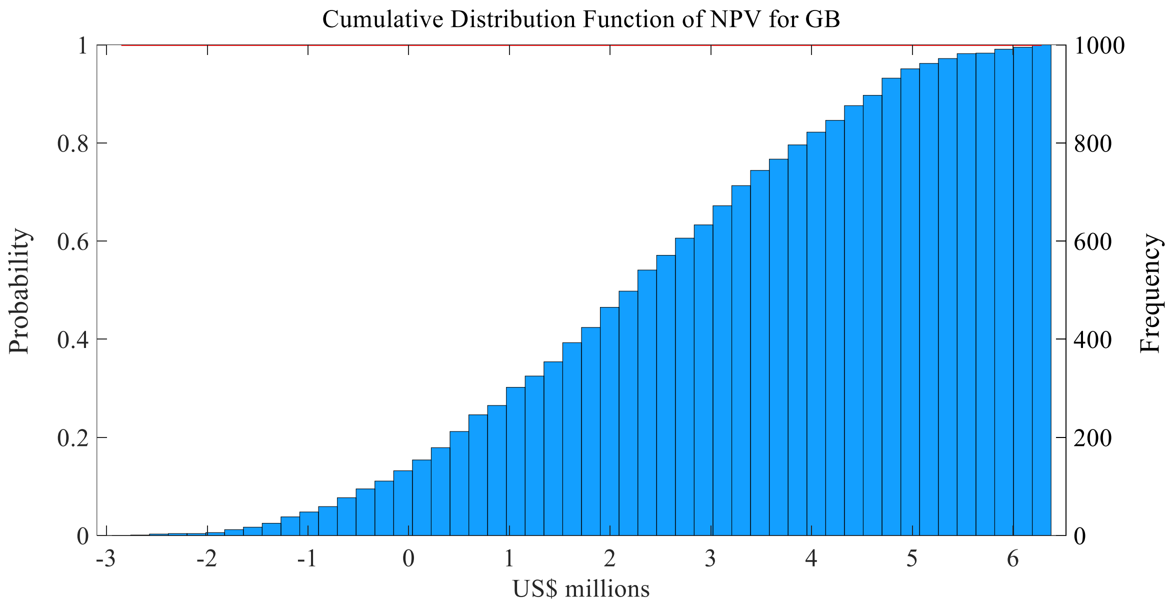

Fig. 8.4 Cumulative Distribution Function of GB’s NPV.

From the analysis, it was observed that the probability of achieving a positive NPV at a threshold of US$ 2.09 million was 49% (Fig. 8.4). Monte Carlo simulations yielded a mean

NPV of US$ 2.07 million with a standard deviation of US$ 1.84 million (Fig. 8.5). This finding suggests that, on average, GB investments are financially viable in the Ghanaian context. Still, there is a notable level of variability.

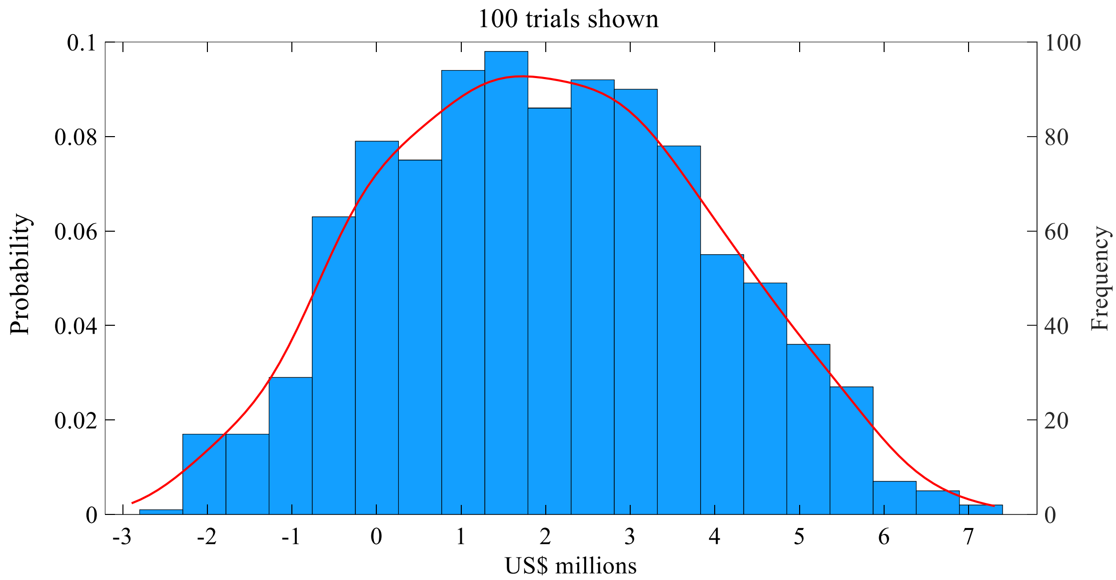

Fig. 8.5 Monte Carlo simulation of GB's NPV.

8.4 Chapter Summary, Contributions and Limitations

In this chapter, the CBA of GB offices was implemented using a 50-year lifecycle (i.e., from design and deconstruction). In addition, the GB integrated with renewable resources (GB-RE) was evaluated. Information for this study was collected through primary data on actual building costs and a broad literature review that provides up-to-date and well-linked compilations of important datasets related to GB costs and benefits. The data were analysed using the discounted NPV method. Emergent results from emerging and developing economies demonstrate that GB requires less than 6% extra cost but offers over 37% energy and water savings in the lifecycle. The LCC budgets of GB and GB-RE per square meter were 36% and 74% lower, respectively, than those of non-GB. The cost-benefit ratio of GB was 1.31, indicating that the benefits outweigh the building's costs and are expected to deliver a positive return on investment. This justifies the increase in investment and maintenance costs owing to GB features. The NPV of GB benefits over the project life cycle was US$37.38/m^2. GB-RE increased the cost-benefit ratio to 1.44 and NPV to US$97.21/m^2. This study adds to GB literature by providing new evidence on the business case of GBs from a whole-building lifecycle perspective in the context of emerging and developing economies. Therefore, it can form the primary basis for developers and investors in such economies to evaluate the expected costs and associated benefits of GB. This initial assessment can also be adopted in future evaluations of GB costs and benefits when the inventory of such buildings becomes sufficiently large for direct and comparative evaluations. Sensitivity and risk analyses proved the accuracy of the results and the robustness of the study.

Despite the contributions of this study, it has some limitations. First, the cost-benefit performance of GB was implemented through a single private green office building in Ghana; therefore, the scope of this study was limited. This is because of the low inventory of GBs and inadequate data on their cost and performance in Ghana. Hence, both the primary data and standards were adopted to calculate the LCC of the project. There may be higher uncertainties in the generalisation of the costs and benefits of GB, as they depend on the quantitative results of a single study. The assumptions for the average escalation rates of the electricity and water tariffs may be incorrect. Therefore, the accuracy of the results should be measured as a function of the accuracy of the LCC variables. As the GB inventory in Ghana becomes large enough, there could be a direct and comparative cost-benefit evaluation of GBs, thereby improving the accuracy of the results accrued. The estimated LCC budget can be updated with more accurate information about the actual building performance as it becomes available over time or due to changing requirements, standards, and conditions. Again, the developed LCC budget can serve as an LCC cost performance baseline for direct measurement and comparison with actual LCC spending, particularly in emerging and developing economies. Thus, it is recommended that more similar case studies from other geographical and climatic regions, especially within emerging and developing economies, be developed based on LCC to provide more conclusive evidence on the generalisation of costs and benefits of GB. In the next chapter, how different sources of finance, especially green finance, affect the profitability of GB is considered based on the NPV results from the GBs in this chapter.

CHAPTER 9 - ECONOMIC FEASIBILITY ASSESSMENT MODEL FOR GREEN FINANCE IN GREEN BUILDING

9.1 Introduction

In the previous chapter, the CBA of a green office building in Ghana was implemented using a 50-year lifecycle (i.e., from design and deconstruction). In addition, the GB integrated with renewable resources (GB-RE) was evaluated to determine the CBA, NPV, and IRR. This chapter evaluates the financing risk of different financing solutions for the GB project in the previous chapter. This is done to determine the optimal weight necessary to diversify the traditional finance options in the capital market and GF solutions. This study used bank loans and green bonds as financing solutions for the GB project under study.

Information for this study was collected through primary data of actual building costs and a broad literature review that provides up-to-date and well-linked compilations of important data sets related to green bonds in developing countries (refer to Table 3.8). To achieve the objectives of the present chapter, the data collection and analysis methods for CBA, NPV, and E (NPV) are discussed in Chapter 2. Chapter 3 presented a comprehensive literature review of the GB and finance cost studies. This chapter also discusses key findings and provides theoretical and practical implications and the study's limitations. A summary is provided at the end of the chapter.

The findings of this chapter are critical to addressing the gap of a few studies on GF-in-GB, particularly in a developing country context. To date, there have been few studies on GF-in-GB in the literature. Consequently, this study adds to the GF and GB literature by providing new evidence on optimal diversification and financing solutions for GBs from a whole-building lifecycle perspective in the context of emerging and developing economies. Therefore, it can form a primary basis for developers and investors in such economies to evaluate expected returns on GB investments. This initial assessment could also be adopted in future evaluations of GB investments and expected returns when the inventory of such GBs becomes sufficiently large for direct and comparative evaluations. In addition, as GF is expected to increase in developing countries, large amounts of data would become available for a more in-depth analysis.

9.2 Analysis and Discussion of Results

9.2.1 Profitability Analysis

As shown in the previous chapter, the NPV, CBA and IRR were used to explore the profitability of both GB and GB-RE projects. This section focuses on just the GB project. As noted, the NPV method helps discount all project cash flows to the present-based year on the assumed discount rate (17.68%), as discussed in Chapter 8. A summary of the results used for further analysis is provided in Table 9.1 below.

Table 9.1 Net present value of GB (US$)

GB costs and benefits	GB (US$)
Additional total GB cost	
Total GB investment and consultancy cost	3,690,664.83
Additional annual maintenance cost (due to GB features)	10,238.89
Total additional GB cost	**3,700,903.72**
Annual savings	
Energy savings	614,770.56
Water savings	56,193.70
Annual carbon savings	30,719.80
Productivity and health savings	30,155.63
Total annual GB savings	**731,839.69**
Present value of additional green cost	3,723,123.07
Present value of annual green savings	4,867,431.15
NPV	**1,144,308.08**

The NPV findings for GB with varying discount rates (4%–24%) are presented in Fig. 9.1. These results are consistent with those in Chapter 8. Consistent with existing studies, lower discount rates improved the NPV of GB projects.

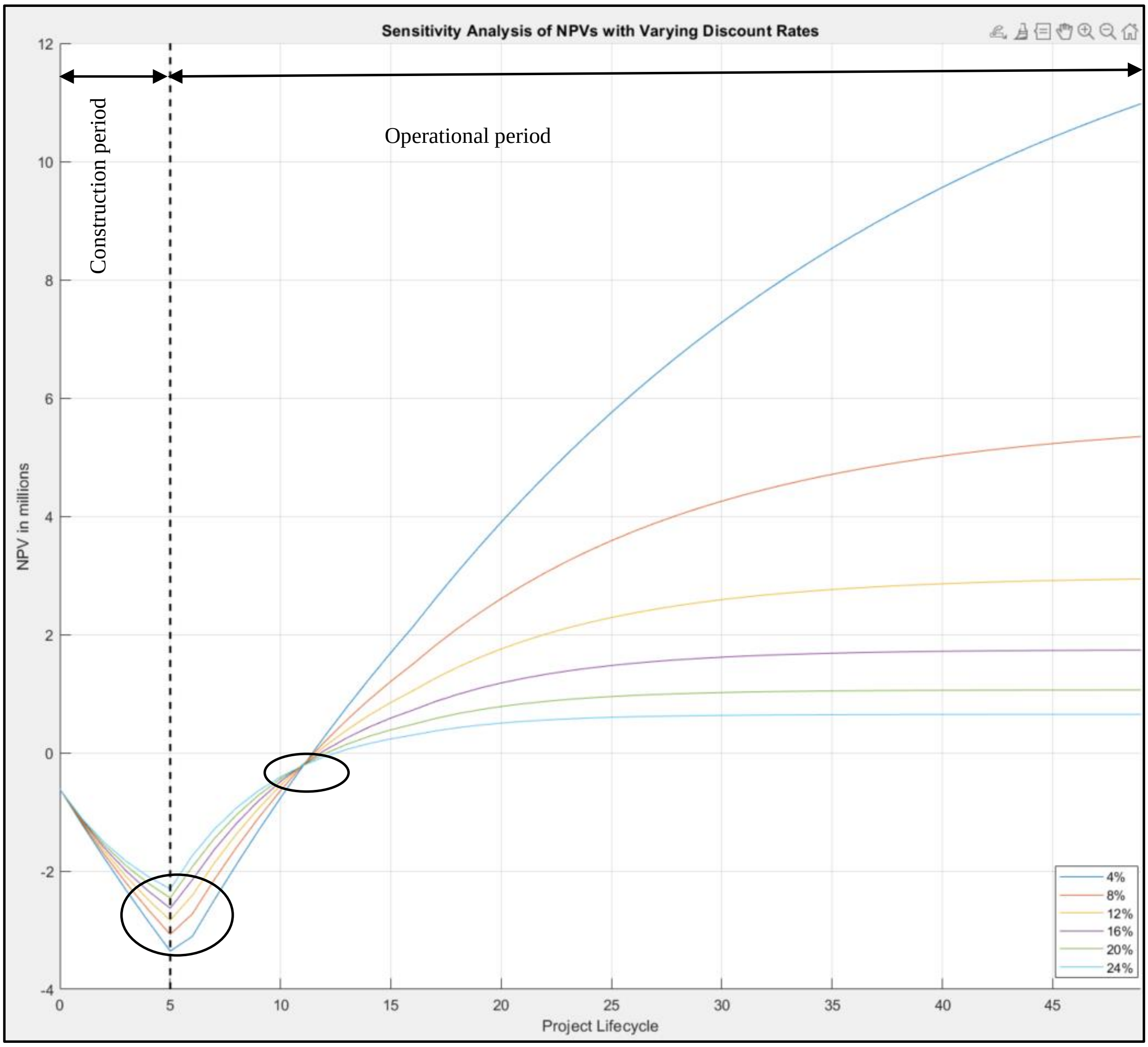

Fig. 9.1 NPV of GB in Ghana with varying discount rates.

9.2.2 Sensitivity Analysis

A gradient sensitivity analysis was conducted using Expert Choice Software to ascertain the cost of the project that is sensitive to the LCC. Expert Choice software engages decision-makers by structuring a decision into parts, proceeding from the goal to objectives to sub-objectives down to the alternative courses of action and controls. Decision makers then use a combination of simple pairwise comparison judgments or ratio-based ratings throughout the hierarchy to arrive at overall priorities for the alternatives or the relative risk events. The decision problem may involve social, political, technical, and economic factors (https://www.expertchoice.com/ahp-software). This sensitivity analysis was carried out using the Expert Choice software to explore the effects of LCC of the GB due to different costs (Taghizadeh-Hesary et al., 2022). Hence, this study used the gradient sensitivity analysis through the Expert Choice Software to prioritise the financing cost impacts of the examined GB projects.

