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Research Article

Do We Know Enough About Green Buildings? A Meticulous SWOT Analysis Using Fuzzy-based Approach

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Received: 26/11/2025
Revised: 22/12/2025
Accepted: 29/12/2025
Published: 11/01/2026

Volume: 2026
Issue: 01
Pages: 25--54

Abstract

Sustainability has become a critical focus in the construction industry, yet a detailed understanding of the factors shaping green building adoption remains limited. This study investigates the Strengths, Weaknesses, Opportunities, and Threats (SWOT) associated with green building implementation and employs a fuzzy-based DEMATEL approach to analyse the interrelationships among these factors. Key findings reveal that improved resident comfort, enhanced GDP, lack of end-user knowledge and awareness, and bureaucratic inefficiencies significantly influence green building adoption. Expert validation further identified that tax rebates, financial incentives, and subsidies are essential strategies for promoting sustainable construction practices. The study also highlights the importance of integrating regulatory support, stakeholder engagement, and sustainable technologies to enhance policy effectiveness. By systematically combining SWOT with fuzzy DEMATEL, the research provides a rigorous framework to assess factor importance and causal interdependencies under uncertainty. The outcomes offer actionable insights for policymakers and industry practitioners, guiding the design of incentive programs, regulatory frameworks, and implementation strategies. This study contributes to academic scholarship and equips decision-makers with a practical, evidence-based approach to advancing green building adoption, fostering sustainability, and supporting long-term development in the construction sector.

Keywords: Green buildings; SWOT; Fuzzy sets; Fuzzy DEMATEL; Sustainability

Highlights

- Governance barriers act as primary drivers shaping smart city project performance
- Fuzzy-ISM reveals hierarchical dependencies among policy, social, and technical barriers
- ML validation confirms governance and social factors most strongly affect project outcomes

Introduction

Ecological destruction and resource shortages have prompted countries worldwide to implement various mitigation measures to reduce greenhouse gas (GHG) emissions. With pressure mounting on governments to combat climate change, there is a need for various sectors of various economies to find lasting solutions to this environmental menace. As one of the most energy-intensive industries, accounting for over forty per cent (40%) of global energy consumption, the construction industry has a crucial role in reversing climate issues (Shen & Li, 2023a). However, although efforts are in place to combat climate change, the Global Buildings Climate Tracker has revealed that the buildings and construction sector still needs to do more to achieve decarbonization by 2050. For instance, in 2021, the level of decarbonisation dropped to 8.1 from 11.3 in 2020 (United Nations Environment Programme, UNEP, 2022). Notwithstanding, of late, the level has begun shooting. This is because the operational energy demand in buildings has exceeded previous peaks by over 3%, thereby shooting to about 4% (IEA, 2022). This statistic is worrying, and much needs to be done by the global construction sector.

Although not enough, the construction industry is adopting strategies that could minimise environmental threats. Key among such strategies is the development and adoption of green buildings. According to Filippini & Obrist (2022), green buildings have become a development trend in the global construction industry. Green buildings are environmentally responsible and resource-efficient throughout their life cycle, from siting and design through construction, operation, maintenance, renovation, and deconstruction (United States Environmental Protection Agency [USEPA], 2016). The 2022 Global Status Report for Buildings and Construction reports show a growing recognition of global green building certification systems. Currently, there are seventy-four (74) green building certification systems across the globe, with one hundred and eighty-four (184) countries having buildings certified with any of the 74 certification systems (UNEP, 2022). Unfortunately, despite years of promotion and rapid technological advancements, green building project development is still limited and uncertain (Lu et al., 2022; Shen & Li, 2023b). Could this be because we need to learn more about green buildings?

Green buildings have emerged as a critical solution for global environmental concerns and the urgent need to combat climate change. These sustainable structures aim to reduce energy consumption, enhance occupant well-being, and minimise environmental impact (Ketut Acwin Dwijendra et al., 2023). From developed nations to rapidly urbanising regions, the focus on green building development remains steadfast. Challenges such as cost, occupant comfort, and energy efficiency persist, but innovations in building technologies continue to drive progress (Darko & Chan, 2017). Over the years, 42,000 private and 8,000 government buildings have been spread across urban landscapes. According to EARTH.ORG, these buildings consume approximately 90% of electricity and emit about 60% of carbon dioxide annually. In response to this problem in the housing sector, the Green Building Council (HKGBC) developed a green certification standard, BEAM Plus. This certification standard is expected to assist the Environment Bureau's Climate Action Plan 2030+ towards a carbon reduction target of 65-70% by 2030. The BEAM Plus assessment tool was launched in 2010 following collaboration between the Green Building Council and the Building Environmental Assessment Society to revise the criteria for assessing the sustainability of construction projects. By 2020, over 1,500 new buildings had been certified, and more than half of all private developments had participated in BEAM Plus, with a total green area of 1 million square meters, according to EARTH.ORG, 2023.

In recent years, according to EARTH.ORG, although stakeholders such as governments, environmental organisations, and green building–related companies have actively promoted green building development, its overall effectiveness and large-scale impact remain limited. The primary challenges lie in cost-effectiveness and technical expertise. Due to land scarcity and rising construction costs, baseline development expenses are already high, and the adoption of green building technologies can further increase upfront costs by nearly 10% (Satola et al., 2022), which discourages widespread implementation (Filiou et al., 2023; Love et al., 2012). Although more than 1,000 green building projects have been registered, their influence on the overall construction industry remains marginal. This is mainly because energy consumption and environmental pollution are dominated by existing buildings rather than newly constructed ones (Kumph et al., 2018; Y. Li et al., 2022). Retrofitting or modifying existing buildings is considerably more complex than constructing new green buildings, as it involves multiple stakeholders, including governments, builders, and residents, making large-scale implementation difficult and slow.

Beyond economic and technical constraints, limited stakeholder awareness and insufficient understanding of the trade-offs associated with green building technologies further impede adoption (Ghaffarianhoseini et al., 2013a; Liu et al., 2018). While previous studies have examined individual drivers and barriers, the interrelationships among strengths, weaknesses, opportunities, and threats influencing green building adoption remain insufficiently explored, particularly under uncertainty. This study addresses this gap by employing a fuzzy-based analytical approach to capture the complex causal interactions governing green building implementation, thereby providing timely insights to support sustainable construction decision-making.

To fill the above research gap, the following research questions are:

- What are the key factors that influence sustainability in construction projects?
- How do the identified factors influencing sustainability in construction projects interrelate, and what are these interrelationships?
- Based on the identified factors and their interrelationships, what recommendations can be formulated to enhance sustainable practices in the construction sector, and how can these be prioritised effectively through expert interviews?

This study has succinctly addressed the research gap to answer the above-mentioned research question. The following research objectives are drawn:

- Identify the factors influencing sustainability in construction projects.
- Investigate the interrelationships among the identified factors using Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL).
- Formulate recommendations and prioritise them for enhancing sustainable practices in the respective sector using expert interviews.

This study significantly contributes to the existing knowledge by addressing the research gap concerning the interrelationships among Strengths, Weaknesses, Opportunities, and Threats associated with implementing green buildings. Employing a fuzzy-based approach offers a nuanced understanding of these complex relationships, providing invaluable insights for academia, industry, policymakers, researchers, and practitioners engaged in sustainable construction practices. Beyond academic inquiry, this research holds practical implications, empowering decision-makers to formulate targeted policies and practitioners to design resilient green building projects. Moreover, by demonstrating the efficacy of this methodology, the study sets a precedent for future research, thereby refining best practices and driving innovation in sustainable construction on a broader scale.

Literature review

This section establishes the intellectual and theoretical basis for the study, providing a structured analysis of key concepts, relevant theories, and existing frameworks that inform the research. It critically reviews the literature to situate the study within the broader academic discourse and to identify gaps that the research seeks to address. Additionally, it introduces a conceptual model that guides the study's approach, offering a lens through which the research problem is examined.

1.1 Green Building: Concept, definition and its development

Green buildings (GBs) are key in helping countries meet their commitments under the Paris Agreement on Climate Change (Shen, Y., Faure, 2021a). The terms green building, sustainable building, high-performance building, sustainable construction, green construction, and high-performance construction have been used synonymously in the literature. Numerous varying definitions have been given for GBs. According to the World Green Building Council (WGBC) (2019), a GB is a building whose design, construction, or operation reduces or eliminates negative impacts. Such a building has the potential to create a positive impact on the climate and the natural environment. (Cheng & Das, 2014) defined green buildings as structures built to be environmentally responsible and energy efficient throughout their life cycle. According to (Xiong et al.2015 Hu et al., 2023), GBs are buildings designed to reduce waste, pollution, and environmental degradation. They are resource-efficient throughout their lifecycle, from siting and design through construction, operation, maintenance, and final disposal. In Kibert's view [7], a GB is a healthy facility designed and built resource-efficiently using ecologically based principles.

As much as GBs seek to protect and preserve the environment, it is necessary to ensure that they can meet the requirements and satisfaction of their occupants. Ever since the built environment adopted the GB phenomenon, there have been various studies conducted that talk about the ability of green buildings to minimise adverse environmental impacts, as well as several reviews to evaluate how well these buildings are faring in comparison with conventional or non-green buildings (Agyekum et al., 2023). For a building to be classified as GB, it must be built in compliance with a certification tool. According to (Shen, Y., Faure, 2021b) GB compliance can be evaluated using a rating system that incorporates public or private standards. Currently, there are seventy-four (74) green building certification systems across the globe, with one hundred and eighty-four (184) countries having buildings certified with any of the 74 certification systems (UNEP, 2022).

Ghaffarianhoseini et al. (Ghaffarianhoseini et al., 2013b), define a green building rating system (GBRS) as "a comprehensive framework developed by construction authorities, international organisations, or private consultancy companies to assess and verify the sustainability and greenness of buildings ."Key among these GBRSs is Building Research Establishment's Environmental Assessment Method (BREEAM), used in the UK; Leadership in Energy and Environmental Design (LEED), used in the USA; Excellence in Design for Greater Efficiencies (EDGE), developed and used by the International Finance Corporation; Green Star - Australia (GS) used in Australia; Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) used in Japan; Green Mark (GM) used in Singapore; Built Environment Assessment Method (BEAM) used in Hong Kong; and the DGNB used in Germany, among others.