The results showed that, in addition to maintenance cost and cost of installation of GB features, the sensitivity analysis (refer to Fig. 9.2) reveals that GB projects in Ghana are also sensitive to financing costs such as bank loans, green bonds, repayment period, and discount rates.

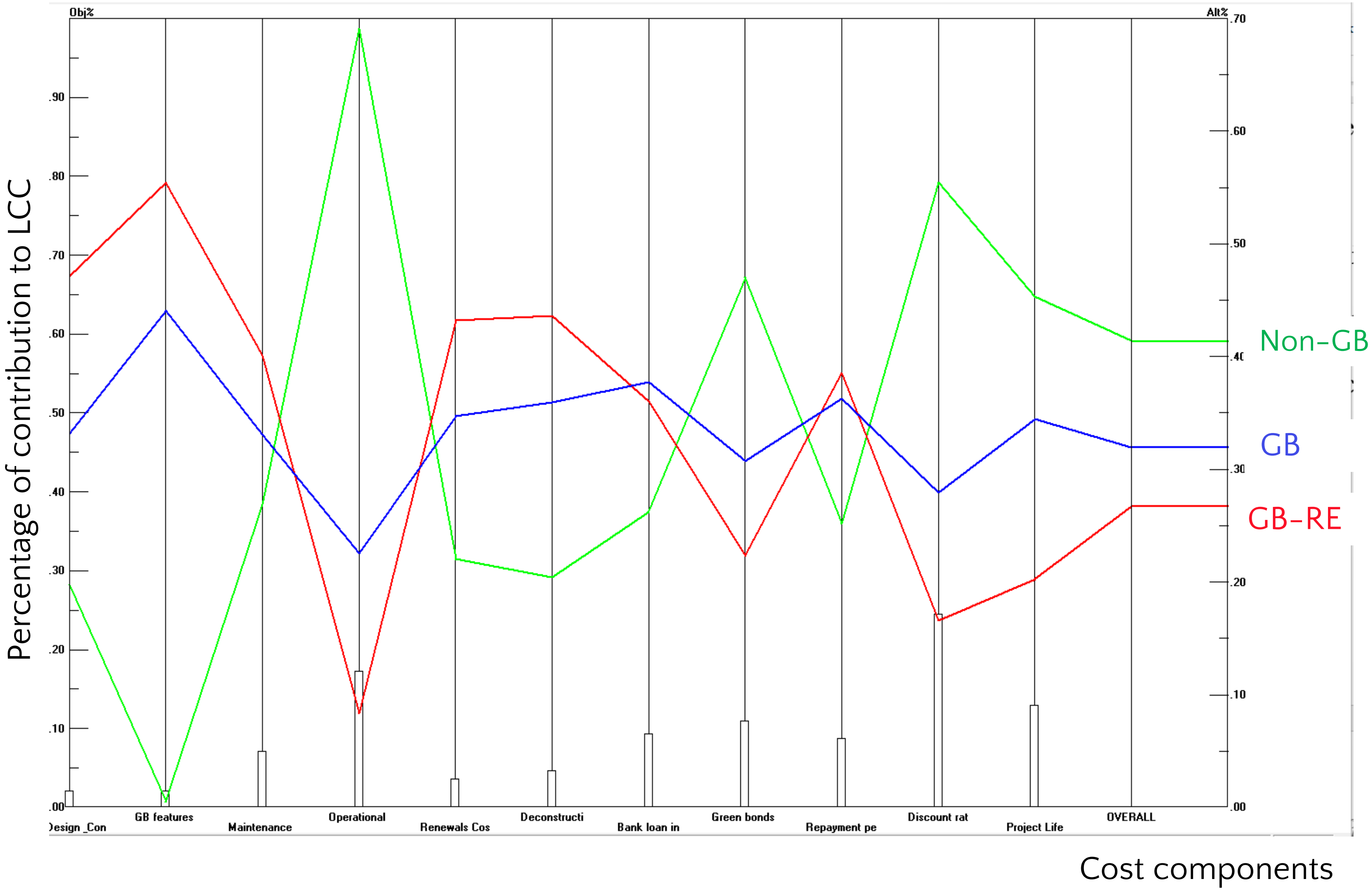

Fig. 9.2 The sensitivity of LCC of GB and non-GB projects in Ghana.

For instance, the high sensitivity to discount rates could be due to the capital-intensive nature of GB projects (Gabay et al., 2014; Kats, 2003). However, the reduced costs in the GB and GB-RE projects reduce the impact of discount rates on their LCC values, as shown in Fig. 9.2. In addition, high interest rates on bank loans and green bond coupon rates impact investment returns and could be responsible for attracting investors to GB projects in Ghana. The following section evaluates the impact of financing risk on the profitability of a GB project in Ghana.

9.2.3 Financing Risk of a GB project

The empirical results and sensitivity analysis above emphasise the role of financing solutions in lowering GB projects' financing risk. These findings are consistent with Taghizadeh-Hesary et al. (2022)'s study of the financing risk of hydrogen projects in China. As noted, all the data required to calculate the economic and financial feasibility of the GB project in Ghana were gathered through interviews with experts on projects and building management. Table 9.2 reports the financing cost indicators.

Table 9.2 Financing costs of GB projects

Parameter of Costs	Value	Reference
Average monthly interest rate	17.68%	(Bank of Ghana, 2023)
Average green bond coupon rate	6.97%	Refer to Table 3.8
Project lifecycle	50 years	Primary data
Repayment period	10 years	Primary data

Different shares of bank loans and green bonds were defined (refer to Table 2.8), and the expected NPV of the GB project was analysed using scenario analysis. Based on Eqn. 2.21-2.22, the $E(NPV)$ considering financing risks at different interest rates are calculated. While Fig. 9.1 considered only varying discount rates, the $E(NPV)$ included the financing risks.

Now, based on Eqn. 2.22, the $E(NPV)$ is considered, which is the expected NPV of a GB project based on financing risks. To this end, the GF data gathered from CBI were evaluated, and only *six* of the available data had Moody's risk ratio evaluation (Table 9.3). The issuers included Growthpoint, Acorn Project (Two) LLP, Access Bank of Nigeria Plc., City of Johannesburg, African Development Bank, and the Africa Finance Corporation.

Table 9.3 Moody's credit risk evaluation of green bonds in Africa

SN	Issuer	Rating
1.	Growthpoint	Baa3
2.	Acorn Project (Two) LLP	B1
3.	Access Bank of Nigeria Plc.	B2 [b]
4.	City of Johannesburg	A1
5.	African Development Bank	Aaa
6.	Africa Finance Corporation	A3

[b] The credit risk evaluation of B was evaluated by S&P and Fitch's B and is equivalent to B in Moody's rating
Sources: (CBI, 2023)

From Table 9.3, the highest risk (B2) is for the Access Bank of Nigeria Plc, and the lowest risk (Aaa) is recorded by the African Development Bank. Using Table 9.4, the different long-term ratings of the nine groups are addressed. The nine classifications were further grouped into three major categories: upper-middle quality (As with number 1), middle quality (Bs with number 2), and poor quality (Cs with number 3) (Table 9.4). Based on this, the average ratio of six issuers was calculated as 0.7 (meaning that the average green issuers within the subregion have medium quality with moderate risk or can recover the principal and interest).

Table 9.4 Moody's credit rating scale and definitions

SN	Rating	Description
1.	Aaa	The highest quality with minimal risk
2.	Aa1, Aa2, Aa3	High quality with very low credit risk
3.	A1, A2, A3	Upper-medium quality with low credit risk
4.	Baa1, Baa2, Baa3	Medium quality with moderate credit risk
5.	Ba1, Ba2, Ba3	Speculative with substantial credit risk
6.	B1, B2, B3	Speculative with high credit risk
7.	Caa1, Caa2, Caa3	Poor standing with very high credit risk
8.	Ca	Highly speculative and are likely in, or very near default
9.	C	Lowest-rated class and typically in default, with little prospect of recovery in principal and interest

Source: Moody's Analytics (2023)

Eqn. 2.22 was then used to calculate the $E(NPV)$ considering the financing risk. Fig. 9.3 shows E (NPV) at different discount rates.

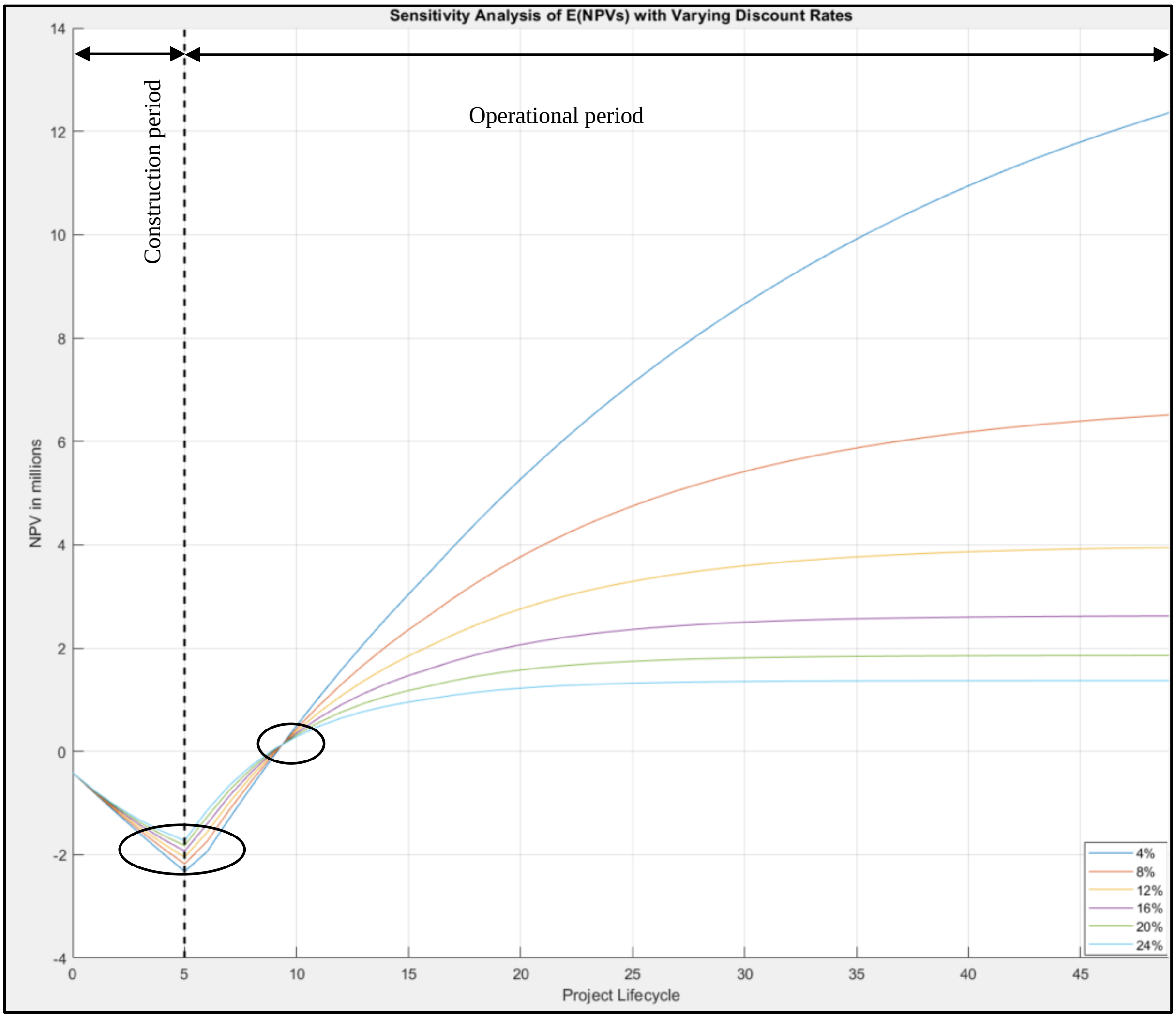

Fig. 9.3 E(NPVs) of GB in Ghana with varying discount rates.

In addition, since investors always seek to optimise their financing portfolio, Eqn. 2.23-2.27 was utilised to calculate the utility of investors. Subsequently, Eqn. 2.28 was used to determine the optimal weight of bank loans and green bonds based on scenario analysis (refer to Table 2.8). Based on the data gathered from the projects, green bonds in Africa, and financing risks (0.7, as mentioned above), the optimal weight of bank loans for GB projects in Ghana is 42%. This means that the weight of the green bonds is 58% (1– 0.42). Hence, it is more desirable to rely on green bonds than on bank loans alone. Diversifying the financial channels to include GF tools, such as green bonds, can help reduce financing risk and increase the rate of return of projects (Taghizadeh-Hesary et al., 2022). It is, therefore, important for governments in developing countries such as Ghana to promote GF for sustainable projects, particularly within the built environment sector. A similar study of hydrogen projects in China revealed that an appropriate mix of bank loans and green bonds is critical for lowering the financing risks of green projects (Taghizadeh-Hesary et al., 2022). In addition, it can increase the inflow of green investments because investors may perceive such diversification as a means of reducing costs in the long term.

9.3 Chapter Summary, Contributions and Limitations

GB has become a potent means of reducing excessive energy consumption and carbon emissions in the buildings and construction sector. Therefore, it is critical to evaluate the economic and technical feasibility of these projects. While the concept of GB is rapidly developing in developed countries, developing countries are yet to fully explore the potency of GBs as part of measures to reduce their housing deficit and to reduce the negative impacts of conventional construction on the environment. As a result, this section of the thesis focused on the profitability and sensitivity analysis of a green office building in Ghana and proposes GF to increase the economic feasibility of such projects.

Based on the study findings, the following conclusions were drawn. First, GB projects in Ghana are sensitive to financing costs, such as bank loans, green bonds, repayment periods, and discount rates. It was discussed that the capital-intensive nature or additional cost of going green and the role of discount rates and/or interest rates affect the rate of return of projects in the long term. Therefore, decreasing the financing risk of GB projects is critical. A lower financing risk can make the NPV of a project more profitable, and the NPV becomes positive over a shorter horizon. In addition, GF mechanisms, such as green bonds, provide a viable alternative for reducing the financing risks of GB projects. With green bond issuers in Africa possessing medium quality with moderate risk and the ability to recover their principal and interest, green bonds can potentially be promoted to finance GB projects in Ghana and other developing countries. The results showed that the optimal weight for bank loans for the GB project was calculated to be approximately 42%. This means using more green bonds (58%) for GB projects is essential and profitable. Moreover, diversification of financing for GB projects using conventional channels (bank loans) and GF sources (e.g., green bonds and green loans) is crucial. Studies have shown that green bonds deliver the most effective diversification and hedging benefits for diversified portfolios (Kuang, 2021; Naeem et al., 2021; Rannou et al., 2021).

Despite the contributions, this study has some limitations. First, the NPV was based on a single green office building in Ghana; therefore, the scope of this study was limited. This is because of the low inventory of GBs and inadequate data on their cost and performance in Ghana. Hence, both the primary data and standards were adopted to calculate the LCC of the project. There may be higher uncertainties in the generalisation of the NPV of GB as they depend on the quantitative results of a single study. Again, the financing cost data are a combination of both primary and secondary data. Based on available data on Africa, very few green bonds have been issued on the continent, with only four focusing on GB projects. As more green bonds are issued in the sub-region, the data may become large and adequate for a more in-depth analysis. Again, since no green bonds have been issued thus far in Ghana, the study was based on an average of the data sourced within the subregion due to the similarities it shares with the countries. As the sample data on GF increases on the continent and countries, future studies may focus on more country-specific data analysis, considering the peculiarities and risk factors of each country despite some commonalities that exist among them. As GF-in-GB data becomes significant in developing countries, more advanced artificial intelligence methods and optimisation algorithms can be used to explore how GF-in-GB can be optimised. In the next chapter, being the final chapter, the general conclusions, contributions, limitations of the thesis, and directions for future studies are presented.

CHAPTER 10 - CONCLUSIONS, CONTRIBUTIONS, AND FUTURE RESEARCH DIRECTIONS

10.1 Introduction

Chapters 1-9 present various aspects of this research. Chapter 1 presented the introduction to this thesis, Chapter 2 described the research methodology, and Chapter 3 focused on the literature review of the subject of this thesis. In Chapters 4-9, the empirical findings of the specific objectives outlined in this study were reported. This present and final chapter concludes this thesis. It begins with a review of the objectives, key findings, and major conclusions of the research study. In addition, the theoretical, pedagogical, managerial, and policy implications and relevance of this study are presented. Finally, this chapter reports on the limitations of the present study and offers future research directions and recommendations.

10.2 Review of Research Objectives and Conclusions

This study aimed to explore the dynamism of GF-in-GB projects of developing regions using Ghana as a case study to aid the development of a CBA assessment model to evaluate the economic feasibility of GF-in-GB projects. To achieve this, the following specific objectives were established:

1. To evaluate the interactions between the critical drivers of GF-in-GB.
2. To investigate the interrelationships between the critical barriers of GF-in-GB.
3. To develop a risk assessment model for GF-in-GB.
4. To assess the interdependencies of the strategies that can be adopted to promote GF-in-GB.
5. To develop a CBA assessment model to evaluate the economic feasibility of GF-in-GB projects.

Several methods were adopted to realise these objectives, including FDM, FDEMATEL, NPV, IRR, scenario analysis, sensitivity analysis and Monte Carlo simulation (refer to Chapter 2). While the principal findings and conclusions in relation to each objective are presented in Chapters 4-9, they are summarised and highlighted below by reviewing each of the research objectives.

Objective 1: To evaluate the interactions between the critical drivers of GF-in-GB in Ghana.

- A comprehensive literature review revealed 16 potential drivers of GF-in-GB. The drivers were classified into four major categories, regulatory drivers, financial drivers, organisational drivers, and environmental and social drivers.
- A two-round linguistic evaluation questionnaire survey was conducted with a group of 12 experts with GF and/or GB experiences in Ghana.
- In round one, FDM was employed to screen out insignificant drivers in the Ghanaian context. Eight drivers were identified as relevant and significant for the second round of the questionnaire survey regarding linguistic evaluation.
- Subsequently, FDEMATEL was employed to analyse the results of the second-round linguistic evaluation questionnaire survey. This method was applied to identify the interdependence of the eight criteria of drivers.
- Drivers with the *highest prominence or importance* values have the potential to affect and/or be affected by other drivers, and managers and policymakers should prioritise promoting or pursuing these in the short term. The findings showed that increased awareness of GF models in GB was the *most important criterion*, with a value of 40.4029.
- Similarly, drivers with the *highest net cause* values have the greatest long-term impact on the entire system; therefore, they should receive more attention than equal attention. In contrast to the importance criteria, climate commitments, improved access to and lower

cost of capital, favourable macroeconomic conditions and investment returns, promotion of responsible and ethical investment, and preferential capital requirements for low-carbon assets are *net causes*, whereas regulatory incentives for GF, increased awareness of GF models in GB, and reduced business and financial risks belong to the effect-group and are *net receivers*.

- The results revealed that GF-in-GB actors and policymakers should pay more attention to *five causes* (Climate commitments; Improved access to and lower cost of capital; Favourable macroeconomic conditions and investment returns; Promotion of responsible and ethical investment, and Preferential capital requirements for low-carbon assets) the effect-group drivers which are *receivers* (Regulatory incentives for GF; Increased awareness of GF models in GB; and Reduced business and financial risk).

Objective 2: To investigate the interrelationships between the critical barriers of GF-in-GB in Ghana.

- A systematic literature review and meta-analysis were conducted to identify barriers to GF. A thorough screening of related studies revealed that 22 barriers were relevant to GF-in-GB. The identified barriers were grouped into five major categories of barriers: financial barriers, regulatory barriers, organisational barriers, technical barriers, and structural barriers.
- A two-step fuzzy-Delphi-DEMATEL methodology was a suitable method to assess the interrelationship between the barriers.
- In the first round, 16 out of 22 barriers were identified by experts as critical barriers using FDM.
- Based on FDEMATEL in the second round, the experts established interrelationships and prioritised barriers.

- The results revealed regulatory barriers to be the most significant barrier and had the most powerful influence on the entire GF-in-GB system. It was also a major source of other barriers, such as organisational and technical barriers.
- In terms of criteria, the results showed that split incentives, inadequate private investment, inadequate management support, and limited green projects deserved critical attention because they showed high importance and cause indexes.

Objective 3: To develop a risk assessment model for GF-in-GB in Ghana.

- A systematic literature review was conducted to identify the principal risk factors for GF-in-GB. Thorough screening led to the identification of 30 relevant documents that addressed GF risk factors that can be adapted to the GB sector. The identified risk factors were grouped into seven major risk attributes: climate transition risks, climate physical risks, liability risks, market risks, liquidity risks, credit risks, and sector risks.
- Linguistic evaluation questionnaire surveys were conducted with experts to develop valid GF-in-GB risk criteria.
- The risk factors identified in the literature review were validated using the FDM.
- FDEMATEL was further applied to identify the interdependence of 14 criteria of risk factors. The FDEMATEL method is based on FDM results.
- The results showed that the attributes (categories) and criteria (risk factors) of GF-in-GB are interrelated and could belong to either the cause or effect group.
- Causal group risk factors have the highest significance and should be considered in GF-in-GB implementation. These risk factors can help managers and other stakeholders undertake proactive and reactive steps in adopting GF practices in GB. Prominent among them were "*construction delays owing to complicated permitting processes*", "*risks associated with the occurrence of climate- and weather-related events leading to property damage*", "*up-*

front risks or capital-intensive nature of GBs", "*greenwashing risks*", and "*uncertain macroeconomic factors*".

Objective 4: To assess the interdependencies of the strategies that can be adopted to promote GF-in-GB in Ghana.

- A comprehensive literature review was conducted to identify GF strategies that can be adapted to promote GF-in-GB. These strategies are intended to de-risk and overcome adoption barriers to GF-in-GB. The identified strategies were grouped under the following categories: financial strategies, policy strategies, technological strategies, market strategies, and behavioural strategies.
- This study evaluated the interdependencies of the strategies of GF-in-GB with a group of experts using linguistic evaluation questionnaire surveys.
- A hybrid approach based on the FDM and FDEMATEL methodologies was used to identify the critical strategies and show the cause-effect relationship among GF-in-GB strategies.
- The results showed that the attributes (categories) and criteria (strategies) of GF-in-GB are interrelated and could belong to either the cause or effect group.
- Five strategies were identified in the cause group: increased information disclosure and better transparency; increased R&D support for GF-in-GB; public-private partnerships to facilitate GF from the private sector; developments in climate-related policy and regulation to stimulate private investment; and increased government participation as "leader by example". These strategies, also known as driving and critical strategies, have a direct impact on the GF-in-GB system and demand a high priority.

Objective 5a: To develop a CBA model for a GB project in Ghana.

- This section focused on the LCC and CBA of a GB office in Ghana. The LCC and CBA of the GB office was implemented using a 50-year lifecycle (i.e., from design and deconstruction).
- In addition, the GB integrated with renewable resources (GB-RE) was evaluated.
- Information for this study was collected through primary data on actual building costs and a broad literature review that provides up-to-date and well-linked compilations of important datasets related to GB costs and benefits.
- Data were analysed using the discounted NPV method, IRR, and sensitivity and risk analyses using Monte Carlo Simulations.
- Emergent results from emerging and developing economies demonstrate that GB requires less than 6% extra cost but offers over 37% energy and water cost savings in the lifecycle. The LCC budgets of GB and GB-RE per square meter were 36% and 74% lower, respectively, than those of non-GB.
- The cost-benefit ratio of GB was 1.31, indicating that the benefits outweigh the building's costs and are expected to deliver a positive return on investment.
- The NPV of GB benefits over the project life cycle was US$42.70/$m^2$. GB-RE increased the cost-benefit ratio by 10% to 1.44 and NPV to US$97.21/$m^2$.

Objective 5b: To develop a lifecycle economic feasibility assessment model for GF-in-GB projects in Ghana.

- This section focused on the economic feasibility of a GF-in-GB project in Ghana from an LCC perspective.
- Using profitability analysis, financing risk analysis, and sensitivity analysis of the cost of a GB project and financing cost parameter building, the economic feasibility of the project in Ghana was evaluated.

- The study findings revealed that the GB project in Ghana was sensitive to financing costs, such as bank loans, green bonds, repayment periods, and discount rates.
- The results showed that the lower financing risks associated with GF made the NPV of the project more profitable, and the NPV was positive on a shorter horizon.
- To increase the profitability of the diversified portfolio of investors, the optimal weight for bank loans for the GB project was calculated to be approximately 42%. This means using more green bonds (58%) for GB projects is essential and profitable.

10.3 Novelty and Contributions of the Study

10.3.1 Originality of the Study

Several studies have focused on the drivers, barriers, risk factors, and strategies to promote GB development, but it is still faced with financing challenges. This study, therefore, investigates how innovative green finance can be used to promote GB development. Unlike conventional finance, GF is structured solely to finance or re-finance green projects such as GBs. The thesis, therefore, closes the knowledge gap of limited studies on GF-in-GB using multiple and novel methodological approaches. Consequently, the study established a comprehensive and validated list or criteria of drivers, barriers, risk factors, and strategies of GF-in-GB using linguistic evaluation questionnaire surveys. First, through a comprehensive and systematic literature review, a set of criteria for the different parameters (drivers, barriers, risk factors, and strategies) were identified. Based on FDM and FDEMATEL results, this study developed a cause-effect relationships between the drivers, barriers, risk factors, and strategies of GF-in-GB. Second, a cost-benefit and risk analysis of a green office building was developed using Ghana as a case study. The NPV results from the GB were further analysed using different financing solutions. Therefore, an economic feasibility assessment model for GF-in-GB was developed based on IRR, NPV, E(NPV), profitability analysis, and sensitivity and risk analysis. Using scenario analysis, this study revealed the optimal weights for the diversification of financing for GB projects using conventional channels (bank loans) and GF sources (such as green bonds and green loans).

10.3.2 Theoretical Contributions

This study makes significant contributions to the literature on GF and GB. The identification and prioritisation of factors (drivers, barriers, risk factors, and strategies) using the MCDM method provide a systematic way to analyse how to promote the most influential factors. First, a theoretical checklist of the drivers of GF-in-GB is established through a systematic literature review. Using expert inputs via FDM, critical drivers of GF-in-GB in Ghana were developed. Furthermore, the influence of critical drivers was determined using DEMATEL to rank the drivers' prominence/importance. Subsequently, the cause-effect relationship between the drivers was established. In addition, a valid set of barriers and criteria were developed from the literature to ascertain the interactions among them. The interactions among the barriers were evaluated by experts using a linguistic scale based on the validated barriers and criteria. These findings contribute to filling the knowledge gap concerning the interrelationship between the barriers to GF-in-GB and could serve as a useful reference for future research in similar areas. The risk factors for GF-in-GB were shortlisted and evaluated by FDM experts. The outcomes derived from the FDEMATEL procedure enabled the identification of cause-effect relationships among the risk factors. This study developed a checklist of strategies to promote GF-in-GB. FDM and FDEMATEL were used to screen out and model the interrelationship between the strategies identified.

Moreover, a whole-building LCC of a GB from the perspective of a typical emerging and developing economy (Ghana) was evaluated in this study. The CBA of a green office building was developed using a 50-year lifecycle (i.e., from design and deconstruction). Furthermore, the GB was integrated with renewable resources (GB-RE) such as solar PVs and underground water harvesting to assess its impact on profitability. Using profitability and risk analyses of bank loans and green bonds, this study investigated the optimal weight for exploring multiple financial solutions for a GB project in Ghana by incorporating GF mechanisms.

10.3.3 Managerial and Practical Implications

This study highlights significant managerial and practical implications. Significant criteria for promoting GF-in-GB in developing countries are discussed. The findings and interrelationship frameworks developed in this study contribute to the understanding of GF-in-GB stakeholders such as GB developers, green banks and insurance firms, institutional investors, green investors, and government and policymakers. First, the comprehensive checklist of influential drivers, barriers, risk factors, and strategies developed in this study can aid in the effective planning and execution of GF-in-GB initiatives, thereby minimising the likelihood of failure. Managers and stakeholders can deduce which barriers or risk factors require significant attention and how to effectively utilise influential drivers and strategies to ensure the successful implementation of a GF-in-GB system.

Furthermore, managers can identify which GF-in-GB factors constitute cause-and-effect groups, thereby facilitating proper categorisation and prioritisation of the adoption and implementation of a robust GF-in-GB system. The models developed in this study contribute to the comprehension of the interrelations among the various criteria of drivers, barriers, risk factors, and strategies. This understanding is crucial for determining the level of dependence and the impact of each factor, thereby enhancing the optimum allocation of constrained resources based on the cause-effect matrix.

The CBA of GBs in Ghana can form a primary basis for developers and investors in developing and emerging economies to evaluate the expected costs and associated benefits of GB. This initial assessment can also be adopted in future evaluations of GB costs and benefits when the inventory of such buildings becomes sufficiently large for direct and comparative evaluations. The model for determining the optimal weight for diversification of financing solutions for GB projects could be explored by investors seeking to optimise their financing portfolios by combining traditional financing options (e.g., bank loans) and GF mechanisms (e.g., green bonds and green loans). Knowledge of the risks of financing mechanisms could lead to the optimal allocation of appropriate financial solutions to advance green projects. To increase the inflow and profitability of green investments, diversification could be explored to reduce costs in the long term.

10.3.4 Pedagogical Contributions

The study provides construction project finance and management students and teachers with new perspectives on how to effectively implement GF-in-GB projects. The key findings could facilitate changes in green construction project finance and management curricula required to equip the next generation of industry practitioners and leaders, consultants, government officials, and policymakers with competencies and technical know-how to implement innovative financing in sustainable construction and infrastructure projects. The results revealed that low risks associated with GF lower the financing risks of green projects, thereby increasing profitability. It is, therefore, important for governments in developing countries such as Ghana to promote GF for sustainable projects, particularly within the built environment sector. GF mechanisms such as green bonds and green loans could be explored as a means to de-risk green investments.

10.3.5 Policy Implications

The findings of this study can be a useful guide in decision-making for policymakers and stakeholders who want to reduce barriers by concentrating on the most influential ones. Through the cause-effect matrix, the uncertainties and complexities associated with barriers can be addressed, and the communication of the results is enhanced through graphical representation. The application of the interdependence framework in policy formulation can be facilitated by considering and giving due importance to the causal and influential drivers, barriers, risk factors, and strategies identified in this study.