1.2 Strengths and Opportunities Associated with Green Building Adoption

The contribution of GBs, as a strategy adopted by the construction sector to combat climate change, stems from their strengths and opportunities. A critical comparative review of the related literature is carried out, and this section recounts some of the strengths and opportunities associated with GB development.

GBs possess numerous strengths. These strengths are widely reported in the literature. The strengths associated with GB development have been classified into economic, social, and environmental for this review. Studies have shown that green construction can save many by increasing staff productivity, enhancing health and safety, and lowering energy, maintenance, and operational costs. Although GBs are slightly more expensive than conventional ones, their lower operating and maintenance costs make them significantly more cost-effective (Geng et al., 2019). The economic strength associated with GBs relates to the financial stability of companies where financial benefits are conferred upon the related firms during building construction and post-construction phases, since the supply of green materials is more stable than traditional ones (i.e., due to less fluctuation from scarcity or demand) (Abisuga and Okuntade, 2020a). Another essential economic strength of GBs is the profitability it renders to the property market (Khoshbakht et al., 2018). GBs now offer great market potential for all investors globally. GBs represent a $24.7 trillion investment opportunity across emerging markets by 2030 (International Finance Corporation, 2017). This means that for smart investors seeking to drive profitable change in the built industry, GBs present a compelling business case. GBs also possess some ecological-stemmed monetary benefits. Ecologically based construction provides financial benefits and advantages in the form of saving energy and water resources (i.e., energy saving), reducing waste, reducing the cost of maintaining employees' health, and minimising operational needs. The social strengths associated with GB developments include improved comfort of residents (Abisuga and Okuntade, 2020b; Agyekum et al., 2023; Fu et al, 2021a), an enhanced psychological well-being of residents, and improved aesthetics. Empirical evidence has shown that green features effectively improve occupant comfort and satisfaction (Fu et al, 2021b). Since green buildings are associated with interior design elements like improved lighting sources, thermal conditions, ergonomic features, and upgraded air quality, among others, residents in such GBs experience a marked improvement in their health, stress levels, and overall quality of life (Cosola et al., 2023; Elias & Khai, 2015).

GBs also possess some environmental strengths. Key among them is a reduction in natural resource consumption (Dario Bottino-Leone, Marco Larcher, Daniel Herrera-Avellanosa & Troi, 2019a), a reduction in the pollution of waterways (Dario Bottino-Leone et al., 2019), a reduction in energy consumption (Siva et al., 2017a), and noise reduction, among others. In addition, GBs have the potential to alleviate negative impacts on the natural environment by using less water, energy, and other natural resources (J. Teng et al., 2019). Furthermore, such buildings employ renewable energy sources and eco-friendly materials, reducing emissions and other waste (Liu et al., 2022). Amid the global drive toward net zero, several challenges remain. A critical challenge to decarbonisation is the emissions from the building sector. Notwithstanding this, GBs present opportunities that make it easier to overcome some of these challenges. After a comparative review of the related literature, these opportunities have been grouped into economic, environmental, and technological categories.

The economic opportunities associated with GBs have been identified in the literature as improved gross domestic products (GDPs) of countries (Abisuga and Okuntade, 2020b; Marotta et al., 2023a), job creation (Abisuga and Okuntade, 2020b), and reduction in carbon taxes (Ravasio et al., 2020), among others. In addition, sustainable construction projects enhance national economic performance. (Darko, Chan, Ameyaw, et al., 2017a) a classified GDP as the cause and the cure for environmental degradation. This assertion is buttressed by the Environmental Kuznets Curve (EKC), which depicts the relationship between environmental degradation and GDP in an inverted U-shaped form (Marotta et al., 2023b). This means that once there is an initial rapid economic growth in any country, environmental degradation increases.

Notwithstanding, it gets to a point where the impact of the degradation is felt (e.g., modern-day climate change). This problem advances technologies (e.g., GB development in the construction sector) that tend to reverse this trend. With technological advancements, environmental quality improves alongside GDP. In addition to the improved GDP, Green-based construction projects enhance multiple businesses and employment, as well as occupational and regulatory efficiency, while poverty is eradicated (Abisuga and Okuntade, 2020b). Ravasio et al. (2020) also indicated that with GBs, there is an opportunity to reduce carbon taxes. This is because the entire life cycle of green buildings can provide energy savings for users and reduce their tax burden. The environmental opportunities associated with GBs have been classified as reduced adverse environmental effects in the long run, optimised energy sources (Siva et al., 2017b), and improved ecological balance. Through better site selection, design, construction, operation, maintenance, and demolition, the construction and planning of buildings will be more in line with green affinity, leading to an enhancement in the sustainability of buildings and a reduction in the negative impact of buildings on human health and the environment. There is also an opportunity for a great deal of energy to be saved for future use by exploiting sustainable-based features (e.g., photovoltaic cells on a building's roof) (Hussien et al., 2023). The ecological balance provides a dynamic equilibrium within a community of organisms where genetic, species, and ecosystem diversity remain relatively stable and subject to gradual changes through natural succession. In terms of improving the ecological balance, when the damage caused to nature is sustainably decreased through contracting buildings, the lives of many different species are preserved.

Literature reveals the technological opportunities of GBs to include improved resiliency of constructed facilities (Champagne and Aktas, 2016a), improved knowledge exchange (Annie R Pearce, 2007a), and revitalised industrialisation (Abisuga and Okuntade, 2020b). Building resilience is becoming increasingly important as the Earth's climate changes and deviates from historical climate data (Champagne and Aktas, 2016b). Hence, more than ever, resilient design principles have become essential. Unlike conventional buildings, sustainable, smart-based technologies used in green buildings enhance the resilience of constructed facilities against disasters (e.g., typhoons, earthquakes) (Champagne and Aktas, 2016b). Regarding the improved knowledge exchange, green building policies can promote the knowledge exchange of technical capabilities and border crossing between construction companies (Pearce, 2007b). In addition, (Abisuga and Okuntade, 2020b) iterated that green innovation advances discoveries and educational values when given adequate support. This brings about innovative breakthroughs and revitalises industrialisation.

1.3 Weaknesses and Threats Associated with Green Building Adoption

Despite the numerous strengths and opportunities associated with green buildings, weaknesses and threats are also reported. After the comparative review of the related literature, the weaknesses associated with GBs have been classified as economic, technological, and social. A key economic weakness is the high initial cost. and high maintenance costs. The technological weaknesses are identified as the need for skilled personnel and up-to-date technology (Siva et al., 2017b). Finally, the social weaknesses of GBs are identified as end users' resistance to adopting new technology (Chini et al, 2017a; Dhakal and Chevalier, 2016a). Sustainable construction requires a long-term view of the costs of green buildings, considering both capital and operating costs. Economically, due to the installation of sustainability-based features within GBs, the initial cost of completing GBs is generally higher than that of conventional projects. Furthermore, some sustainably built features require relatively large expenditures for maintenance (e.g., green roofs, green walls). Technological constraints, such as the need for more experts familiar with green building construction, impede further adoption of such projects. Moreover, the inadequately skilled labour to accomplish the required installation in a particular GB is another stumbling block (J. Wu & Ying, 2024a). Furthermore, to be certified under relevant green building rating tools, a building must include green features (e.g., green walls, green roofs, solar panels, atriums, skylights). However, there is a need for appropriate and advanced technology within the current market for such installations, and the absence of such technology affects the implementation (Siva et al., 2017b).

Socially, there has always been resistance among the people living in a society (particularly older people) towards the adoption of new technologies since they view it as expensive and not economical for the time being (Chini et al, 2017b; Dhakal and Chevalier, 2016b; Kumah, Victoria Maame Afriyie, Kofi Agyekum, Edward Ayebeng Botchway, Hayford Pittri, 2022). Furthermore, because the end user of a building is usually the final decision-maker in adopting green building technologies, their lack of understanding of the perceived economic benefits of new green building innovations constitutes a significant obstacle. The literature reviewed the threats associated with GB development, both economic and governmental. The economic threats were identified as a lack of financial incentives. Also, the inadequate data on the lifecycle cost of GBs poses a severe threat to the development of such buildings. The governmental/Managerial threats associated with GB development are reported to include conflicts between different stakeholders (Siva et al., 2017b), flawed bureaucratic administration (Annie R Pearce, 2007b), flawed loan systems, and lack of organisational/institutional leadership (Carolyn et al., 2019).

Although numerous studies have explored the definitions, strengths, weaknesses, opportunities, and threats of green buildings, literature often presents these aspects in isolation without systematically comparing or synthesising findings across contexts. For instance, while economic benefits such as energy savings, reduced operational costs, and increased productivity are widely reported, the cost-effectiveness of green buildings varies across regions and market conditions, indicating contextdependent outcomes (Santana et al., 2023a). Similarly, technological opportunities, such as improved resilience and knowledge exchange, are highlighted in some studies, whereas others emphasise challenges, including insufficiently skilled labour and limited access to advanced materials, reflecting a gap between potential benefits and practical implementation. Social and environmental impacts, including occupant comfort, improved health, reduced pollution, and ecological balance, are generally acknowledged, yet their interconnections with economic and technological factors are rarely analysed. Overall, the literature presents a fragmented view, lacking a comprehensive understanding of how these factors interact and influence green building adoption under uncertainty. This gap underscores the need for an integrated analytical approach, such as the fuzzy-based SWOT–DEMATEL method employed in this study, to systematically assess factor interrelationships and support evidence-based policy and practice.

Methodology

This research unfolded across three distinct phases. The initial phase introduced the SWOT analysis method, a systematic approach established in the 1980s, enabling an objective assessment of the current situation by identifying internal Strengths (S), Weaknesses (W), external Opportunities (O), and Threats (T) pertinent to the research subject. The second phase involved data collection through expert questionnaire surveys, while the final phase employed fuzzy DEMATEL techniques to explore the interconnections among identified factors. This study adhered to the depicted research flow in Figure 1.