The CBA of GBs could also serve as a policy assessment guide to develop the GB market in Ghana and other emerging and developing economies. In addition, building energy codes and standards that promote GB development can further promote building energy efficiency in the country. Similarly, governments in developing countries could explore the use of measures such as the establishment of green credit guarantee corporations as used in China to enhance the credit risk of proposed green projects seeking GF to lower the financing risks of such projects. The government could develop carbon policies such as carbon trading, carbon neutrality goals, and spillover tax effects in the form of tax returns for funding GB projects to potentially increase the profitability of green projects (Yoshino et al., 2019).

10.4 Limitations of the Study

Despite the contributions of this research to achieving the aim and objectives of this thesis, some limitations exist. First, due to the novelty of GB adoption in Ghana, which is still in its initial stages, the linguistic evaluation questionnaire survey for this research study was based on relatively small samples of industry and academic experts with GB experience. GF is still budding and in its developmental stage in Ghana; therefore, limited experts with GF experience were available for multiple rounds of surveys. Second, the analysis of GF-in-GB was limited to Ghana. As a result, the evaluations and assessments made in this study were generally subjective and might have been influenced by respondents' experiences and attitudes. Hence, this limits the generalisability of the results beyond the Ghanaian context. However, the lessons of this study are easily adaptive to other developing countries due to the comparability between emerging economies.

In addition, the analysis of GF-in-GB was limited to a single case of a green office building in Accra (Ghana) due to a lack of data on the few existing GBs in Ghana. Further, this study employed historical data on green bonds issued in sub-Saharan Africa as the basis to evaluate the GF mechanism, since no green bonds have so far been issued in Ghana. Therefore, it may be difficult to generalise these findings beyond green office building financing. This is because other GB uses may have different parameters in terms of EUI, water usage, and carbon intensity. In addition, financing conditions for different building uses, such as residential buildings, may vary. In addition, different countries have different credit risk evaluations; therefore, using the average of green bonds issued across the subregion could impact the findings and results. Similarly, this limits the generalisability of the results beyond green office buildings in Accra (Ghana). However, the lessons of this study are easily adaptive to other developing countries due to the comparability between emerging economies.

Specific research objective-specific limitations are presented in the chapter summary, contribution, and limitations sections of Chapters 4 – 9.

10.5 Future Research Directions

Although this thesis has analysed several issues that are crucial to the adoption and development of GF-in-GB within the built environment sector, several avenues for future research exist:

- First, the analysis presented in this study was based on the results of 12 experts with GF and GB experiences in Ghana. Future research should consider a larger scale in terms of the number of respondents. This study can be extended to other developing and developed countries. Future research that incorporates distinct perspectives of different stakeholders of GF-in-GB, such as issuers, investors, developers, governments, and non-governmental organisations, may provide further understanding of how different stakeholders perceive different factors that promote or inhibit GF-in-GB from a global, regional, or other local perspective.

- Future research may incorporate intelligent models, such as neural networks and adaptive fuzzy inference systems, to explain how the identified influential GF-in-GB factors can be optimised under different constraints for maximum impact.
- Additionally, this study is based on the current development of GB in Ghana and the potential to incorporate GF into GB financing in the country. GB development issues may progress with evidence of GF in the country, and it may be useful for research to adapt the methodology of this research to refine and improve the results, especially when GF-in-GB in Ghana becomes more active and mature with more data for in-depth analysis. It is expected that with time, GF and GB experts in Ghana may gain more experience in the best approaches and measures to promote GF-in-GB from a local perspective.
- Furthermore, because this study was based on a single green office building in Accra (Ghana), future studies may incorporate more buildings across the country and with different uses to enhance the generalisability of the results. However, the established risk framework for GF-in-GB can be adapted to any context.
- Finally, although the findings and implications of the study may be useful for policymakers and practitioners in other developing countries since this study focused on the developing country of Ghana, future studies could focus on more developing countries. This could help establish findings, models, and implementation strategies that can aid in the effective and efficient implementation of GF-in-GB in specific countries. This is because sustainability within the built environment sector is highly contextual (Jarrar and Al-Zoabi, 2008), and not all GBs need to be the same (Debrah and Owusu-Manu, 2021). Due to distinct climatic conditions, unique cultures and traditions, diverse building types and ages, and wide-ranging environmental, economic, and social priorities of different economies, GBs have

been approached differently regarding design, construction, and O&M. Moreover, different credit rating scores of different green bond issues from different issuers in different countries could impact the financing risks of GF-in-GB.

10.6 Summary of the Thesis

This thesis developed an economic feasibility assessment model for GF-in-GB in Ghana. It is organised into ten chapters. Chapter 1 focused on the introduction and overview of the thesis. The research methodology adopted for this study is presented in Chapter 2. Chapter 3 reviewed related and extant literature using systematic literature review methods. Chapter 4 presented the empirical findings of the drivers of GF-in-GB based on expert opinions using MCDM. Empirical findings on the barriers to GF-in-GB are discussed in Chapter 5. Chapters 6 and 7, respectively, focused on the empirical findings of the risk factors and strategies of GF-in-GB. The emergent findings of the whole-building LCC of GB using Ghana as a case study are presented in Chapter 8. Chapter 9 focused on an economic feasibility assessment model for GF-in-GB. Finally, the conclusions, contributions, limitations and future research directions are presented in Chapter 10.

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APPENDICES

Appendix A: Research Questionnaire

Appendix A.1: Questionnaire survey regarding linguistic evaluation – Round One

PART I

Analyzing the interrelationship between barriers, risk factors, drivers and strategies of green finance in green building in Ghana using Fuzzy-Delphi-DEMATEL method.

Linguistic evaluation questionnaire survey to assess the growth and development of green finance in green building in Ghana.

Letter to Participant

Dear Participant,

My name is Caleb Debrah, and I am a PhD student at the Hong Kong Polytechnic University in the Department of Building and Real Estate. My thesis focuses on green finance in green building in Ghana. The study aims to evaluate the economic feasibility of green finance in green building projects. My research is being supervised by Prof. Albert Chan and Dr. Darko, who may be contacted at albert.chan@ and amos.darko1@

To help with my research, I would invite you to assist me in completing the attached questionnaire survey regarding linguistic evaluation. This survey will comprise two successive rounds. You have been chosen to contribute because of your academic, research, or practising experience in green building, green finance, or both. Thank you for your participation, and I am extremely grateful for your time.

Your views and experience are vital for completing this questionnaire, which will take approximately 15 minutes of your time. Confidentiality of your responses will be strictly ensured. Responses will only be analysed and reported in aggregated form; so non one response will be identifiable and no personal or company names will be included in the research writeup.

I look forward to your valued response. Once again, thank you for your immeasurable contribution and valuable time in making this survey a success. If you have queries, please you are most welcome to contact:

Caleb Debrah
Department of Building and Real Estate, The Hong Kong Polytechnic University
Tel: +852 6636 ; +233 246 32 ; **Email**: caleb.debrah@

Section A: Information of Participant

Q1. Please indicate your level of experience on the subject (*please tick applicable*)

☐ Green building

☐ Green finance

☐ Both

☐ None

Q2. Please indicate your years of industrial and / or research experience in green finance and /or green building

☐ 1-5 years

☐ 6-10 years

☐ 11-15 years

☐ 16-20 years

☐ Above 20 years

Q3. Please tick all categories apply (*multiple answers allowed and recommended*)

☐ Please indicate your highest academic qualification: Bachelor's ☐ Master's ☐ PhD ☐

☐ Faculty member at an academic institution or research institute

☐ Invited to present at a conference

☐ Published at least three peer-reviewed journal articles

☐ Chair of a nationally recognised committee ***Click here to indicate committee name***

☐ Member of a nationally recognised committee ***Click here to indicate committee name***

☐ Writer or editor of a book chapter

☐ Writer or editor of a book

☐ Please indicate your professional registration ***Click here to indicate which applies***

Q4. Please indicate the category you belong to (*please tick applicable*)

☐ Academia/research institute

☐ Financial institution (banks, pension funds, etc.) ***Click here to indicate firm type***

☐ Investment management ***Click here to indicate investment type***

☐ Independent investor/owner

☐ Real estate private equity fund

☐ Listed real estate company/REIT

☐ Real estate developer

☐ Consulting firm

☐ Contractor firm

☐ Government agency/local housing authority

☐ Other (s) (please specify): ***Click here to enter text***

Q5. Please indicate your professional background

☐ Green finance/finance expert

☐ Investment manager

☐ Architect

☐ Project / construction manager

☐ Engineer

☐ Quantity surveyor

☐ Academic/researcher

☐ Government representative or agent (please specify): ***Click here to enter text***

☐ Client ☐ Other (s) (please specify): ***Click here to enter text***

Q6. Which type of green building supply have you ever been involved in as a practitioner or researcher? (*multiple answers allowed and recommended*)
☐ Residential buildings or homes
☐ Commercial, public, and institutional buildings
☐ Retail facilities
☐ Healthcare facilities
☐ Laboratories
☐ Schools
☐ New green building
☐ Existing building
☐ All of the above

Q7. Which type of green building certification have you ever been involved in as a practitioner or researcher?
☐ US LEED
☐ IFC EDGE
☐ Green Star South Africa-Ghana
☐ Other (s) (please specify): ***Click here to enter text***

Q8. Which type of green finance certification have you ever been involved in as a practitioner or researcher?
☐ Climate Bonds standards and certification scheme
☐ Moody's green bonds assessments
☐ Standard & Poor's (S&P's) green evaluations
☐ Green bond indices (Bank of America Merill Lynch, Barclays MSCI, S&P's, and Solactive indexes)
☐ Other (s) (please specify): ***Click here to enter text***

Q9. To what extent have green finance impacted your investment decision in green building?
☐ No impact on investment decisions
☐ Plans to incorporate but no action taken
☐ Prefer green finance such as green bonds where available and where competitively priced
☐ Mandates or targets
☐ Specific green bond funds
☐ Other (s) (please specify): ***Click here to enter text***

Q11. What are your preferred channels of green fixed income investments in green building? (*tick applicable*)
☐ Sovereign green bonds
☐ Development bank green bonds
☐ Corporate green bonds
☐ Pure play bonds (where more than 75% of revenue is generated by clean assets)
☐ Private placements of green bonds
☐ Green loans
☐ Other (s) (please specify): ***Click here to enter text***

SECTION B: CRITICAL BARRIERS TO GREEN FINANCE IN GREEN BUILDING PROJECTS:

Q12. In measuring barriers to GF-in-GB projects, how would you rate the impact of the following barriers

0= equal; 1=moderate; 2=strong; 3= demonstrated; 4=extreme

Interaction Type:	***Effect Level:***
Positive	Extreme: **4**
	Demonstrated: **3**
	Strong: **2**
Negative	Moderate: **1**
	Equal: **0**

Remark: The blank in the matrix means the effect that ***row*** barrier put on the ***column*** barrier.

Barriers of green finance in green building

SN	Preliminary barriers	Description
BC1	Split incentives	Expected returns of financial suppliers differ from the GB firms' goals.
BC2	Short termism	The focus of managers and investors on the short time horizon, prioritising a near-time shareholder interest over the long-term growth of the company.
BC3	Limited GF supply	Limited access to capital for green companies, especially SMEs
BC4	Capital adequacy & liquidity issues	High and rigorous collateral requirements of SMEs, limited assets and weak balance sheets, limited capital and liquidity of SMEs.
BC5	Costly process	High transaction costs associated with green projects.
BC6	Economic instability	Uncertain economic conditions.
BC7	Policy & regulatory uncertainty	Uncertainty of the regulatory and policy environment.
BC8	Political instability	Political instability causes hindrances on the path to GF adoption
BC9	Regulatory requirement	Conflicting government policy signals/framework to promote green transition
BC10	Greenwashing	Reputational risk due to misleading information on environmental performance of green firms.
BC11	Inadequate management support	Failure of top and middle management to embrace GF in operation activities, unsupportive organisation structure for green transition.
BC12	Inadequate private investment	Low involvement of the private sector in GF.
BC13	Limited knowledge & technical expertise	Limited knowledge and lack of professional experience in GF.
BC14	R&D challenges	Lack of research and development innovation in GF.
BC15	Technological uncertainty	Technology-risk associated with uncertain GB technologies.
BC16	Limited green projects	Lack of identifiable GF/bankable green projects.
BC17	Lack of harmonised global standards & guidelines	Lack of standardised framework/guidelines or global standards to structure green projects.
BC18	Risks perception	Risk factors such as climate-related risk, reputational risk, systemic risk.
BC19	Lack of universal definition for "green projects"	Lack of a clear definition of what is GF-in-GB.
BC20	Inadequate transparency and consistency with GF	Absence of adequate accountability and transparency in assessing green projects, lack of reporting/disclosure regulations.
BC21	Information asymmetry	Imperfect information where parties to a transaction have access to different levels of information.
BC22	Lack of quality historical data	Problems of data accessibility, lack of clear and reliable data to inform decisions.

Please using the scale below, rank the impact each barrier on each other: **0= equal; 1=moderate; 2=strong; 3= demonstrated; 4=extreme**
Remark: The blank in the matrix means the effect that ***row*** barrier put on the ***column*** barrier.

Interaction	**BC1**	**BC2**	**BC3**	**BC4**	**BC5**	**BC6**	**BC7**	**BC8**	**BC9**	**BC10**	**BC11**	**BC12**	**BC13**	**BC14**	**BC15**	**BC16**	**BC17**	**BC18**	**BC19**	**BC20**	**BC21**	**BC22**
BC1	0																					
BC2		0																				
BC3			0																			
BC4				0																		
BC5					0																	
BC6						0																
BC7							0															
BC8								0														
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BC10										0												
BC11											0											
BC12												0										
BC13													0									
BC14														0								
BC15															0							
BC16																0						
BC17																	0					
BC18																		0				
BC19																			0			
BC20																				0		
BC21																					0	
BC22																						0

Please provide short comments, recommendations or suggestions if necessary.

SECTION C: RISKS FACTORS OF GREEN FINANCE IN GREEN BUILDING PROJECTS:

Q13. In measuring the risks factors of green finance in green building projects, how would you rate the impact of the following risk factors on each other using the scale: **0= equal; 1=moderate; 2=strong; 3= demonstrated; 4=extreme**

Remark: The blank in the matrix means the effect that ***row*** risks put on the ***column*** risks.

Risk factors of green finance in green building

SN	Preliminary risk factors	Description
RC1	Compensation for climate-related losses or damages	Contingent climate compensation risks and liabilities.
RC2	Judicial decisions and sanctions imposed by laws	Climate change litigation as financial risk, information related to judicial decisions and sanctions imposed by (climate) laws
RC3	Regulatory pressures and policy risks (e.g., prohibitions, environmental taxes, carbon pricing)	Risks and opportunities that may be triggered by climate mitigation and adaption policies.
RC4	Technological innovation risk	Risks associated with new GB technologies.
RC5	Reputation risk due to shifting consumer and investor preferences	Increasing reputational risk to green firms based on changing market or consumer sentiment.
RC6	Risks associated with the occurrence of climate- and weather-related events leading to property damage	Risks associated with the occurrence of climate- and weather-related events (e.g., floods, storms, etc.) leading to property damage.
RC7	Low adaptation capabilities of GB and GF firms	Limited green technical capacity of GB and GF firms to implement GF-in-GB
RC8	Mismatch between the short-term financial decision-making and long-term impacts of climate change	Mismatch between long-term payback periods associated with climate change adaptation investments, the increased investment risk posed by inherent climate vulnerabilities, and the short-term horizons and low risk appetite of most private investors.
RC9	Sluggish demand for high-rated GBs	GB development is relatively sluggish, and the market is still in the exploratory stage
RC10	Long payback period for GBs	Maturity mismatch or short terms of loans period from banks.
RC11	Uncertain market value for GBs	Uncertainties in the increase asset value for GBs.
RC12	Uncertain macroeconomic factors	Uncertain economic conditions, economic instability
RC13	High income tax rates	The impact of high-income tax rates on profitability of GF
RC14	Inadequate credit rating of GB firms	Inadequate credit rating of green building firms, thus denying access to green loans
RC15	Breach of contract due to change of property owners	Consequential damages arising from a breach of contract are an additional risk that may accompany a failure to achieve the certification goal.
RC16	Green level promised by real estate developers for GBs did not materialize	GB does not meet projected efficiency levels during operational period.
RC17	Default risk of GBs	Loss of assets due to expropriation or default in payment
RC18	Insufficient cash flow of GB firms	The need of GB firms to advance payment of retrofit and/or GB costs resulting in high debt ratio and insufficient cash flow.
RC19	Up-front risks or capital-intensive nature of GBs	High upfront capital or additional investment costs of GB finance.
RC20	Construction delays owing to complicated permitting processes	Delay risks from construction due to complicated permitting processes.
RC21	Lack of third-party evaluation of GBs	Lack of independent evaluation mechanism in the sector.
RC22	Increased competition with conventional building	Trade-offs between conventional and GB financing, conservative investment cultures of developers.
RC23	Greenwashing risks	Reputational risk due to misleading information on environmental performance of green firms.
RC24	Inadequate green experience or qualification	The lack of technical structure results from a lack of technical expertise, eventually hindering GF implementation
RC25	Lack of transparency reporting of GB projects	Absence of adequate accountability and transparency in assessing green projects.

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<u>Risks factors of green finance in green building projects</u>

In measuring the risks factors of green finance in green building projects, how would you rate the impact of the following risk factors:

0= equal; 1=moderate; 2=strong; 3= demonstrated; 4=extreme

Interaction	RC1	RC2	RC3	RC4	RC5	RC6	RC7	RC8	RC9	RC10	RC11	RC12	RC13	RC14	RC15	RC16	RC17	RC18	RC19	RC20	RC21	RC22	RC23	RC24	RC25
RC1	0																								
RC2		0																							
RC3			0																						
RC4				0																					
RC5					0																				
RC6						0																			
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RC22																						0			
RC23																							0		
RC24																								0	
RC25																									0

Please provide short comments, recommendations or suggestions if necessary.

SECTION D: DRIVERS OF GREEN FINANCE IN GREEN BUILDING PROJECTS:

Q14. In measuring the drivers of green finance in green building projects, how would you rate the impact of the following drivers: **0=equal; 1=moderate; 2=strong; 3=demonstrated; 4=extreme**

Drivers of green finance in green building

SN	Preliminary drivers	Description
DC1	Government support for green finance	Government service channels that give priority to GF-in-GB firms and projects; Government's active role in GF projects.
DC2	Regulatory incentives for green finance	Tax incentives, subsidies, exemptions, price support.
DC3	Mandatory climate-relative financial disclosures	Introduce mandatory requirements for large green firms and financial institutions to disclose their climate-related risks and opportunities adapting frameworks such as the Task Force on Climate-Related Financial Disclosures (TCFD)
DC4	Favourable macroeconomic conditions and investment returns	Sound financial system conducive to low interest rates; better financial returns or incentives.
DC5	Improved access to and lower cost of capital	Broadened investor base or attracting more investors.
DC6	Reduced business and financial risk	Reduces overall portfolio risk.
DC7	Reasonable maturity/investment period	Maturity period or long-term investment mindset of green investors
DC8	Preferential capital requirements for low-carbon assets	Penalising capital requirements for high-carbon assets (e.g., Carbon pricing, higher prices for unstainable energy forms and non-green building).
DC9	Improve corporate branding or reputation	Investing in sustainable projects to increase the positive corporate image of investors. This serves as a strong signalling tool - easy way to communicate to clients and stakeholders how investments are contributing to sustainability (i.e., higher environmental ratings and lower CO2 emissions).
DC10	Institutional/peer pressure	Follows the concern of other institutional investors or peers investing in green projects
DC11	Management commitment	Commitment from internal stakeholders, internal politics, internal legitimacy
DC12	Positive fundamentals or green credentials of issuer/developer	Satisfactory green credentials at pre- and post-issuance; ESG ratings of issuer
DC13	Ecological and corporate social responsibility	Corporate social responsibility to the environment and society (business legitimacy)
DC14	Climate commitments	Climate commitments such as the SDGs and Paris Agreement.
DC15	Promotion of responsible and ethical investment	Conservation of the environment and resources or benefits to the environment; investing in ethical investment ventures that protect the environment, such as GBs, is perceived to be responsible.
DC16	Increased awareness of GF models in GB	Awareness creation of/media influence on GF-in-GB

Drivers of green finance in green building

Interaction	**DC1**	**DC2**	**DC3**	**DC4**	**DC5**	**DC6**	**DC7**	**DC8**	**DC9**	**DC10**	**DC11**	**DC12**	**DC13**	**DC14**	**DC15**	**DC16**
DC1	0															
DC2		0														
DC3			0													
DC4				0												
DC5					0											
DC6						0										
DC7							0									
DC8								0								
DC9									0							
DC10										0						
DC11											0					
DC12												0				
DC13													0			
DC14														0		
DC15															0	
DC16																0

Please provide short comments, recommendations, or suggestions if necessary.

SECTION E: STRATEGIES OF GREEN FINANCE IN GREEN BUILDING PROJECTS:

Q15. In measuring the strategies of green finance in green building projects, how would you rate the impact of the following strategies on each: **0=equal; 1=moderate; 2=strong; 3=demonstrated; 4=extreme**

Remark: The blank in the matrix means the effect that ***row*** strategy put on the ***column*** strategy.

	Strategies to promote green finance in green building
SC1	Improving access to capital for small-scale green building projects
SC2	Encouraging climate scenario analysis by adopting existing guidelines such as TFCD (Task Force on Climate-Related Financial Disclosures)
SC3	Capturing multiple green building benefits in valuation and accounting methods
SC4	Increased information disclosure and better transparency
SC5	Institutionalization and mechanisms for managing carbon emission trading for buildings
SC6	Quality climate risks and other ESG data for investor (and customer) assessment
SC7	Integrating climate risk exposure assessment into green finance in green building projects
SC8	Reputable third-party green certification and labels
SC9	Harmonise green finance in green building standards
SC10	Continuous improvement of incentive policies for GF-in-GB
SC11	Access to targeted green financial instruments for green building
SC12	Innovation of financial instruments that enable public/private risk sharing
SC13	New technology and disruptive business models for green finance in green building
SC14	Innovative Fintech solutions for green finance in green building
SC15	Simplification of administrative procedures linked with GB projects (e.g., permitting and licensing procedures)
SC16	Increased R&D support for green finance in green building
SC17	Public-private partnerships to facilitate green finance from the private sector
SC18	Developments in climate-related policy and regulation to stimulate private investment
SC19	Increased government participation as "leader by example"
SC20	Ensuring compliance of both public and private actors to green standards

Strategies to promote green finance in green building

Interaction	**SC1**	**SC2**	**SC3**	**SC4**	**SC5**	**SC6**	**SC7**	**SC8**	**SC9**	**SC10**	**SC11**	**SC12**	**SC13**	**SC14**	**SC15**	**SC16**	**SC17**	**SC18**	**SC19**	**SC20**
SC1	0																			
SC2		0																		
SC3			0																	
SC4				0																
SC5					0															
SC6						0														
SC7							0													
SC8								0												
SC9									0											
SC10										0										
SC11											0									
SC12												0								
SC13													0							
SC14														0						
SC15															0					
SC16																0				
SC17																	0			
SC18																		0		
SC19																			0	
SC20																				0

-The End-

A sincere thank you for completing this questionnaire; your assistance is very much appreciated and valued. Your input will help with my thesis but also future construction sustainability research and education.

PART II

Analyzing the interrelationships between the categories of barriers, risk factors, drivers and strategies of 'green finance in green building' in Ghana using Fuzzy-Delphi-DEMATEL method

Linguistic evaluation questionnaire survey to assess the growth and development of *green finance in green building* in Ghana.

Letter to Participant

Dear Participant,

Thank you for participating in the initial questionnaire survey regarding linguistic evaluation to assess the interrelationships between the barriers, risk factors, drivers and strategies of green finance in green building in Ghana. I deeply appreciate your response and I would be extremely grateful if you could assist in ranking the group characteristics in the initial survey.

This second round focuses on the group influences of the various factors and should take approximately 15 minutes or less to complete. **There are no right or wrong answers, only your much needed expert opinions**. Your responses will be kept with the strictest confidentiality and used for only academic purpose.

Without your support, this research would not be successful. I am extremely thankful to you for your participation and previous time.

I would be grateful if you could please complete and send me the questionnaire by email caleb.debrah@ on or before Friday, 10 February 2023. Should you have any queries, please feel free to contact me.

Caleb Debrah
PhD Candidate
Department of Building and Real Estate
The Hong Kong Polytechnic University
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Tel: +233 246 32

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SECTION A: CATEGORIES OF BARRIERS TO GF-in-GB PROJECTS:

Q1. In measuring barriers to green finance in green building projects, how would you rate the impact of the following barriers on each other using the scale: **0= equal; 1=moderate; 2=strong; 3= demonstrated; 4=extreme**

Interaction Type:	***Effect Level:***
Positive	Extreme: **4**
	Demonstrated: **3**
	Strong: **2**
Negative	Moderate: **1**
	Equal: **0**

Remark: The blank in the matrix means the effect that ***row*** barrier put on the ***column*** barrier.

	Barriers of green finance in green building
B1	Financial barriers
B2	Regulatory barriers
B3	Organisational barriers
B4	Technical barriers
B5	Structural barriers

Interaction	**B1**	**B2**	**B3**	**B4**	**B5**
B1	0				
B2		0			
B3			0		
B4				0	
B5					0

SECTION B: RISKS FACTORS OF GREEN FINANCE IN GREEN BUILDING PROJECTS:

Q2. In measuring the risks factors of green finance in green building projects, how would you rate the impact of the following risk factors on each other using the scale: **0= equal; 1=moderate; 2=strong; 3= demonstrated; 4=extreme**

Remark: The blank in the matrix means the effect that ***row*** risks put on the ***column*** risks.

	Risk factors of green finance in green building
R1	Liability risks
R2	Climate transition risks
R3	Climate physical risks
R4	Market risks
R5	Credit risks
R6	Liquidity risks
R7	Sector risks

Interaction	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**
R1	0						
R2		0					
R3			0				
R4				0			
R5					0		
R6						0	
R7							0

SECTION C: DRIVERS OF GREEN FINANCE IN GREEN BUILDING PROJECTS:

Q3. In measuring the drivers of green finance in green building projects, how would you rate the impact of the following drivers on each other: **0=equal; 1=moderate; 2=strong; 3=demonstrated; 4=extreme.**

Remark: The blank in the matrix means the effect that ***row*** driver put on the ***column*** driver.

	Drivers of green finance in green building
D1	Regulatory drivers
D2	Financial drivers
D3	Organisational drivers
D4	Environmental and social drivers

Interaction	**D1**	**D2**	**D3**	**D4**
D1	0			
D2		0		
D3			0	
D4				0

SECTION D: STRATEGIES OF GREEN FINANCE IN GREEN BUILDING PROJECTS:

Q4. In measuring the strategies of green finance in green building projects, how would you rate the impact of the following strategies on each: **0=equal; 1=moderate; 2=strong; 3=demonstrated; 4=extreme**

Remark: The blank in the matrix means the effect that ***row*** strategy put on the ***column*** strategy.

	Strategies of green finance in green building
S1	Market strategies
S2	Financial strategies
S3	Technological strategies
S4	Policy strategies

Interaction	**S1**	**S2**	**S3**	**S4**
S1	0			
S2		0		
S3			0	
S4				0

Please provide short comments, recommendations, or suggestions, if any.

-The End-

A sincere thank you for completing this questionnaire; your assistance is very much appreciated and valued. Your input will help with my thesis but also future construction sustainability research and education.

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Appendix A.2: Questionnaire survey regarding linguistic evaluation – Round Two

Analyzing the interrelationship between barriers, risk factors, drivers and strategies of green finance in green building in Ghana using Fuzzy-Delphi-DEMATEL method.

Linguistic evaluation questionnaire survey to assess the growth and development of green finance in green building in Ghana

Letter to Participant

Thank you for participating in the previous round of the questionnaire survey to validate the criteria of barriers and risk factors of green finance in green building from existing literature. Please this final round seeks to confirm the validity of the criteria and enhance the reliability after screening out insignificant criteria after the first round.

This round should take approximately 30 minutes to complete. **There are no right or wrong answers, only your much needed expert opinions**. Your responses will be kept strictly confidential and used only for academic purposes.

Without your support, this research would not be successful. I am extremely thankful to you for your participation and previous time.

I would be grateful if you could please complete and send me the questionnaire by email caleb.debrah@ on or before Friday, 10 February 2023. Should you have any queries, please feel free to contact me.

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Tel: +852 6636 ; +233 246 32
Email: caleb.debrah@

SECTION A: DRIVERS OF GF-in-GB PROJECTS:

Q1. In measuring the drivers of GF-in-GB projects, how would you rate the impact of the following drivers on each other?

NE= No effect; L=Low; A=Average; H= High; VH=Very high

Interaction Type:	***Effect Level:***
Positive	Very high: **VH**
	High: **H**
	Average: **A**
Negative	Low: **L**
	No effect: **NE**

Remark: The blank in the matrix means the effect that ***row*** driver put on the ***column*** driver.