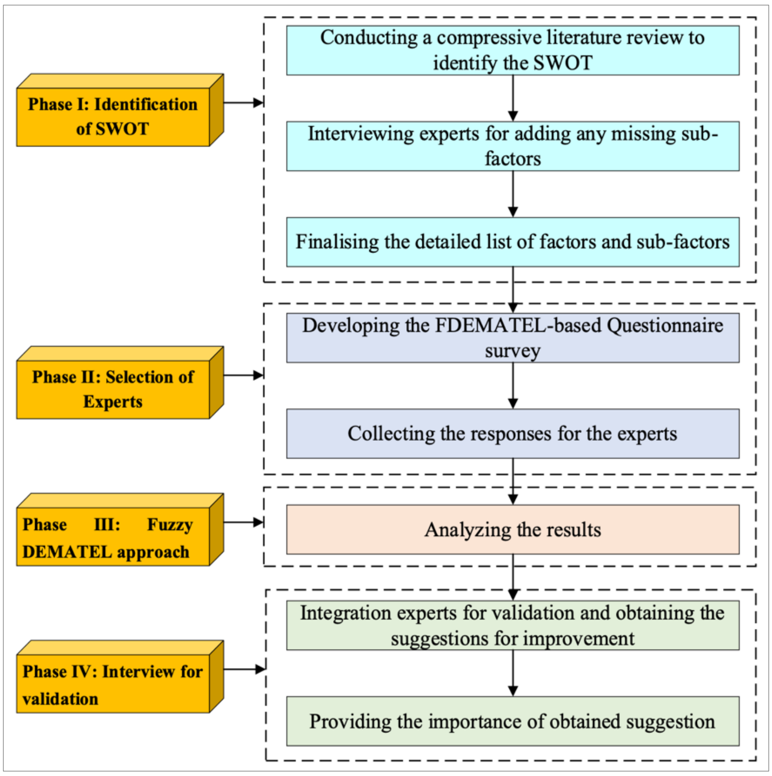

Figure 1: The flow chart of the Research Methodology.

1.4 Phase I: Identification of SWOT

A comprehensive literature review was conducted to identify the key environmental factors influencing green building policy, which were then systematically categorised into strengths, weaknesses, opportunities, and threats (see Tables 1 and 2). In this process, both the current context of green building policy and potential future factors that could impact the building environment were carefully considered. While SWOT provides a structured framework for identifying these internal and external factors, it does not capture the interrelationships or causal effects among them. To address this limitation, a fuzzy-based DEMATEL approach was integrated, enabling the handling of uncertainty and subjectivity in expert judgments while modelling causal relationships among SWOT factors. This combined approach enables a rigorous, quantitative assessment of factor importance and interdependencies, making it particularly suitable for analysing the complex, multi-dimensional challenges of green building policy, where economic, social, environmental, technological, and managerial factors interact under uncertainty.

Interview with the experts to finalise the list of factors

Interview experts and ask them about their views on green building policy. These experts have bachelor's degrees in engineering and 5-10 years of working experience (see Table 3). In their careers, two of them are architects, one a civil engineer, and the other a faculty Manager; these experts have different specialities, come from different jobs, have more experience, and can put forward more unique opinions. Therefore, through the interview, we found the factors that affect green building, formed the influencing factors list, and conducted a SWOT analysis.

Table 1: Strengths and Opportunities stemming from implementing green building policy.

Category	**Factor**	**Sub-factor**	**Code**	**Definition**	**Source of Identification**	
					Literature Review	**Experts**
Strengths	**Economic**	Financial stability for companies	S1	Financial benefits are conferred upon the related firms during building and post-construction phases since the supply of green materials is more stable than traditional ones (i.e., due to less fluctuation from scarcity or demand).	✓ (Abisuga and Okuntade, 2020b)	
		Profitability of the property market value/rents	S2	Due to the use of sustainable-oriented features within the buildings, higher property market value, higher rents, and fewer vacancies are achieved.	✓ (Song et al., 2024)	
		Ecological-stemmed monetary benefits	S3	Ecologically-based construction provides financial benefits and advantages in the form of saving energy and water resources (i.e., energy saving), leading to reducing the amount of waste, reducing the cost of maintaining the health of employees, and minimising the cost of operational needs.	✓ (Pathiranage et al., 2024)	
	Social	Improved residents' comfort	S4	The quality of life of the green buildings' residents is improved, resulting from living in an eco-friendly environment (e.g., the residents' comforts resulting from the use of HVAC).	✓ (Abisuga and Okuntade, 2020b)	
		Improved residents' psychological mood	S5	Due to the use of green-oriented features within green building (such as green roofs, green walls, or sustainable-based interior decoration), a significant improvement in the psychological mood of the residents of such buildings is witnessed.	✓ (Huang et al., 2015)	

		Improved ascetical attraction	S6	The city's landscape becomes more charming and appealing to passersby due to the use of greenery within such buildings.		✓
	Environmental	Reduction in natural resource consumption	S7	A significant reduction in water consumption (up to 50% by organising a closed water cycle) can be achieved. Moreover, recycling timber from old buildings using materials made from agricultural waste and buying timber from sustainable forests helps reduce their depletion.	✓ (Ding et al., 2018)	
		Reduction in pollutants of waterways	S8	Storm drains that drain water from roofs of buildings, driveways, and hard surfaces are the main cause of pollution of coastal waters and the closure of beaches. Placing ecological buildings in previously developed areas prevents the spread of water pollution.	✓ (Barbosa & Azar, 2018)	
		Reduction in energy consumption	S9	The demand for heating and cooling loads within the green-certified building has significantly decreased.	✓ (Soleimanijavid et al., 2024)	
		Noise reduction	S10	By installing green-based components within the walls and roofs of buildings, a significant reduction in the noise penetrating the buildings from the environment is achieved.		✓
Opportunities	**Economic**	Improved GDP	O1	Sustainable construction projects lead to improving the national domestic economic exhibitions.	✓ (Ng et al., 2024)	
		Job creation	O2	Green-based construction projects enhance multiple businesses, employment, and occupational and regulatory efficiency while eradicating poverty.	✓ (Darko, Chan, Owusu-manu, et al., 2017)	
		Reduction in carbon taxes	O3	The whole life cycle of green buildings can provide energy savings to the users and reduce the taxes paid by the users.	✓ (Tam et al., 2017)	
	Environmental	Reduce adverse environmental effects in the long run	O4	Through better site selection, design, construction, operation, maintenance, and demolition, the construction and planning of buildings will be more in line with green affinity, enhancing the sustainability of buildings and reducing the negative impact of buildings on human health and the environment.	✓ (Shuang et al., 2024)	
		Optimised energy sources	O5	A great deal of energy can be saved for future use through the exploitation of sustainable-	✓ (Chiwaridzo, 2024)	

				based features (e.g., the use of photovoltaic cells on a building's roof)		
		Improved ecological balance	O6	When the damages caused to nature by maintaining the ecological balance are sustainably decreased through constructing buildings, the lives of many different species are preserved.	✓ (Ghaffarianhoseini et al., 2013c)	
	Technological	Improved resiliency of constructed facilities	O7	Sustainable and smart technologies used in green buildings enhance the resilience of constructed facilities against disasters (e.g., typhoons, earthquakes).		✓
		Improved knowledge exchange	O8	Green building policies can promote the knowledge exchange of technical capabilities and border crossing between construction companies.	✓ (Moussa, 2019)	
		Revitalized industrialization	O9	When given adequate support, green innovation advances discoveries and educational values, bringing about innovative breakthroughs and revitalising industrialisation.	✓ (Ziogou et al., 2018)	

Table 2: Weaknesses and Threats stemming from the implementation of the green buildings policy.

Category	**Factor**	**Sub-factor**	**Code**	**Definition**	**Source of Identification**	
					Literature Review	**Experts**
Weaknesses	**Economic**	High initial cost	W1	Due to the installation of sustainable-based features within these buildings, the initial cost associated with completing such construction projects is mostly higher than traditional ones.	✓ (Macrae & Tozer, 2024)	
		High maintenance-related costs	W2	There are some sustainably built features for which relatively large expenses must be spent on their required maintenance (e.g., green roofs, green walls, etc.)		✓
	Technological	The need for skilled personnel	W3	The shortage of experts familiar with green building construction projects hampers the further adoption of such projects. Moreover, the lack of enough skilled labourers to accomplish the required installation is another stumbling block.	✓ (H. Wu et al., 2022; J. Wu & Ying, 2024b)	

		The need for up-to-date technology	W4	To be certified with the related green building rating tools, a building must be equipped with some green-oriented features (e.g., green walls, green roofs, solar panels, atriums, skylights, etc.). However, for such installations, there is a need for appropriate, advanced technologies currently available in the market.	✓ (Kaashi & Vilventhan, 2023)	
	Social	End users' resistance to taking up new technology	W5	There has always been resistance among people in society (particularly the elderly) to adopting new technologies, as they view them as expensive and not economically viable in the short term.	✓ (Cheshmehzangi et al., 2021)	
		Lack of end users' knowledge and awareness	W6	The end user of a building is usually the final decision-maker in adopting green building technology. Their lack of understanding of the perceived economic benefits of adopting new green building innovations constitutes a major obstacle.	✓ (Kurita et al., 2023)	
Threats	**Economic**	Lack of financial incentives	T1	The current financial incentives are mostly available for new construction, and there are no policies to support sustainable non-profit organisations.	✓ (Fredriksson et al., 2022)	
		Lack of sufficient data on lifecycle cost	T2	The impact of lifecycle cost in BEAM Plus implementation is not fixed but varies with different owners and company operating models. It is hard to determine and develop a policy to let the developers follow and complete the lifecycle cost.	✓ (Maqbool et al., 2023)	
	Governmental / Managerial	Conflicts between different stakeholders	T3	Close collaboration between multiple stakeholders involved in the development and operation of the building is required, including architects, engineers, and end users.	✓ (W. He et al., 2024)	
		Flawed bureaucratic administration	T4	Due to the complex and sophisticated bureaucratic administration, the law overshadowed the inclination towards constructing such projects.	✓ (Olanrewaju et al., 2022)	
		Flawed loan system	T5	The green loan from lenders, banks, and financial experts usually do not have sufficient knowledge and awareness of green buildings, which could hinder the green loan development in Hong Kong. Some interviewees mentioned that the construction industry	✓ (Loosemore et al., 2021)	

				should not interfere in the bank's decisions.		
		Lack of organisational or institutional leadership	T6	A few organisations or institutions seek to take the lead in establishing the green building industry.	✓ (Ikudayisi et al., 2023)	

Table 3: The details of the experts who participated in the interviews.