Drivers of GF-in-GB

	Drivers screening out	**Weights**	**Decision**
D1	Government participation/support for GF	0.515	Unaccepted
D2	Regulatory incentives for GF	0.532	Accepted
D3	Mandatory climate-relative financial disclosures	0.514	Unaccepted
D4	Favourable macroeconomic conditions and investment returns	0.532	Accepted
D5	Improved access to and lower cost of capital	0.523	Accepted
D6	Reduced business and financial risk	0.526	Accepted
D7	Reasonable maturity/investment period	0.510	Unaccepted
D8	Preferential capital requirements for low-carbon assets	0.524	Accepted
D9	Improve corporate branding or reputation	0.513	Unaccepted
D10	Institutional/peer pressure	0.513	Unaccepted
D11	Management commitment	0.518	Unaccepted
D12	Positive fundamentals or green credentials of issuer/developer	0.519	Unaccepted
D13	Ecological and corporate social responsibility	0.505	Unaccepted
D14	Climate commitments	0.525	Accepted
D15	Promotion of responsible and ethical investment	0.534	Accepted
D16	Increased awareness of GF models in GB	0.526	Accepted
	Threshold (α)	**0.521**	

Final screened drivers of GF-in-GB in Ghana

	Significant drivers	**Description**
D2	Regulatory incentives for green finance	Tax incentives, subsidies, exemptions, price support.
D4	Favourable macroeconomic conditions and investment returns	Sound financial system conducive to low interest rates; better financial returns or incentives.
D5	Improved access to and lower cost of capital	Broadened investor base or attracting more investors.
D6	Reduced business and financial risk	Reduces overall portfolio risk.
D8	Preferential capital requirements for low-carbon assets	Penalising capital requirements for high-carbon assets (e.g., Carbon pricing, higher prices for unstainable energy forms and non-green building).
D14	Climate commitments	Climate commitments such as the SDGs and Paris Agreement.
D15	Promotion of responsible and ethical investment	Conservation of the environment and resources or benefits to the environment.
D16	Increased awareness of GF models in GB	Awareness creation of/media influence on GF-in-GB

Please using the scale below, assess the effect of the above drivers on each other:
NE= No effect; L=Low; M=Medium; H= High; VH=Very high

Interaction	**D2**	**D4**	**D5**	**D6**	**D8**	**D14**	**D15**	**D16**
D2	NE							
D4		NE						
D5			NE					
D6				NE				
D8					NE			
D14						NE		
D15							NE	
D16								NE

SECTION B: STRATEGIES OF GF-in-GB PROJECTS:
Q2. In measuring the strategies of GF-in-GB projects, how would you rate the effect of the following strategies on each: **NE= No effect; L=Low; M=Medium; H= High; VH=Very high**

Remark: The blank in the matrix means the effect that ***row*** strategy put on the ***column*** strategy.

Final screened strategies to promote GF-in-GB

	Significant strategies	**Weights**	**Decision**
S1	Improving access to capital for small-scale GB projects	0.545	Accepted
S2	Encouraging climate scenario analysis by adopting existing guidelines such as TFCD (Task Force on Climate-Related Financial Disclosures)	0.531	Unaccepted
S3	Capturing multiple GB benefits in valuation and accounting methods	0.533	Unaccepted
S4	Better quality information (Increased information disclosure and better transparency)	0.542	Accepted
S5	Institutionalization and mechanisms for managing carbon emission trading for buildings	0.531	Unaccepted
S6	Enhancing data for climate-related risk assessment	0.542	Accepted
S7	Integrating climate risk exposure assessment into GF-in-GB projects	0.519	Unaccepted
S8	Reputable third-party green certification and labels	0.535	Unaccepted
S9	Harmonise GF-in-GB standards	0.543	Accepted
S10	Continuous improvement of incentive policies for GF-in-GB	0.541	Accepted
S11	Access to targeted green financial instruments for GB	0.537	Accepted
S12	Innovation of financial instruments that enable public/private risk sharing	0.542	Accepted
S13	New technology and disruptive business models for GF-in-GB	0.515	Unaccepted
S14	Innovative Fintech solutions for GF-in-GB	0.524	Unaccepted
S15	Simplification of administrative procedures linked with GB projects (e.g., permitting and licensing procedures)	0.528	Unaccepted
S16	Increased R&D support for GF-in-GB	0.538	Accepted
S17	Public-private partnerships to facilitate GF from the private sector	0.537	Accepted
S18	Developments in climate-related policy and regulation to stimulate private investment	0.543	Accepted
S19	Increased government participation as “leader by example”	0.541	Accepted
S20	Ensuring compliance of both public and private actors to green standards	0.547	Accepted
	Threshold (α)	**0.536**	

Final Screened Strategies to promote GF-in-GB in Ghana

	Strategies Screened Out	Description
S1	Improving access to capital for small-scale GB projects	Providing easier access to GF especially to SMEs.
S4	Better quality information	Increased information disclosure and better transparency, access to climate data to boost financial innovation.
S6	Enhancing data for climate-related risk assessment	Quality climate risks and other ESG (environment, sustainability, and governance) data for investor assessment.
S9	Harmonise GF-in-GB standards	Standardised framework/guidelines or global standards to structure green projects.
S10	Continuous improvement of incentive policies for GF-in-GB	Government incentives (e.g., spillover-tax-returns to increase rate of return, green subsidies).
S11	Access to targeted GF instruments for GB	Access to targeted financial instruments (e.g., government loans, equity investments, risk insurance and public guarantees)
S12	Innovation of financial instruments that enable public/private risk sharing	Public-private finance relationship in sharing risks and gains of GF innovation.
S16	Increased R&D support for GF-in-GB	Co-investment into R&D (research and development) for green projects.
S17	Public-private partnerships to facilitate GF from the private sector	Government collaboration with private actors to promote GB through GF opportunities.
S18	Developments in climate-related policy and regulation to stimulate private investment	Developing policy actions that either constrain activities that contribute to climate change or promote adaptation; regulatory developments to include new disclosure or reporting requirements.
S19	Increased government participation as "leader by example"	Increase scale of public green investments to attract institutional funding.
S20	Ensuring compliance of both public and private actors to green standards	Implementation standardised metrics and transparent reporting frameworks.

Please using the scale below, assess the effect of the above strategies on each other:
NE= No effect; L=Low; M=Medium; H= High; VH=Very high

Interaction	**S1**	**S4**	**S6**	**S9**	**S10**	**S11**	**S12**	**S16**	**S17**	**S18**	**S19**	**S20**
S1	NE											
S4		NE										
S6			NE									
S9				NE								
S10					NE							
S11						NE						
S12							NE					
S16								NE				
S17									NE			
S18										NE		
S19											NE	
S20												NE

SECTION C: CRITICAL BARRIERS TO GF-in-GB PROJECTS:

Q3. In measuring barriers to GF-in-GB projects, how would you rate the effect of the following barriers on each other using the scale?

NE= No effect; L=Low; A=Average; H= High; VH=Very high

Interaction Type:	***Effect Level:***
Positive	Very high: **VH**
	High: **H**
	Average: **A**
Negative	Low: **L**
	No effect: **NE**

Remark: The blank in the matrix means the effect that ***row*** barrier put on the ***column*** barrier.

	Critical barriers to GF-in-GB		
	Barriers Screening Out	**Weights**	**Decision**
B1	Split incentives	0.527	Accepted
B2	Short termism	0.506	Unaccepted
B3	Limited GF supply	0.522	Unaccepted
B4	Capital adequacy & liquidity issues	0.531	Accepted
B5	Costly process	0.519	Unaccepted
B6	Economic instability	0.555	Accepted
B7	Policy & regulatory uncertainty	0.530	Accepted
B8	Political instability	0.511	Unaccepted
B9	Regulatory requirement	0.525	Accepted
B10	Greenwashing	0.526	Accepted
B11	Inadequate management support	0.525	Accepted
B12	Inadequate private investment	0.539	Accepted
B13	Limited knowledge & technical expertise	0.509	Unaccepted
B14	R&D challenges	0.519	Unaccepted
B15	Technological uncertainty	0.526	Accepted
B16	Limited green projects	0.534	Accepted
B17	Lack of harmonised global standards & guidelines	0.528	Accepted
B18	Risks perception	0.531	Accepted
B19	Lack of universal definition for "green projects"	0.526	Accepted
B20	Inadequate transparency and consistency with GF	0.542	Accepted
B21	Information asymmetry	0.534	Accepted
B22	Lack of quality historical data	0.538	Accepted
	Threshold (α)	**0.525**	

Final screened critical barriers to green finance in green building

	Critical barriers	Description
B1	Split incentives	Expected returns of financial suppliers differ from the GB firms' goals.
B4	Capital adequacy & liquidity issues	High and rigorous collateral requirements of SMEs, limited assets and weak balance sheets, limited capital and liquidity of SMEs.
B6	Economic instability	Uncertain economic conditions.
B9	Regulatory requirement	Conflicting government policy signals/framework to promote green transition
B10	Greenwashing	Reputational risk due to misleading information on environmental performance of green firms.
B11	Inadequate management support	Failure of top and middle management to embrace GF in operation activities, unsupportive organisation structure for green transition.
B12	Inadequate private investment	Low involvement of the private sector in GF.
B15	Technological uncertainty	Technology-risk associated with uncertain GB technologies
B16	Limited green projects	Lack of identifiable GF/bankable green projects
B17	Lack of harmonised global standards & guidelines	Lack of standardised framework/guidelines or global standards to structure green projects.
B18	Risks perception	Risk factors such as climate-related risk, reputational risk, systemic risk
B19	Lack of universal definition for "green projects"	Lack of a clear definition of what is GF-in-GB.
B20	Inadequate transparency and consistency with GF	Absence of adequate accountability and transparency in assessing green projects, lack of reporting/disclosure regulations.
B21	Information asymmetry	Imperfect information where parties to a transaction have access to different levels of information.
B22	Lack of quality historical data	Problems of data accessibility, lack of clear and reliable data to inform decisions.

Please using the scale below, assess the effect of the above barriers on each other:
NE= No effect; L=Low; A=Average; H= High; VH=Very high

Interaction	B1	B4	B6	B9	B10	B11	B12	B15	B16	B17	B18	B19	B20	B21	B22
B1	NE														
B4		NE													
B6			NE												
B9				NE											
B10					NE										
B11						NE									
B12							NE								
B15								NE							
B16									NE						
B17										NE					
B18											NE				
B19												NE			
B20													NE		
B21														NE	
B22															NE

SECTION D: RISKS FACTORS OF GF-in-GB PROJECTS:

Q4. In measuring the risks factors of green finance in green building projects, how would you rate the effect of the following risk factors on each other using the scale?

NE= No effect; L=Low; A=Average; H= High; VH=Very high

Remark: The blank in the matrix means the effect that ***row*** risks put on the ***column*** risks.

Risk Factors of GF-in-GB

	Risk factors screening out	**Weights**	**Decision**
R1	Compensation for climate-related losses or damages	0.540	Accepted
R2	Judicial decisions and sanctions imposed by laws	0.519	Unaccepted
R3	Regulatory pressures and policy risks (e.g., prohibitions, environmental taxes, carbon pricing)	0.539	Accepted
R4	Technological innovation risk	0.542	Accepted
R5	Reputation risk due to shifting consumer and investor preferences	0.532	Unaccepted
R6	Risks associated with the occurrence of climate- and weather-related events leading to property damage	0.539	Accepted
R7	Low adaptation capabilities of GB and GF firms	0.512	Unaccepted
R8	Mismatch between the short-term financial decision-making and long-term impacts of climate change	0.528	Unaccepted
R9	Sluggish demand for high-rated GBs	0.531	Unaccepted
R10	Long payback period for GBs	0.537	Accepted
R11	Uncertain market value for GBs	0.533	Unaccepted
R12	Uncertain macroeconomic factors	0.546	Accepted
R13	High income tax rates	0.517	Unaccepted
R14	Inadequate credit rating of GB firms	0.522	Unaccepted
R15	Breach of contract due to change of property owners	0.531	Unaccepted
R16	Green level promised by real estate developers for GBs did not materialise	0.539	Accepted
R17	Default risk of GBs	0.534	Unaccepted
R18	Insufficient cash flow of GB firms	0.540	Accepted
R19	Up-front risks or capital-intensive nature of GBs	0.535	Accepted
R20	Construction delays owing to complicated permitting processes	0.547	Accepted
R21	Lack of third-party evaluation of GBs	0.546	Accepted
R22	Increased competition with conventional building	0.551	Accepted
R23	Greenwashing risks	0.535	Accepted
R24	Inadequate green experience or qualification	0.523	Unaccepted
R25	Lack of transparency reporting of GB project	0.547	Accepted
	Threshold (α)	**0.535**	

Final screened risk factors of GF-in-GB

	Significant risk factors	Description
R1	Compensation for climate-related losses or damages	Contingent climate compensation risks and liabilities.
R3	Regulatory pressures and policy risks (e.g., prohibitions, environmental taxes, carbon pricing)	Risks and opportunities that may be triggered by climate mitigation and adaption policies.
R4	Technological innovation risk	Risks associated with new GB technologies.
R6	Risks associated climate and natural disasters	Risks associated with the occurrence of climate- and weather-related events (e.g., floods, storms, etc.) leading to property damage
R10	Long payback period for GBs	Maturity mismatch or short terms of loans period from banks.
R12	Uncertain macroeconomic factors	Uncertain economic conditions, economic instability
R16	Green level promised by real estate developers for GBs did not materialize	GB does not meet projected efficiency levels during operational period.
R18	Insufficient cash flow of GB firms	The need of green building firms to advance payment of retrofit and/or green building costs resulting in high debt ratio and insufficient cash flow.
R19	Up-front risks or capital-intensive nature of GBs	High upfront capital or additional investment costs of GB finance.
R20	Construction delays owing to complicated permitting processes	Delay risks from construction due to complicated permitting processes.
R21	Lack of third-party evaluation of GBs	Lack of independent evaluation mechanism in the sector.
R22	Increased competition with conventional building	Trade-offs between conventional and GB financing, conservative investment cultures of developers.
R23	Greenwashing risks	Reputational risk due to misleading information on environmental performance of green firms.
R25	Lack of transparency reporting of GB project	Absence of adequate accountability and transparency in assessing green projects.

Please using the scale below, assess the effect of the above risk factors on each other:
NE= No effect; L=Low; A=Average; H= High; VH=Very high

Interaction	**R1**	**R3**	**R4**	**R6**	**R10**	**R12**	**R16**	**R18**	**R19**	**R20**	**R21**	**R22**	**R23**	**R25**
R1	NE													
R3		NE												
R4			NE											
R6				NE										
R10					NE									
R12						NE								
R16							NE							
R18								NE						
R19									NE					
R20										NE				
R21											NE			
R22												NE		
R23													NE	
R25														NE

Please provide short comments, recommendations, or suggestions, if any.

-The End-

A sincere thank you for completing this questionnaire; your assistance is very much appreciated and valued. Your input will help with this thesis but also future construction sustainability research and education.

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Appendix A.3: Questionnaire for Green Building Costs-and-Benefits Case Study

Evaluating the economic feasibility of green finance in green building: A case study of green office buildings in Ghana with IFC EDGE Final certification.

Letter to Participant

Dear Participant,

My name is Caleb Debrah, and I am a PhD student at the Hong Kong Polytechnic University at the Department of Building and Real Estate. My thesis focuses on green finance in green building in Ghana. The study aims to evaluate the economic feasibility of green finance in green building projects. My research is being supervised by Prof. Albert Chan, who may be contacted at albert.chan@ .

In order to help with my research, I would invite you to assist me to complete the attached questionnaire survey regarding linguistic evaluation. This survey will comprise of two successive rounds. You have been chosen to contribute because of participation or involvement in green building development in Ghana. Thank you for your participation and I am extremely grateful for your time.

Your views and experience are vital for completing this questionnaire which will take approximately ten minutes of your time. Due to the nature of the case study, confidentiality of your responses cannot be ensured. Responses on the case will be analysed and reported to inform stakeholders of the costs and benefits associated with similar office green buildings as yours. This is to help bridge the present gap of a lack of readily available benefits and costs data on successful green building in Ghana. While personal data would be kept confidential, building profile, green building features and cost estimates will be included in the research writeup.

I look forward to your valued response. Once again, thank you for your immeasurable contribution and valuable time in making this survey a success. If you have queries, please you are most welcome to contact:

Caleb Debrah

Department of Building and Real Estate, The Hong Kong Polytechnic University

Tel: +852 6636 ; +233 246 32 ; **Email**: caleb.debrah@

Section A: Information of Participant

Q1. Please indicate your level of experience on the subject (*please tick applicable*)
☐ Green building
☐ Green finance
☐ Both
☐ None

Q2. Please indicate your years of industrial and / or research experience in green finance and /or green building
☐ 1-5 years
☐ 6-10 years
☐ 11-15 years
☐ 16-20 years
☐ Above 20 years

Q3. Please indicate your professional background
☐ Green finance/finance expert
☐ Investment manager
☐ Architect
☐ Project / construction manager
☐ Engineer
☐ Quantity surveyor
☐ Academic/researcher
☐ Government representative or agent
☐ Client
☐ Other (s) (please specify): ***Click here to enter text***

Q4. Which type of green building supply have you ever been involved in? (*multiple answers allowed and recommended*)
☐ Residential buildings or homes
☐ Commercial, public, and institutional buildings
☐ Retail facilities
☐ Healthcare facilities
☐ Laboratories
☐ Schools
☐ New green building
☐ Existing building
☐ All of the above

Q5. Apart from the IFC EDGE, what other green building certification have you ever been involved in?
☐ ***Click here to enter text***

Q6. Which type of green finance certification have you ever been involved in as a practitioner or researcher?
☐ Climate Bonds standards and certification scheme
☐ Moody's green bonds assessments
☐ Standard & Poor's (S&P's) green evaluations
☐ Green bond indices (Bank of America Merill Lynch, Barclays MSCI, S&P's, and Solactive indexes)
☐ Other (s) (please specify): ***Click here to enter text***

Q7. Which of the following green buildings were you involved in?

☐ World Bank Group Office, Accra
☐ Cal Bank Head Office Tower
☐ Atlantic Tower
☐ Other (s) (please specify): ***Click here to enter text***

Q8. What was your role on the project? (*tick applicable*)

☐ Project manager
☐ Quantity surveyor
☐ Construction manager
☐ Engineer (please specify): ***Click here to enter text***
☐ Owner / Client
☐ Architect
☐ Green building consultant
☐ Green finance expert
☐ Green building assessor
☐ Energy consultant
☐ Government agent (please specify): ***Click here to enter text***
☐ Other (s) (please specify): ***Click here to enter text***

Section B: Case study of green building offices in Ghana with Final IFC EDGE certification

Q9. Profile of green building offices

Building profile	Description
Building Name	
Owner	
Building function	Office buildings
Year of construction	
No. of floors	
No. of occupants	
Shape	
GIFA (m^2)	
Life cycle	
Building height (m)	
Location	
Climate condition	
Certified (Level)	
Type of certification (Year)	
Energy savings (predicted %)	
Water savings (predicted %)	
Less embodied energy in materials (%)	
Total CO_2 savings	

Q10. Cost categories of life cycle cost

Non-construction element	**Cost**	**Operation Element**	**Cost**
NC1 design & planning		OC1 energy	
NC2 supervision		OC2 water	
NC3 construction management		OC3 cleaning	
Construction costs		OC4 security & health	
CC1 substructure		OC5 management	
CC2 superstructure		**Maintenance & repair costs**	
CC3 finishes		M1 main building	
CC4 fittings & equipment		M2 plumbing & sanitary	
CC5 services		M3 electrical installation	
CC6 external works		M4 air conditioning & HVAC	
CC7 green building features		M510 lift	
CC8 others		M6 security system	
End of life costs		M7 fire protection	
EL1 waste & transport		M8 xs	
EL2 labour works		**Additional cost category**	
Renewal costs			
R1 replacement			

Please provide short comments, recommendations, or suggestions if necessary.

-The End-

A sincere thank you for completing this questionnaire; your assistance is very much appreciated and valued. Your input will help with my thesis but also future construction sustainability research and education.

Appendix B: Results and Findings

Appendix B.1: FDM – Barriers Screening Out

Criteria	a_j	b_j	c_j	s_j	**Decision**
BC1	0.000	0.582	1.000	0.527	Accepted
BC2	0.000	0.518	1.000	0.506	Unaccepted
BC3	0.000	0.566	1.000	0.522	Unaccepted
BC4	0.000	0.592	1.000	0.531	Accepted
BC5	0.000	0.557	1.000	0.519	Unaccepted
BC6	0.000	0.665	1.000	0.555	Accepted
BC7	0.000	0.590	1.000	0.530	Accepted
BC8	0.000	0.533	1.000	0.511	Unaccepted
BC9	0.000	0.573	1.000	0.525	Accepted
BC10	0.000	0.575	1.000	0.526	Accepted
BC11	0.000	0.568	1.000	0.525	Accepted
BC12	0.000	0.617	1.000	0.539	Accepted
BC13	0.000	0.528	1.000	0.509	Unaccepted
BC14	0.000	0.556	1.000	0.519	Unaccepted
BC15	0.000	0.577	1.000	0.526	Accepted
BC16	0.000	0.602	1.000	0.534	Accepted
BC17	0.000	0.584	1.000	0.528	Accepted
BC18	0.000	0.593	1.000	0.531	Accepted
BC19	0.000	0.577	1.000	0.526	Accepted
BC20	0.000	0.627	1.000	0.542	Accepted
BC21	0.000	0.603	1.000	0.534	Accepted
BC22	0.000	0.613	1.000	0.538	Accepted
Threshold (α)				**0.525**	

Appendix B.2: Defuzzification Procedure from Expert 1

	B1			B2			B3			B4			B5		
B1	[0.000	0.000	0.250]	[0.750	1.000	1.000]	[0.250	0.500	0.750]	[0.500	0.750	1.000]	[0.750	1.000	1.000]
B2	[0.250	0.500	0.750]	[0.000	0.000	0.250]	[0.750	1.000	1.000]	[0.500	0.750	1.000]	[0.000	0.000	0.250]
B3	[0.750	1.000	1.000]	[0.250	0.500	0.750]	[0.000	0.000	0.250]	[0.500	0.750	1.000]	[0.000	0.000	0.250]
B4	[0.000	0.000	0.250]	[0.500	0.750	1.000]	[0.750	1.000	1.000]	[0.000	0.000	0.250]	[0.750	1.000	1.000]
B5	[0.500	0.750	1.000]	[0.750	1.000	1.000]	[0.750	1.000	1.000]	[0.500	0.750	1.000]	[0.000	0.000	0.250]

	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$	$s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$	$s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$	$s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$	$s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$	$s\tilde{z}^f_{uij}$
B1	[0.000	0.000	0.000]	[0.750	1.000	0.750]	[0.250	0.500	0.500]	[0.500	0.750	0.750]	[0.750	1.000	0.750]
B2	[0.250	0.500	0.500]	[0.000	0.000	0.000]	[0.750	1.000	0.750]	[0.500	0.750	0.750]	[0.000	0.000	0.000]
B3	[0.750	1.000	0.750]	[0.250	0.500	0.500]	[0.000	0.000	0.000]	[0.500	0.750	0.750]	[0.000	0.000	0.000]
B4	[0.000	0.000	0.000]	[0.500	0.750	0.750]	[0.750	1.000	0.750]	[0.000	0.000	0.000]	[0.750	1.000	0.750]
B5	[0.500	0.750	0.750]	[0.750	1.000	0.750]	[0.750	1.000	0.750]	[0.500	0.750	0.750]	[0.000	0.000	0.000]

	S^f_{ltij}	S^f_{rtij}	S^f_{ltij}	S^f_{rtij}	S^f_{ltij}	S^f_{rtij}	S^f_{ltij}	S^f_{rtij}	S^f_{ltij}	S^f_{rtij}
B1	0.000	0.000	0.800	1.000	0.400	0.500	0.600	0.750	0.800	1.000
B2	0.400	0.500	0.000	0.000	0.800	1.000	0.600	0.750	0.000	0.000
B3	0.800	1.000	0.400	0.500	0.000	0.000	0.600	0.750	0.000	0.000
B4	0.000	0.000	0.600	0.750	0.800	1.000	0.000	0.000	0.800	1.000
B5	0.600	0.750	0.800	1.000	0.800	1.000	0.600	0.750	0.000	0.000

	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$
B1	0.000	0.967	0.445	0.698	0.967
B2	0.445	0.000	0.967	0.698	0.000
B3	0.967	0.445	0.000	0.698	0.000
B4	0.000	0.698	0.967	0.000	0.967
B5	0.698	0.967	0.967	0.698	0.000

	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$
B1	0.00	0.70	0.62	0.75	0.66
B2	0.66	0.00	0.97	0.70	0.72
B3	0.48	0.75	0.00	0.62	0.59
B4	0.42	0.56	0.66	0.00	0.75
B5	0.49	0.80	0.79	0.66	0.00

Appendix B.3: Defuzzification Procedure from Expert 1

Table B.4.1

	S1	S4	S6	S9	S10	S11	S12	S16	S17	S18	S19	S20
SC1	0.00, 0.10, 0.30	0.00, 0.10, 0.30	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.30, 0.50, 0.70	0.50, 0.70, 0.90	0.70, 0.90, 1.00	0.30, 0.50, 0.70	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.00, 0.10, 0.30	0.50, 0.70, 0.90
SC4	0.50, 0.70, 0.90	0.00, 0.10, 0.30	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.30, 0.50, 0.70	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.70, 0.90, 1.00	0.30, 0.50, 0.70	0.10, 0.30, 0.50	0.50, 0.70, 0.90
SC6	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.00, 0.10, 0.30	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.30, 0.50, 0.70	0.10, 0.30, 0.50	0.30, 0.50, 0.70	0.50, 0.70, 0.90	0.10, 0.30, 0.50
SC9	0.30, 0.50, 0.70	0.10, 0.30, 0.50	0.30, 0.50, 0.70	0.00, 0.10, 0.30	0.10, 0.30, 0.50	0.70, 0.90, 1.00	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.00, 0.10, 0.30	0.50, 0.70, 0.90	0.30, 0.50, 0.70	0.50, 0.70, 0.90
SC10	0.10, 0.30, 0.50	0.30, 0.50, 0.70	0.30, 0.50, 0.70	0.70, 0.90, 1.00	0.00, 0.10, 0.30	0.00, 0.10, 0.30	0.70, 0.90, 1.00	0.70, 0.90, 1.00	0.30, 0.50, 0.70	0.10, 0.30, 0.50	0.10, 0.30, 0.50	0.70, 0.90, 1.00
SC11	0.50, 0.70, 0.90	0.50, 0.70, 0.90	0.70, 0.90, 1.00	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.00, 0.10, 0.30	0.50, 0.70, 0.90	0.00, 0.10, 0.30	0.10, 0.30, 0.50	0.00, 0.10, 0.30	0.70, 0.90, 1.00	0.10, 0.30, 0.50
SC12	0.70, 0.90, 1.00	0.30, 0.50, 0.70	0.10, 0.30, 0.50	0.30, 0.50, 0.70	0.50, 0.70, 0.90	0.30, 0.50, 0.70	0.00, 0.10, 0.30	0.30, 0.50, 0.70	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.50, 0.70, 0.90
SC16	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.70, 0.90, 1.00	0.10, 0.30, 0.50	0.30, 0.50, 0.70	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.00, 0.10, 0.30	0.50, 0.70, 0.90
SC17	0.00, 0.10, 0.30	0.50, 0.70, 0.90	0.30, 0.50, 0.70	0.10, 0.30, 0.50	0.70, 0.90, 1.00	0.00, 0.10, 0.30	0.50, 0.70, 0.90	0.30, 0.50, 0.70	0.00, 0.10, 0.30	0.50, 0.70, 0.90	0.50, 0.70, 0.90	0.10, 0.30, 0.50
SC18	0.10, 0.30, 0.50	0.30, 0.50, 0.70	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.50, 0.70, 0.90	0.50, 0.70, 0.90	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.00, 0.10, 0.30	0.10, 0.30, 0.50	0.50, 0.70, 0.90
SC19	0.30, 0.50, 0.70	0.50, 0.70, 0.90	0.00, 0.10, 0.30	0.70, 0.90, 1.00	0.30, 0.50, 0.70	0.70, 0.90, 1.00	0.10, 0.30, 0.50	0.30, 0.50, 0.70	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.00, 0.10, 0.30	0.30, 0.50, 0.70
SC20	0.00, 0.10, 0.30	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.30, 0.50, 0.70	0.50, 0.70, 0.90	0.10, 0.30, 0.50	0.70, 0.90, 1.00	0.10, 0.30, 0.50	0.00, 0.10, 0.30	0.30, 0.50, 0.70	0.10, 0.30, 0.50	0.00, 0.10, 0.30

Table B.4.2

	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$	$s\tilde{z}^f_{lij},s\tilde{z}^f_{mij},s\tilde{z}^f_{uij}$
SC1	0.00, 0.00, 0.00	0.00, 0.00, 0.00	0.50, 0.60, 0.60	0.10, 0.20, 0.20	0.30, 0.40, 0.40	0.50, 0.60, 0.60	0.70, 0.80, 0.70	0.30, 0.40, 0.40	0.10, 0.20, 0.20	0.56, 0.67, 0.67	0.00, 0.00, 0.00	0.50, 0.60, 0.60
SC4	0.50, 0.60, 0.60	0.00, 0.00, 0.00	0.10, 0.20, 0.20	0.50, 0.60, 0.60	0.10, 0.20, 0.20	0.30, 0.40, 0.40	0.50, 0.60, 0.60	0.10, 0.20, 0.20	0.70, 0.80, 0.70	0.33, 0.44, 0.44	0.10, 0.20, 0.20	0.50, 0.60, 0.60
SC6	0.50, 0.60, 0.60	0.11, 0.22, 0.22	0.00, 0.00, 0.00	0.10, 0.20, 0.20	0.50, 0.60, 0.60	0.10, 0.20, 0.20	0.50, 0.60, 0.60	0.30, 0.40, 0.40	0.10, 0.20, 0.20	0.33, 0.44, 0.44	0.50, 0.60, 0.60	0.10, 0.20, 0.20
SC9	0.30, 0.40, 0.40	0.11, 0.22, 0.22	0.30, 0.40, 0.40	0.00, 0.00, 0.00	0.10, 0.20, 0.20	0.70, 0.80, 0.70	0.10, 0.20, 0.20	0.50, 0.60, 0.60	0.00, 0.00, 0.00	0.56, 0.67, 0.67	0.30, 0.40, 0.40	0.50, 0.60, 0.60
SC10	0.10, 0.20, 0.20	0.33, 0.44, 0.44	0.30, 0.40, 0.40	0.70, 0.80, 0.70	0.00, 0.00, 0.00	0.00, 0.00, 0.00	0.70, 0.80, 0.70	0.70, 0.80, 0.70	0.30, 0.40, 0.40	0.11, 0.22, 0.22	0.10, 0.20, 0.20	0.70, 0.80, 0.70
SC11	0.50, 0.60, 0.60	0.56, 0.67, 0.67	0.70, 0.80, 0.70	0.10, 0.20, 0.20	0.50, 0.60, 0.60	0.00, 0.00, 0.00	0.50, 0.60, 0.60	0.00, 0.00, 0.00	0.10, 0.20, 0.20	0.00, 0.00, 0.00	0.70, 0.80, 0.70	0.10, 0.20, 0.20
SC12	0.70, 0.80, 0.70	0.33, 0.44, 0.44	0.10, 0.20, 0.20	0.30, 0.40, 0.40	0.50, 0.60, 0.60	0.30, 0.40, 0.40	0.00, 0.00, 0.00	0.30, 0.40, 0.40	0.50, 0.60, 0.60	0.11, 0.22, 0.22	0.50, 0.60, 0.60	0.50, 0.60, 0.60
SC16	0.10, 0.20, 0.20	0.56, 0.67, 0.67	0.70, 0.80, 0.70	0.10, 0.20, 0.20	0.30, 0.40, 0.40	0.50, 0.60, 0.60	0.10, 0.20, 0.20	0.00, 0.00, 0.00	0.50, 0.60, 0.60	0.11, 0.22, 0.22	0.00, 0.00, 0.00	0.50, 0.60, 0.60
SC17	0.00, 0.00, 0.00	0.56, 0.67, 0.67	0.30, 0.40, 0.40	0.10, 0.20, 0.20	0.70, 0.80, 0.70	0.00, 0.00, 0.00	0.50, 0.60, 0.60	0.30, 0.40, 0.40	0.00, 0.00, 0.00	0.56, 0.67, 0.67	0.50, 0.60, 0.60	0.10, 0.20, 0.20
SC18	0.10, 0.20, 0.20	0.33, 0.44, 0.44	0.10, 0.20, 0.20	0.50, 0.60, 0.60	0.10, 0.20, 0.20	0.50, 0.60, 0.60	0.50, 0.60, 0.60	0.50, 0.60, 0.60	0.10, 0.20, 0.20	0.00, 0.00, 0.00	0.10, 0.20, 0.20	0.50, 0.60, 0.60
SC19	0.30, 0.40, 0.40	0.56, 0.67, 0.67	0.00, 0.00, 0.00	0.70, 0.80, 0.70	0.30, 0.40, 0.40	0.70, 0.80, 0.70	0.10, 0.20, 0.20	0.30, 0.40, 0.40	0.50, 0.60, 0.60	0.11, 0.22, 0.22	0.00, 0.00, 0.00	0.30, 0.40, 0.40
SC20	0.00, 0.00, 0.00	0.56, 0.67, 0.67	0.10, 0.20, 0.20	0.30, 0.40, 0.40	0.50, 0.60, 0.60	0.10, 0.20, 0.20	0.70, 0.80, 0.70	0.10, 0.20, 0.20	0.00, 0.00, 0.00	0.33, 0.44, 0.44	0.10, 0.20, 0.20	0.10, 0.20, 0.20