No. of Experts	Degree	Experience	Occupation
1	Bachelor of Engineering	5-10	Civil Engineering
2	Bachelor of Engineering	5-10	Architecture
3	Bachelor of Engineering	5-10	Architecture
4	Bachelor of Engineering	5-10	Facility Manager

1.5 Phase II: Selection of Experts

Phase II focused on the systematic selection of experts to evaluate the strengths, weaknesses, opportunities, and threats associated with implementing the Hong Kong Building Environmental Assessment Method (HKBEAM). Expert opinions were collected through a structured questionnaire survey and semi-structured interviews targeting professionals involved in green building policy and practice in Hong Kong. A total of forty-six experts participated in the questionnaire survey, and at least five experts were subsequently selected for in-depth interviews to support causal analysis using the DEMATEL technique. Experts were selected based on three criteria: (i) possession of a relevant undergraduate or higher degree in construction, engineering, or a green building–related discipline; (ii) professional experience or academic involvement in the construction industry; and (iii) demonstrated knowledge and experience in green building practices or policies. Only experts meeting all three criteria were included in the study to ensure the reliability and validity of the findings. The distribution of experts by job role, years of experience, education level, and highest degree obtained is presented in Figure 2(a–d).

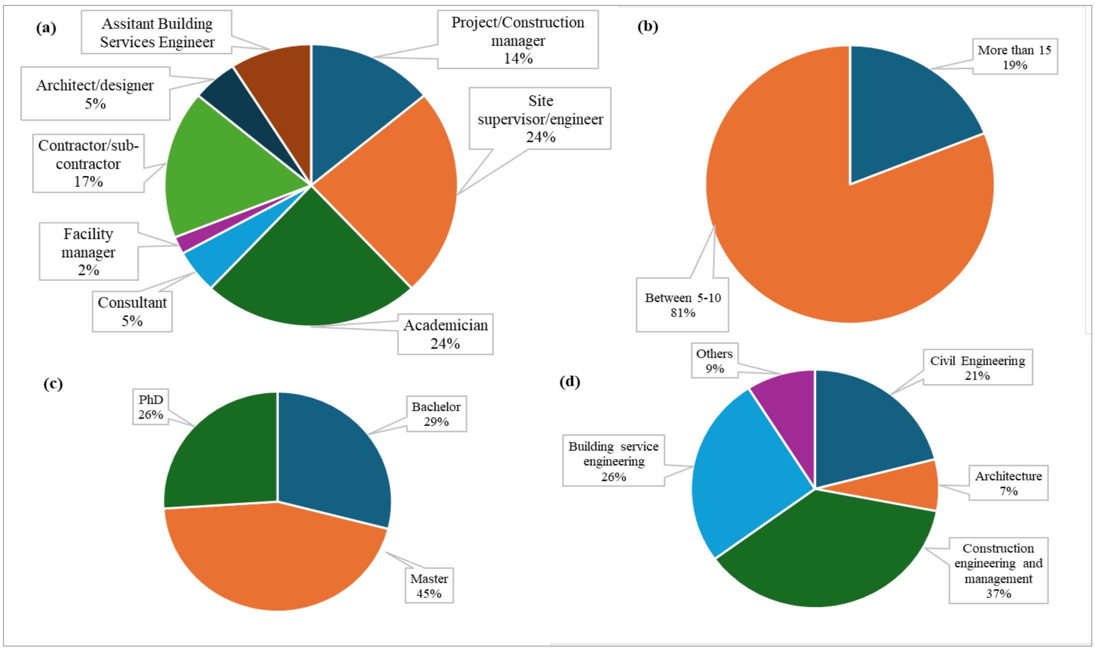

Figure 2: Demographic details of experts: (a) Job/Position of Experts; (b) Year of Experience of Experts; (c) Education Level of Experts and (d) Degree of Experts

According to the graph, most selected experts are academicians, site supervisors, or engineers. The education level of the selected experts is Master's. The year of experience of the selected experts is between 5 and 10 years. The selected exports mostly finished a degree in construction engineering and management.

1.6 Phase III: Fuzzy DEMATEL approach

The DEMATEL method works based on directed graphs (digraphs); it essentially separates the factors involved into two groups: cause and effect (Singh et al., 2023). Digraphs are more valuable than directionless graphs since they can indicate the directed relationships of sub-systems. A digraph normally depicts a communication network or some dominant relationships between individuals. It shows the contextual relationships amongst the elements existing within the system, where the numerical notions denote the influence strength (Lu et al., 2022). For that reason, DEMATEL can convert the relationships between the causes and effects of factors into an intelligible structural model of the system. When a decision is to be made, decision-makers normally judge based on their expertise and experience. Remember that in environments loaded with uncertainty, it is a demanding task to exactly evaluate the criteria for DEMATEL or any other decision-making method (Macrae and Tozer, 2024). To address such challenges, fuzzy sets have been proposed in the literature. The fuzzy-based DEMATEL method proposed in this study considers the subjectivity of the experts' responses in the evaluation and calculation processes.

<u>Step 1: Select a team of decision-makers with experience in research issues.</u>

This paper uses 15 lean construction professionals to form a committee to set the decision goal.

<u>Step 2: Determine factors and develop a fuzzy linguistic scale.</u>

A linguistic variable gets values defined by linguistic terms: F ̃ij=(l_ij,m_ij,u_ij) On X is a triangular fuzzy number (TFN) if its membership function μ_(N) ̃(X):X→[0,1] follows Eq.1.

$$\mu_{\tilde{N}}(x) = \begin{cases} 0, x < l \\ \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{r-x}{r-m}, & m \leq x \leq u \\ 0, & x > u \end{cases} \quad (1)$$

Here, this study uses five basic linguistic terms - "Very high," "High," "Low," "Very low," and "No" influence concerning a fuzzy level scale as in Table 4 to evaluate factors against each other.

Table 4. Linguistic scales and the corresponding triangular fuzzy numbers

Linguistic variables	Triangular Fuzzy Number (TFN)	Descriptions
No influence	(0, 0, 0.25)	A particular factor does not influence the other one being compared against
Very low influence	(0, 0.25, 0.5)	A particular factor has a very low influence on the other one being compared against
low influence	(0.25, 0.5, 0.75)	A particular factor has a low influence on the other one being compared against
High influence	(0.5, 0.75, 1)	A particular factor has a high influence on the other one being compared against
Very high influence	(0.75, 1, 1)	A particular factor has a very high influence on the other one being compared against

<u>Step 3: Determine assessments of the team of decision-makers</u>

Let i=1,2,3,...,n are n evaluation factors. The decision-makers are requested to compare factors in pairs to develop $\tilde{F}_{(1)}, \tilde{F}_{(2)}, \dots, \tilde{F}_{(n)}$. The initial direct relation fuzzy matrix $\tilde{F}_{ij}^{K}$ of each decision maker (K) can be defined following Eq. (2):

$$\tilde{F}_{ij}^{(K)} = \begin{bmatrix} 0 & \tilde{F}_{12}^{(K)} & \cdots & \tilde{F}_{1n}^{(K)} \\ \tilde{F}_{21}^{(K)} & 0 & \cdots & \tilde{F}_{2n}^{(K)} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{F}_{n1}^{(K)} & \tilde{F}_{n2}^{(K)} & \cdots & 0 \end{bmatrix} k = 1,2, \ldots P \qquad (2)$$

Where $\tilde{F}_{ij}^{(K)} = (l_{ij}^{(K)}, m_{ij}^{(K)}, u_{ij}^{(K)})$ represents the direct influence of the factor i on factor j.

Step 4: Normalise the direct–relation fuzzy matrix.

The $\tilde{a}_i^{(K)}$ and $S^{(k)}$ are the triangular fuzzy numbers as Eqs (3) and (4).

$$\tilde{a}_i^{(K)} = \sum \tilde{F}_{ij}^{(K)} = (\sum_{i=1}^{n} l_{ij}^{(K)}, \sum_{i=1}^{n} m_{ij}^{(K)}, \sum_{i=1}^{n} u_{ij}^{(K)}) \qquad (3)$$

$$S^{(\mathrm{K})} = max(\sum_{j=1}^{n} u_{ij}^{(\mathrm{k})}) \quad 1 \le i \le n$$

Additionally, to compare the criteria, the linear scale transformation is applied. Then, we obtain the normalised direct-relation fuzzy matrix as $\tilde{N}$(K).

$$\tilde{N}(\mathrm{K}) = \begin{bmatrix} \tilde{N}_{11}^{(K)} & \tilde{N}_{12}^{(K)} & \cdots & \tilde{N}_{1n}^{(K)} \\ \tilde{N}_{21}^{(K)} & \tilde{N}_{22}^{(K)} & \cdots & \tilde{N}_{2n}^{(K)} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{N}_{n1}^{(K)} & \tilde{N}_{n2}^{(K)} & \cdots & \tilde{N}_{nn}^{(K)} \end{bmatrix}; K = 1,2, \ldots, P \qquad (4)$$

Where $\tilde{N}_{ij}^{(K)} = (\widetilde{F}_{ij}^{(K)} / S^{(\mathrm{K})}) = ((l_{ij}^{(K)} / S^{(\mathrm{K})}, m_{ij}^{(K)} / S^{(\mathrm{K})}, u_{ij}^{(K)} / S^{(\mathrm{K})}))$.

We assume that there is at least one i such $\sum_{i=1}^{n} u_{ij}^{(K)} < S^{(\mathrm{K})}$. Eqs (6) and (7) are used to find the average matrix $\tilde{N}$.

$$\tilde{N} = (\widetilde{N}(1) \oplus \tilde{N}(2) \oplus \ldots \tilde{N}(\mathrm{p}))/P \qquad (6)$$

$$\tilde{N}(\mathrm{K}) = \begin{bmatrix} \tilde{N}_{11} & \tilde{N}_{12} & \cdots & \tilde{N}_{1n} \\ \tilde{N}_{21} & \tilde{N}_{22} & \cdots & \tilde{N}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{N}_{n1} & \tilde{N}_{n2} & \cdots & \tilde{N}_{nn} \end{bmatrix} \qquad (7)$$

Where $\tilde{N}_{ij} = (\sum_{k=1}^{P} \tilde{N}_{ij}^{(K)} / P)$.

Step 5: Produce and analyse the structural model

The total relation T can be achieved after normalising the direct-relation matrix. The total-relation fuzzy matrix is shown as Eqs (8), (9), and (10).

$$\tilde{\boldsymbol{T}} = \lim_{V \to \infty} (\tilde{X}^1 + \tilde{\boldsymbol{X}}^2 + \cdots + \tilde{X}^V) \qquad (8)$$

$$\tilde{\boldsymbol{T}} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \tilde{t}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \tilde{t}_{nn} \end{bmatrix} \qquad (9)$$

Where $\tilde{\boldsymbol{t}} = (l_{ij}^{"}, m_{ij}^{"}, u_{ij}^{"})$

Matrix $[l_{ij}^{"}] = X_l \times (1 - X_l)^{-1} \qquad (10)$

Matrix $\left[m_{ij}^{''}\right] = X_m \times (1 - X_m)^{-1}$
Matrix $\left[u_{ij}^{''}\right] = X_u \times (1 - X_u)^{-1}$

<u>Step 6: Produce a causal diagram</u>

The sum of rows and columns is stamped as vectors $\tilde{R}$ and $\tilde{C}$, respectively. The horizontal axis vector $(\widetilde{R} + \widetilde{C})$ called "Prominence" is obtained by adding $\tilde{R}$ to $\tilde{C}$, which determines the factor's importance. We transform the fuzzy number of vectors $\tilde{R}$ into crisp values by applying Eq. (11). The defuzzification step is crucial to defuzzify TFNs into a crisp value. Previous studies utilised various defuzzification techniques, such as the centroid technique [73], graded mean integration representation (GMIR) [74], and integral division [75]. In this study, GMIR, which has the advantage of avoiding a zero in the denominator, is used to formulate the defuzzification.

$$\boldsymbol{Z_k}^{\text{def}} = \frac{\boldsymbol{l+4\times m+U}}{\boldsymbol{6}} \qquad (11)$$

Likewise, the vertical axis $(\widetilde{R} - \widetilde{C})$, "Relation" is calculated by subtracting $\tilde{R}$ from $\tilde{C}$ This involves categorising the criteria into cause-and-effect sets. When $(\widetilde{R} - \widetilde{C})$ it is positive, the criterion is a cause one. When $(\widetilde{R} - \widetilde{C})$it is negative, the criterion is the effect factor. Therefore, the causal model is drawn by mapping the set of $(\widetilde{R} + \widetilde{C}\,, \tilde{R} - \widetilde{C}\,)$.

1.7 Phase IV: Interview for validation

We also validated the results of the influencing factors obtained from the questionnaire through interviews. Interviews were conducted with five respondents, mainly based on individual and focus group discussions. Each interview lasted approximately 30-45 minutes. The interviewees were all bachelor's degree holders or above with green building-related experience to ensure they had a basic knowledge of green building-related policies and to guarantee the rationality of the evaluations and recommendations. Two core questions were used to conduct the interviews: their evaluation of the questionnaire results and their suggestions on improving the influential factors presented to them.

Results

Table 5 presents the computed metrics for the Prominence and Relation of sub-factors within the groups Strengths, Opportunities, Weaknesses, and Threats. Examining the sub-factors within the Strengths (S) category reveals notable findings. Sub-factor S3 is a significant cause factor with a D-R value of -2.714, indicating a pronounced influence on the overall Analysis. In Opportunities (O), sub-factor O1 demonstrates substantial prominence with a D+R of 2.351, emphasising its positive impact. Conversely, in the Weaknesses (W) group, sub-factor W3 emerges as a prominent cause factor, as evidenced by a D-R value of -1.686. Within the Threats (T) category, sub-factor T4 exhibits a strong overall impact with a D+R of 3.009. These detailed insights into specific sub-factors within each category enhance the precision of the Analysis, enabling a more nuanced understanding of the strengths, opportunities, weaknesses, and threats inherent in the subject under study.

Table 5: Prominence and relation of the sub-factors.

Groups	Sub-factors	D	R	D+R	D-R
Strengths	S1	1.484	1.255	2.739	0.229
	S2	1.243	1.172	2.415	0.071
	S3	0.007	2.721	2.728	-2.714
	S4	1.703	0.006	1.709	1.697
	S5	1.123	0.131	1.254	0.992
	S6	0.005	0.886	0.891	-0.881
	S7	2.684	0.002	2.686	2.682
	S8	0.008	1.356	1.364	-1.348
	S9	2.489	0.003	2.492	2.486
	S10	0.004	1.465	1.469	-1.461
Opportunities	O1	1.751	0.6	2.351	1.151
	O2	0.008	0.963	0.971	-0.955
	O3	0.006	1.288	1.294	-1.282
	O4	0.003	0.201	0.204	-0.198
	O5	1.617	0.002	1.619	1.615
	O6	1.004	0.007	1.011	0.997
	O7	1.274	0.004	1.278	1.27
	O8	0.003	0.861	0.864	-0.858
	O9	1.619	0.008	1.627	1.611
Weaknesses	W1	1.54	0.203	1.743	1.337
	W2	0.146	0.637	0.783	-0.491
	W3	0.247	1.933	2.18	-1.686
	W4	0.785	0.008	0.793	0.777
	W5	0.003	1.647	1.65	-1.644
	W6	2.774	0.002	2.776	2.772
Threats	T1	2.33	0.002	2.332	2.328
	T2	0.003	1.834	1.837	-1.831
	T3	1.716	0.006	1.722	1.71
	T4	3.006	0.003	3.009	3.003
	T5	0.003	1.943	1.946	-1.94
	T6	0.007	0.946	0.953	-0.939

Figure 3 and Figure 4 present causal diagram matrices based on the values from Table 5, illustrating the influential sub-factors within the Strengths (S) and Opportunities (O) groups. Figure 3 (A) depicts the Economic dimension for the Strengths group, highlighting S3 as a key causal factor. Figure 3(B) represents the social dimension, emphasising S6, while Figure 3(C) illustrates the Environmental dimension, focusing on S8 and S10 as significant cause factors. Transitioning to Figure 4 reveals causal diagram matrices for the Opportunities group across the Economic (4A), Environmental (4B), and Technological (4C) dimensions. In the Economic dimension (4A), O2 and O3 are identified as influential cause factors. The Environmental dimension (4B) underscores O4, while the Technological dimension (4C) emphasises O8. These visual representations offer a clear overview of the causal relationships among sub-factors, facilitating a nuanced understanding of their influences within the Strategic Analysis.

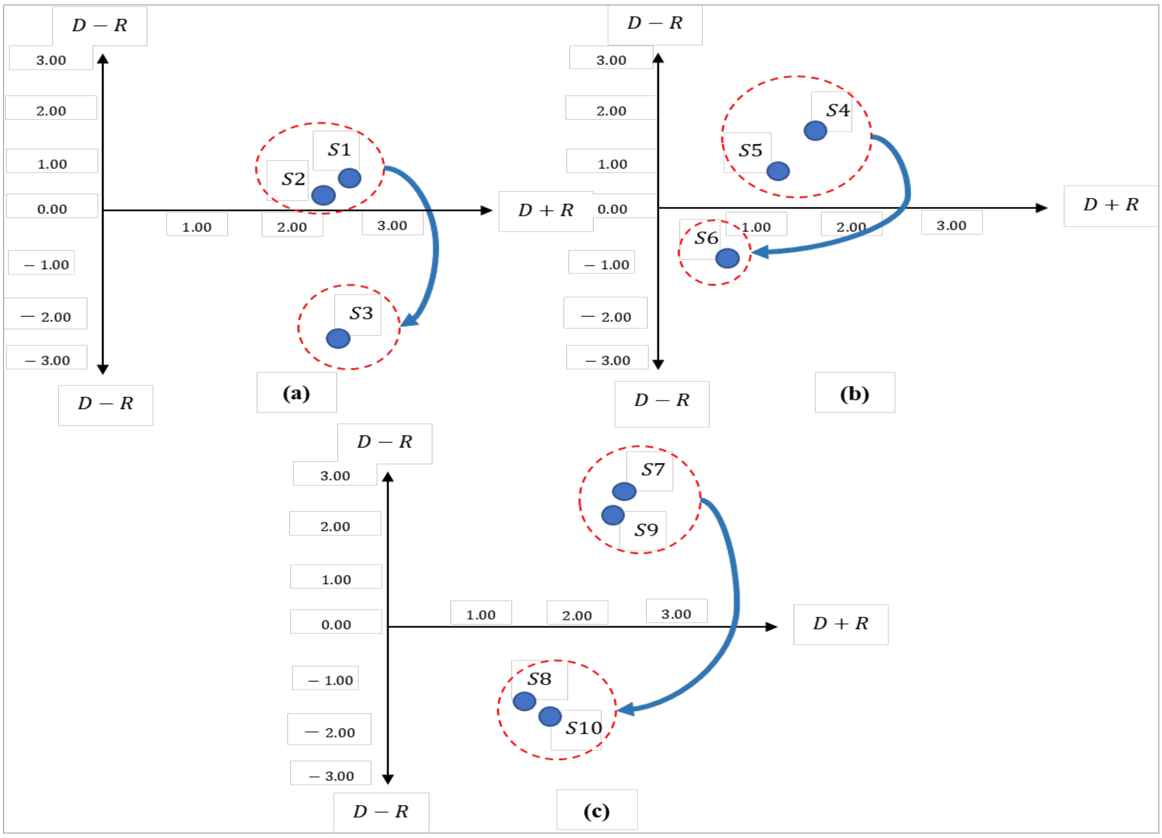

Figure 3: Casual diagram for Strengths group: (a) Economic, (b) Social, (c) Environmental.