Table B.4.3

	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$;	$s\tilde{z}^f_{lij}$	$s\tilde{z}^f_{mij}$
SC1	0.00	0.00	0.00	0.00	0.55	0.6	0.18	0.20	0.36	0.40	0.55	0.60	0.73	0.78	0.36	0.40	0.18	0.20	0.60	0.67	0.00	0.00	0.55	0.60
SC4	0.55	0.60	0.00	0.00	0.18	0.2	0.55	0.60	0.18	0.20	0.36	0.40	0.55	0.60	0.18	0.20	0.73	0.78	0.40	0.44	0.18	0.20	0.55	0.60
SC6	0.55	0.60	0.20	0.22	0.00	0.0	0.18	0.20	0.55	0.60	0.18	0.20	0.55	0.60	0.36	0.40	0.18	0.20	0.40	0.44	0.55	0.60	0.18	0.20
SC9	0.36	0.40	0.20	0.22	0.36	0.4	0.00	0.00	0.18	0.20	0.73	0.78	0.18	0.20	0.55	0.60	0.00	0.00	0.60	0.67	0.36	0.40	0.55	0.60
SC10	0.18	0.20	0.40	0.44	0.36	0.4	0.73	0.78	0.00	0.00	0.00	0.00	0.73	0.78	0.73	0.78	0.36	0.40	0.20	0.22	0.18	0.20	0.73	0.78
SC11	0.55	0.60	0.60	0.67	0.73	0.8	0.18	0.20	0.55	0.60	0.00	0.00	0.55	0.60	0.00	0.00	0.18	0.20	0.00	0.00	0.73	0.78	0.18	0.20
SC12	0.73	0.78	0.40	0.44	0.18	0.2	0.36	0.40	0.55	0.60	0.36	0.40	0.00	0.00	0.36	0.40	0.55	0.60	0.20	0.22	0.55	0.60	0.55	0.60
SC16	0.18	0.20	0.60	0.67	0.73	0.8	0.18	0.20	0.36	0.40	0.55	0.60	0.18	0.20	0.00	0.00	0.55	0.60	0.20	0.22	0.00	0.00	0.55	0.60
SC17	0.00	0.00	0.60	0.67	0.36	0.4	0.18	0.20	0.73	0.78	0.00	0.00	0.55	0.60	0.36	0.40	0.00	0.00	0.60	0.67	0.55	0.60	0.18	0.20
SC18	0.18	0.20	0.40	0.44	0.18	0.2	0.55	0.60	0.18	0.20	0.55	0.60	0.55	0.60	0.55	0.60	0.18	0.20	0.00	0.00	0.18	0.20	0.55	0.60
SC19	0.36	0.40	0.60	0.67	0.00	0.0	0.73	0.78	0.36	0.40	0.73	0.78	0.18	0.20	0.36	0.40	0.55	0.60	0.20	0.22	0.00	0.00	0.36	0.40
SC20	0.00	0.00	0.60	0.67	0.18	0.2	0.36	0.40	0.55	0.60	0.18	0.20	0.73	0.78	0.18	0.20	0.00	0.00	0.40	0.44	0.18	0.20	0.00	0.00

Table B.4.4

	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$
SC1	0.00	0.00	0.58	0.19	0.38	0.58	0.76	0.38	0.19	0.64	0.00	0.58
SC4	0.58	0.00	0.19	0.58	0.19	0.38	0.58	0.19	0.76	0.42	0.19	0.58
SC6	0.58	0.18	0.00	0.19	0.58	0.19	0.58	0.38	0.19	0.42	0.58	0.19
SC9	0.38	0.18	0.38	0.00	0.19	0.76	0.19	0.58	0.00	0.64	0.38	0.58
SC10	0.19	0.38	0.38	0.76	0.00	0.00	0.76	0.76	0.38	0.20	0.19	0.76
SC11	0.58	0.58	0.76	0.19	0.58	0.00	0.58	0.00	0.19	0.00	0.76	0.19
SC12	0.76	0.38	0.19	0.38	0.58	0.38	0.00	0.38	0.58	0.20	0.58	0.58
SC16	0.19	0.58	0.76	0.19	0.38	0.58	0.19	0.00	0.58	0.20	0.00	0.58
SC17	0.00	0.58	0.38	0.19	0.76	0.00	0.58	0.38	0.00	0.64	0.58	0.19
SC18	0.19	0.38	0.19	0.58	0.19	0.58	0.58	0.58	0.19	0.00	0.19	0.58
SC19	0.38	0.58	0.00	0.76	0.38	0.76	0.19	0.38	0.58	0.20	0.00	0.38
SC20	0.00	0.58	0.19	0.38	0.58	0.19	0.76	0.19	0.00	0.42	0.19	0.00

Table B.4.5

	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$	$\tilde{w}_{ij}^{f}$
SC1	0.00	0.000	0.576	0.185	0.378	0.576	0.765	0.378	0.185	0.642	0.000	0.576
SC4	0.58	0.000	0.185	0.576	0.185	0.378	0.576	0.185	0.765	0.419	0.185	0.576
SC6	0.58	0.184	0.000	0.185	0.576	0.185	0.576	0.378	0.185	0.419	0.576	0.185
SC9	0.38	0.184	0.378	0.000	0.185	0.765	0.185	0.576	0.000	0.642	0.378	0.576
SC10	0.19	0.377	0.378	0.765	0.000	0.000	0.765	0.765	0.378	0.205	0.185	0.765
SC11	0.58	0.578	0.765	0.185	0.576	0.000	0.576	0.000	0.185	0.000	0.765	0.185
SC12	0.76	0.377	0.185	0.378	0.576	0.378	0.000	0.378	0.576	0.205	0.576	0.576
SC16	0.19	0.578	0.765	0.185	0.378	0.576	0.185	0.000	0.576	0.205	0.000	0.576
SC17	0.00	0.578	0.378	0.185	0.765	0.000	0.576	0.378	0.000	0.642	0.576	0.185
SC18	0.19	0.377	0.185	0.576	0.185	0.576	0.576	0.576	0.185	0.000	0.185	0.576
SC19	0.38	0.578	0.000	0.765	0.378	0.765	0.185	0.378	0.576	0.205	0.000	0.378
SC20	0.00	0.578	0.185	0.378	0.576	0.185	0.765	0.185	0.000	0.419	0.185	0.000

Appendix B.4: FDEMATEL – Criteria (Strategies) of GF-in-GB

Table B.5.1 Initial direct relation matrix of criteria

	S1	S4	S6	S9	S10	S11	S12	S16	S17	S18	S19	S20
SC1	0.000	0.318	0.495	0.429	0.557	0.575	0.670	0.542	0.470	0.570	0.339	0.532
SC4	0.607	0.000	0.427	0.558	0.445	0.525	0.575	0.461	0.617	0.561	0.482	0.629
SC6	0.511	0.460	0.000	0.413	0.544	0.397	0.544	0.492	0.438	0.500	0.500	0.433
SC9	0.477	0.444	0.477	0.000	0.444	0.621	0.428	0.608	0.411	0.588	0.499	0.548
SC10	0.478	0.508	0.510	0.653	0.000	0.398	0.654	0.605	0.536	0.456	0.435	0.628
SC11	0.574	0.591	0.606	0.477	0.607	0.000	0.624	0.414	0.470	0.384	0.624	0.434
SC12	0.670	0.509	0.397	0.508	0.592	0.589	0.000	0.573	0.600	0.474	0.548	0.564
SC16	0.461	0.576	0.671	0.461	0.492	0.639	0.493	0.000	0.618	0.485	0.369	0.629
SC17	0.447	0.575	0.493	0.428	0.654	0.414	0.623	0.557	0.000	0.622	0.629	0.450
SC18	0.445	0.509	0.461	0.559	0.461	0.607	0.639	0.591	0.489	0.000	0.483	0.581
SC19	0.525	0.608	0.351	0.607	0.526	0.605	0.429	0.461	0.619	0.490	0.000	0.530
SC20	0.319	0.576	0.445	0.493	0.591	0.461	0.653	0.461	0.390	0.516	0.483	0.000

Table B.5.2 Normalised direct relation matrix of criteria

	S1	S4	S6	S9	S10	S11	S12	S16	S17	S18	S19	S20
SC1	0.000	0.053	0.082	0.071	0.093	0.095	0.111	0.090	0.078	0.095	0.056	0.088
SC4	0.101	0.000	0.071	0.093	0.074	0.087	0.095	0.076	0.102	0.093	0.080	0.104
SC6	0.085	0.076	0.000	0.069	0.090	0.066	0.090	0.082	0.073	0.083	0.083	0.072
SC9	0.079	0.074	0.079	0.000	0.074	0.103	0.071	0.101	0.068	0.098	0.083	0.091
SC10	0.079	0.084	0.085	0.108	0.000	0.066	0.108	0.100	0.089	0.076	0.072	0.104
SC11	0.095	0.098	0.101	0.079	0.101	0.000	0.104	0.069	0.078	0.064	0.104	0.072
SC12	0.111	0.084	0.066	0.084	0.098	0.098	0.000	0.095	0.100	0.079	0.091	0.094
SC16	0.076	0.096	0.111	0.077	0.082	0.106	0.082	0.000	0.103	0.080	0.061	0.104
SC17	0.074	0.095	0.082	0.071	0.109	0.069	0.103	0.092	0.000	0.103	0.104	0.075
SC18	0.074	0.085	0.077	0.093	0.077	0.101	0.106	0.098	0.081	0.000	0.080	0.096
SC19	0.087	0.101	0.058	0.101	0.087	0.100	0.071	0.076	0.103	0.081	0.000	0.088
SC20	0.053	0.096	0.074	0.082	0.098	0.076	0.108	0.076	0.065	0.086	0.080	0.000

Table B.5.3 Total interrelation matrix of criteria

	SC1	SC4	SC6	SC9	SC10	SC11	SC12	SC16	SC17	SC18	SC19	SC20	D
SC1	1.398	1.486	1.431	1.481	1.577	1.557	1.690	1.539	1.503	1.511	1.424	1.583	18.181
SC4	1.579	1.527	1.507	1.590	1.657	1.645	1.778	1.620	1.616	1.602	1.532	1.693	19.347
SC6	1.414	1.442	1.293	1.416	1.507	1.466	1.600	1.466	1.435	1.437	1.384	1.502	17.363
SC9	1.480	1.514	1.437	1.423	1.570	1.574	1.665	1.556	1.504	1.523	1.455	1.595	18.297
SC10	1.554	1.598	1.512	1.596	1.580	1.620	1.780	1.634	1.598	1.580	1.518	1.686	19.257
SC11	1.557	1.597	1.514	1.560	1.659	1.544	1.762	1.594	1.577	1.557	1.533	1.645	19.098
SC12	1.622	1.640	1.536	1.617	1.713	1.689	1.729	1.671	1.649	1.624	1.574	1.721	19.786
SC16	1.558	1.614	1.542	1.575	1.663	1.658	1.766	1.548	1.615	1.590	1.516	1.692	19.335
SC17	1.564	1.622	1.522	1.579	1.692	1.636	1.791	1.641	1.531	1.616	1.558	1.676	19.428
SC18	1.544	1.593	1.500	1.577	1.645	1.643	1.772	1.625	1.585	1.503	1.520	1.673	19.180
SC19	1.539	1.589	1.468	1.567	1.636	1.625	1.724	1.589	1.586	1.562	1.429	1.648	18.962
SC20	1.427	1.499	1.400	1.467	1.556	1.517	1.660	1.503	1.469	1.479	1.421	1.478	17.875
R	18.238	18.723	17.663	18.448	19.454	19.174	20.717	18.985	18.667	18.584	17.863	19.592	1.570

Appendix B.5: FDEMATEL – Attributes (Categories) of GF-in-GB

Table B.6.1 Initial direct relation matrix of attributes

	S1	S2	S3	S4
S1	0.0000	0.5550	0.6670	0.5966
S2	0.7244	0.0000	0.6241	0.6846
S3	0.7045	0.6796	0.0000	0.7269
S4	0.6240	0.6445	0.6824	0.0000

Table B.6.2 Normalised direct relation matrix of attributes

	S1	S2	S3	S4
S1	0.0000	0.2629	0.3160	0.2826
S2	0.3432	0.0000	0.2956	0.3243
S3	0.3337	0.3219	0.0000	0.3444
S4	0.2956	0.3053	0.3233	0.0000

Table B.6.3 Total interrelation matrix of attributes

	S1	S2	S3	S4	D
S1	3.3806	3.3691	3.5260	3.5448	13.8206
S2	3.9275	3.4319	3.7973	3.8548	15.0115
S3	4.0341	3.7809	3.6780	3.9771	15.4701
S4	3.7980	3.5712	3.7139	3.5104	14.5935
R	15.1402	14.1532	14.7152	14.8872	3.6810

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