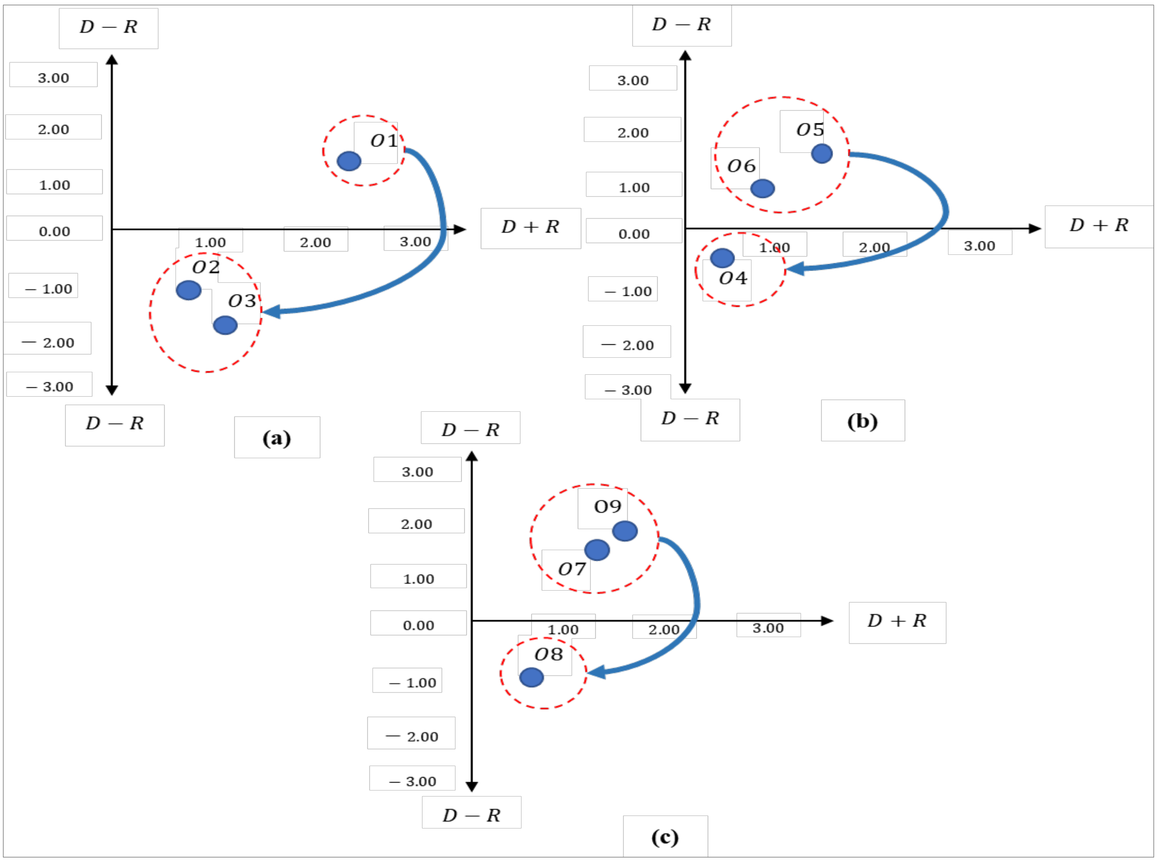

Figure 4: Casual diagram for Opportunities group: (a) Economic, (b) Environmental, (c) Technological.

Figure 5 and Figure 6 present causal diagram matrices for the influential sub-factors within the Weaknesses (W) and Threats (T) groups, respectively, derived from the values in Table 5. Figure 5 (A) represents the economic dimension of the weaknesses group, highlighting W2 as a significant causal factor. Figure 5(B) focuses on the Technological dimension, emphasising W3, while Figure 5(C) illustrates the Social dimension, with W5 identified as a notable cause factor. Figure 6 reveals the causal diagram matrices for the Threats group, covering the Economic (6A) and Governmental/Managerial (6B) dimensions. In the Economic dimension (6A), T2 is a noteworthy causal factor. Figure 6(B) emphasises the Governmental/Managerial dimension, highlighting T5 and T6 as influential cause factors. These causal diagrams visually represent the interrelationships among sub-factors, offering valuable insights for strategic analysis.

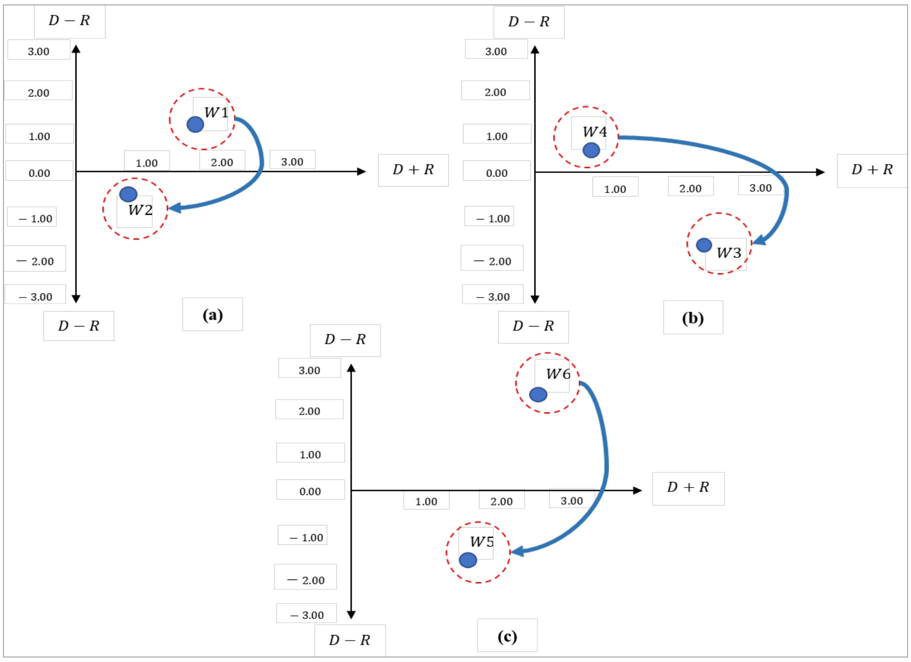

Figure 5: Casual diagram for Weaknesses group: (a) Economic, (b) Technological, (c) Social.

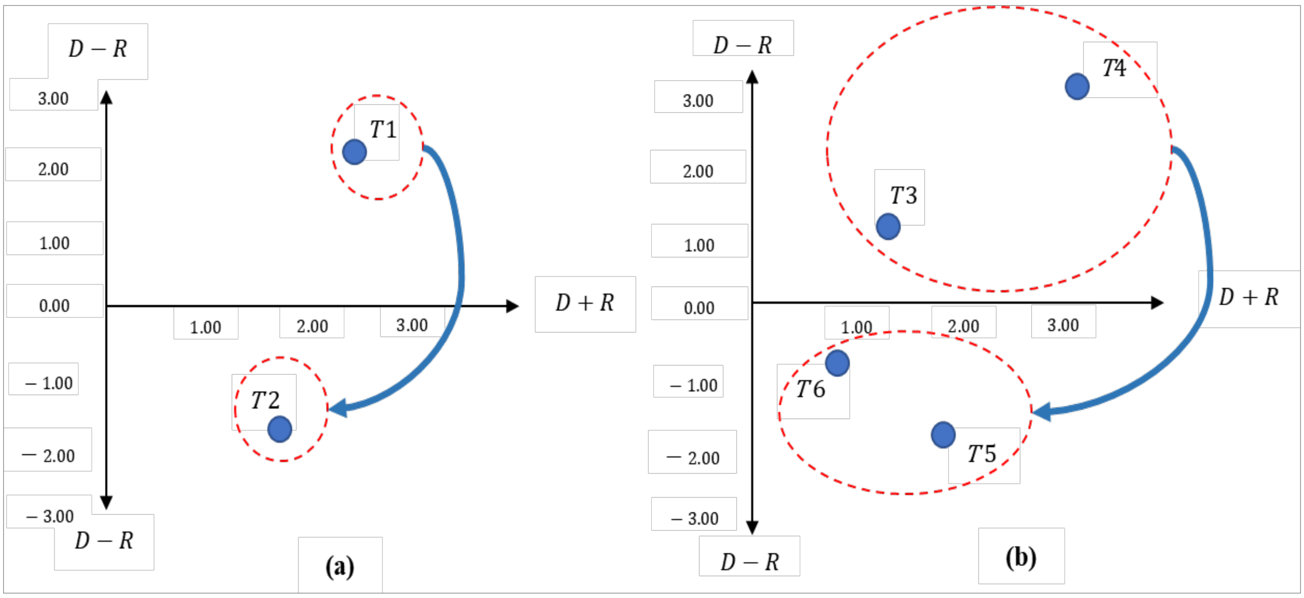

Figure 6: Casual diagram for Threats group: (a) Economic, (b) Governmental/Managerial.

1.8 Validation of recommendations by experts

Table 6 provides valuable suggestions for enhancing the factors influencing green building development. Noteworthy recommendations include raising stakeholder awareness, introducing additional financial incentives, and providing social benefits to foster long-term sustainability. The table suggests practical measures, such as tax rebates for green technology users, specific training for architects, and incorporating environmental analysis in various stages of construction. Additionally, it emphasises the importance of government support, subsidies for green-certified buildings, and improvements to laws and regulations. These suggestions collectively aim to promote the broader acceptance and implementation of green building practices in Hong Kong through a multifaceted approach involving stakeholders, government policies, and industry practices.

Table 6: Suggestions for improvement of the influencing factors.

Code	Suggestions for further improvement
SG1	It is necessary to raise awareness among stakeholders, such as property developers, that, in the long run, it can contribute to developing a green economy.
SG2	The Government can introduce more financial incentives.
SG3	Some social benefits should be given to stakeholders to enhance the long-term and sustainable development of green buildings in Hong Kong (policy incentives)
SG4	Offer tax rebates to users of green technology at the design stage.
SG5	It is useful to provide specific training for architects to enhance their knowledge and proficiency, to broaden the acceptability of green buildings.
SG6	Adding engineers or training existing engineers in relevant fields is to improve the current relevant standards.
SG7	The governors should provide more institutional support.
SG8	The Government needs to subsidise the company (or have more GFA concession) for the company when the green-certified building is intended to be achieved.
SG9	The company can implement energy analysis via a parametric platform in the pre-design stage.
SG10	In the design stage, the company can implement BIM-based environmental Analysis, including energy, water, and waste.
SG11	The company can apply sustainable construction practices, including waste minimisation in the construction stage.
SG12	In the operation stage, the company should be forced to implement BIM-based FM, operation analysis, and management.
SG13	Improve laws and regulations to ensure the development of green buildings.
SG14	The Government can promote people's understanding of green building policy through workshops, seminars, and other publicity.
SG15	The media can publicise the green building policy through certain publicity channels.
SG16	Make clear the cash flow of green buildings in the life cycle.
SG17	Shaping the research environment and promoting the academic exchange of scholars on green building.
SG18	Institutions should have a clear framework for better implementation of green building policies.

Figure 7 visually represents suggestions and their corresponding ranks, focusing on SG9, SG6, and SG17. These specific suggestions hold prominence in the context of the green building analysis. The figure likely displays a comparative ranking, illustrating each suggestion's perceived importance or effectiveness. SG9, emphasising energy analysis in the pre-design stage via a parametric platform; SG6, focusing on incorporating engineers or training existing engineers to improve relevant standards; and SG17, advocating for the academic exchange of scholars on green building, are likely to be highlighted due to their significant impact or potential for positively influencing the green building development process. The figure serves as a concise and visual means of conveying the relative importance of these specific suggestions within the broader set of recommendations.

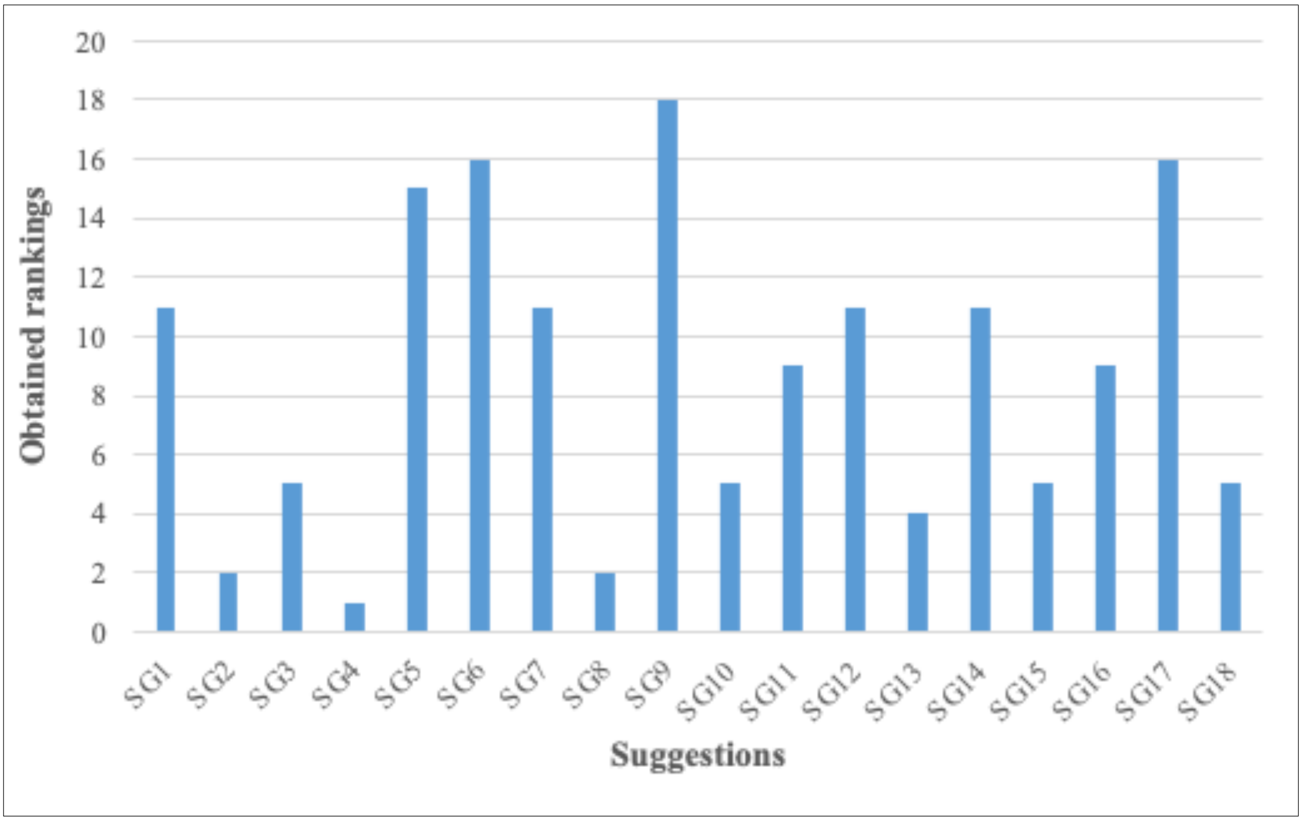

Figure 7: Suggestions and their ranks.

2 Discussion

2.1 The influential sub-factors S&W&O&T

Figure 4(a) shows that the profitability of the property market value or rentals impacts the financial benefits of ecological sustainability for firms. First, property market value and financial stability can influence ecologically based buildings. Various types of environmentally friendly materials are used in ecologically oriented buildings. Compared to traditional materials, green resources will have more consistent pricing. Using green materials has advantages for ecologically based buildings. Green building materials can also lengthen a structure's lifespan. It lowers operating expenses, including maintenance costs (Darko, Chan, Gyamfi, et al., 2017). Additionally, employing green products might improve the working atmosphere. It offers the workers a healthy way of living. The market value of the property will also have an impact on ecologically based buildings. The green building's features, like its ability to save energy and water, determine the rent amount and property value. A sufficiently high level of sustainability will raise both the rent and the property's value (L. Chen et al., 2021).

Figure 3(b) shows that inhabitants' psychological well-being and comfort levels impact the elements that improve ascetical attractiveness. Green buildings can improve the tenants' quality of life. Additionally, it improves the environment for the occupants. The atmosphere of the green building will then make the people feel at ease (Wolfe & Hendriks, 2011). The ascetic appeal will be impacted by the surroundings, which include green structures. It's because the surroundings make the occupants feel happy. Additionally, their psychological well-being will improve if inhabitants feel at peace in a green building environment. The residents may have a stunning outlook thanks to the green building structure (Mishra et al., 2023). Additionally, passersby may be drawn in by the green building's unique design. When people live in a pleasant setting, they are content and happy. It would draw the interest of various passersby as well. Figure 3(c) shows that the reduction in energy and natural resource use has impacted noise reduction and waterway pollution reduction. Water consumption is part of reducing the use of natural resources (Devine & McCollum, 2019). It is set up with 50% more water recycled and closed-cycle water. Furthermore, recycling water use helps keep toxins out of rivers. Additionally, eco-friendly structures might use less energy (Simpeh & Smallwood, 2020).

Moreover, ecological buildings can be created by utilising natural resources. For instance, ecological buildings are constructed using recycled wood from existing structures. Secondly, the positioning of environmentally friendly structures stops water contamination from spreading. Conversely, the calibre of the materials will depend on the calibre of the natural resources. For instance, utilising natural resources to produce components on a green basis. Using environmentally friendly materials can decrease the building's noise level (Chen et al., 2023). Additionally, energy will be required to run the eco-friendly components. With the usage of green construction components, energy consumption can be decreased. The GDP has been impacted by reducing carbon taxes and creating jobs, as shown in Figure 4(a). A nation's GDP can impact carbon taxes and the generation of jobs. For instance, rising GDP increases people's access to employment options (Teng et al., 2023).

Additionally, green building initiatives are receiving money from consumers. Customers are eager to create or invest in green building projects if the GDP is high enough. Subsequently, employment prospects related to green building initiatives will increase. Furthermore, a rise in GDP may result in lower carbon levies. Green buildings, for instance, can save consumers' energy costs and lower their carbon footprint. Customers are then prepared to contribute to green construction projects (Joyram et al., 2022)Regarding Figure 4(b), we found that utilising sustainable features in buildings can reduce energy consumption and the generation of pollutants and waste that are hazardous to the environment and public health due to energy use and transmission. In the meantime, a construction project's ability to employ renewable energy is influenced by better site selection and construction design. Harmful chemicals are produced at lower rates during building, operation, and maintenance when less energy is consumed (Pattinson et al., 2023). Utilising renewable resources contributes to the building's sustainability, lowers the use of toxic materials and natural resources, enhances human well-being, and safeguards the environment. Furthermore, contracting for sustainability in buildings entails employing ecologically friendly materials or construction techniques, which lowers the demand for natural resources. The development of natural resources is substantially prevented, the possibility of overexploitation is minimised, and the natural balance is preserved, regardless of the demand for resources during construction or the demand for resources in the future, such as maintenance (Carolyn et al., 2019).

First, as shown in Figure 4(c), enhancing the resilience of built-in facilities can lessen the harm that unexpected natural disasters do to structures, safeguarding the lives of occupants and the security of the property. Building companies can accomplish long-term development and corporate social responsibility in this way. Since every construction business specialises in a different technology, this will encourage enterprises to share technology or knowledge and even collaborate, leading to win-win outcomes (S. Chen & Gou, 2023). Second, the match between raw and building materials is one of the technologies needed for green innovation in the construction sector. This will support and realise industrialisation, diversification, and revitalisation. Since all building links are interconnected, each industry sector must improve communication and connections to guarantee the creation of green building policies (Waqar et al., 2023).

As seen in Figure 5(a), green designs and the use of renewable energy in construction are necessary for green buildings to meet sustainable development criteria. The lack of maturity and comprehensiveness in the demand for and marketing of green technology and materials necessitates greater expenses. The corporation and the buyer are accountable for the building's stability and robustness. Because of the current building's green features, better upkeep will be needed, increasing the necessary cost (W. He et al., 2024). About Figure 5(b), we discovered that for a structure to be certified by green building grading tools, it must have certain environmentally friendly features, like installing green walls and other materials. But the market for developing green technology and materials is still very young and expensive, so many businesses either give up on getting certified or opt to use products or techniques that don't significantly affect the building as a whole or that other businesses have already started using, like solar panels and skylights. Because of this, there is a stable or even declining market need for professionals in this field, which has resulted in a lack of growth in the number of specialists (Chan et al., 2018; Darko et al., 2018).

See Figure 5(c) to illustrate how the absence of financial incentives will impact the green building policy's cost statistics. Green building generally refers to more sophisticated technology, the requirement to purchase more eco-friendly materials, and eco-friendly design principles. As a result, green buildings are frequently more expensive than traditional buildings, which is why many businesses are reluctant to use them (Shirish & Kakati, 2024). As a result, many nations and areas will accept specific subsidies for environmentally friendly structures. Developers will conceal their financial information to make their projects appear better if there is no financial incentive for green buildings and they are not forced to adopt them. Certain facts will cause the disclosure of green building costs to be less accurate and will not properly disclose pertinent cost information (X. Li et al., 2022).

The end consumers resist adopting new technology, as shown in Figure 6(a). Green buildings will cost more than conventional structures because they use new technologies, purchase green building materials, and employ new designs, which are often more expensive. People are society's primary consumers of green buildings and will take the test to determine which buildings to utilise (Darko, Chan, Ameyaw, et al., 2017b). When it comes to the cost, most people consider the upfront costs and ignore the long-term financial and environmental advantages of green buildings. Because of this mindset, end users will constantly subtly oppose green buildings, making it impossible for them to reap other benefits (Lei et al., 2023).

As shown in Figure 6(b), issues arise from flaws in the bureaucratic management system and stakeholder conflicts. First of all, the primary interests of various stakeholders vary. The rise of the green building industry will influence the traditional construction sector, and some traditional construction companies may not be ready to bear the increased costs. As a result, they may clash with the green building sector and disseminate information about it. The integration of the construction sector will hinder the adoption of green building practices and cause the industry's growth to progress sluggishly (He et al., 2024). In addition to the poor administration of the Government, some government officials are bribed by traditional construction businesses. This would impede the development of green buildings and consequently result in a lack of institutional leadership and efficient organisation. It will also result in a flawed loan system. The field of green building is new. Many banks and financial specialists do not understand the cost of green buildings. They'll consider how much standard buildings cost. As a result, the benefits of lending green buildings cannot be realised (Du et al., 2023). The findings of this study provide actionable insights for industry practitioners to enhance the adoption of green buildings. By identifying key economic, social, technological, environmental, and managerial factors, practitioners can prioritise interventions such as financial incentives, regulatory compliance, and the integration of sustainable technologies like BIM-based environmental analysis. Developers and construction firms can leverage the identified strengths and opportunities to design cost-effective, sustainable projects while mitigating weaknesses and threats, including bureaucratic inefficiencies, high upfront costs, and end-user resistance. The study's results can also inform the development of an implementation framework, guiding stakeholders to strategically align policy incentives, resource allocation, and stakeholder engagement to achieve long-term sustainability and improved performance in green building projects.

2.2 Recommendations by experts

The first suggestion, as shown in Figure 7, is to "Offer tax rebates to users of green technology at the design stage." "The government can introduce more financial incentives" is the second recommendation. When the goal of a green-certified building is realised, the Government must support the business (or grant it extra GFA concessions). All these recommendations constitute measures that provide incentives for green buildings to encourage green building practices (Poshnath et al., 2023).

A key component of encouraging the construction of green buildings is the creation of strong incentive programs. Improving the different tax and fiscal stimulus programs is vital. The Government should create an incentive mechanism that combines market and financial incentives, develop a series of incentive policies tailored to unique circumstances, and bolster the enthusiasm of associated industries, businesses, and consumers by drawing on the experience of Western developed countries. Adopt incentive programs, including tax breaks, low-interest loans, and economic subsidies, to encourage the development of green buildings (Darko & Chan, 2018). Establish specific policy preferences for consumers and investors in construction that satisfy the green building criteria. Tax relief is the most suitable approach of the three incentive strategies mentioned above. Most lending institutions are financial institutions, and banks constitute the majority of low-interest loan providers. They may be able to obtain loans since they are not well-versed in the state of green buildings and do not know how much of a discount should be offered to green building enterprises. Variations are inevitable, and economic subsidies are more intricate (Motamedpooya et al., 2023). Determining the number of subsidies is more challenging, and corruption issues can arise. Certain corporations that express interest will receive additional tax breaks and subsidies from certain officials. The building's size and the applicable percentage of the tax reduction or exemption are typically considered when determining the amount of the reduction or exemption. The human element is minimal and comparatively objective. As such, it is the most straightforward and efficient method for implementing tax exemptions or reductions for green construction developers (Juan & Lee, 2022).

The recommendation to "Improve laws and regulations to ensure the development of green buildings" is placed fourth in Figure 7. The laws and regulations play a significant role in the green building sector. First, when designing green buildings, stakeholders may be guided by regulations and standards. The stakeholders can better understand the green building industry. Stakeholders will be aware of what they can and cannot do, for instance, in the green building project. Stakeholders must account for potential risks when designing a green building. When establishing green buildings, laws and regulations can safeguard the local natural environment and ensure the population's safety (Essuman-Quainoo & Jim, 2023). Additionally, it can improve the green building's performance and provide its occupants with a better living environment.

A couple of recommendations have been ranked as rank 5 in Figure 7, specifically 'In the design stage, the company can implement BIM-based environmental analysis including energy, water, and waste' and 'Some social benefits should be given to stakeholders to enhance the long-term and sustainable development of green buildings (policy incentives).' Initially, most experts recommended that the policy on green buildings incorporate social benefits to encourage the development of green buildings among stakeholders. For instance, if the Government develops long-term, sustainable green buildings, it can enact specific laws and offer social advantages to the stakeholders (Yang et al., 2021). The social benefit may take the form of land support provided to stakeholders or financial support for the construction project, thereby attracting stakeholders and enhancing the long-term, sustainable development of green buildings. Secondly, the business might consider integrating the BIM-based environmental analysis of energy, water, and waste components. The designer and other stakeholders can gain insight into the green building's structure through BIM-based environmental analysis (Qin et al., 2022). Additionally, it illustrates how green buildings work in terms of waste management, water control, and energy efficiency. It improves the green building's architecture and provides a clear view of the structure based on the green building.

Concerning Figure 7, the two suggestions ranked fifth were "Institutions should have a clear framework for better implementation of green building policies" and "The media can publicise the green building policy through certain publicity channels." It must be acknowledged that, although they may not be as alluring as monetary rewards for shareholder participation, they are among the most effective. Limited opportunities or information on green building policies are available to many industry stakeholders. Therefore, for the public to understand green buildings and their regulations, they must be informed about the current state of the environment and policies regarding green construction through the media channels (Santana et al., 2023b). Second, for the relevant institutions, a clear framework for green building policy is required to engage stakeholders and facilitate effective, sustained implementation. Many individuals have an innate tendency to wait and see when it comes to new ideas, and it might not be easy to reference them without a clear framework. To be understood and referred to by a larger audience, a green construction strategy can only be stated in a fundamentally clear framework (Darko & Chan, 2016). This strategy can potentially disseminate information and gain favour among more people for green buildings.

2.3 Implication

Theoretical Implications

This study contributes to the academic literature by advancing the application of SWOT analysis in the context of green building policy evaluation. The findings identify five key dimensions: economic, social, technological, governmental/managerial, and environmental that collectively shape green building policy effectiveness. Notably, the results demonstrate that these factors and their subcomponents are interdependent rather than independent, underscoring the need for integrated, systemic analytical approaches when assessing green building policies. By revealing the interactions among SWOT elements, this research enriches the theoretical understanding of policy-driven sustainability frameworks in the built environment.

Practical Implications

From a practical perspective, the findings provide actionable insights for policymakers and industry practitioners involved in green building development. Experts emphasised that financial incentives, such as tax rebates and gross floor area (GFA) concessions, can significantly encourage the adoption of green buildings. Additionally, strengthening laws and regulatory frameworks is essential to ensure consistent and effective implementation of green building policies. The results also suggest that governments can enhance stakeholder engagement by offering social benefits and actively promoting green building policies through public communication channels, thereby improving awareness and acceptance among developers and residents.

3 Conclusions

This study provides a comprehensive evaluation of green building policy by integrating SWOT analysis with a fuzzy DEMATEL approach, offering a structured understanding of the strengths, weaknesses, opportunities, and threats influencing policy implementation. The findings reveal that factors such as improved resident comfort, enhanced GDP, limited end-user knowledge and awareness, and bureaucratic inefficiencies significantly shape the landscape of green building adoption. Validation of results and formulation of recommendations were conducted through interviews with experienced experts, leading to the identification of tax rebates, financial incentives, and subsidies as paramount strategies for fostering sustainability. Methodologically, the integration of SWOT and fuzzy DEMATEL represents a key theoretical contribution, as it enables the analysis of causal relationships under uncertainty, thereby advancing decision-support tools in sustainable construction research. From a practical perspective, the study provides actionable guidance for policymakers and industry stakeholders, offering insights into priority strategies to promote sustainability and improve green building policy. Although the empirical analysis focuses on Hong Kong, the identified challenges, such as cost barriers, policy coordination, stakeholder awareness, and bureaucratic inefficiencies, are common across many developing and rapidly urbanising regions, making the results broadly relevant.

Despite these contributions, the study has several limitations. First, the expert sample is small and primarily comprises professionals and scholars based in Hong Kong, which may limit the generalisability of the findings to other regions. Second, reliance on expert judgment via questionnaires and interviews introduces subjectivity inherent to qualitative and semi-quantitative evaluation methods. Third, data collection was constrained to a single assessment framework (HKBEAM), which may not capture variations in green building standards across different regions. Future research could address these limitations by expanding the sample, incorporating experts from multiple countries, integrating quantitative performance data, and comparing various green building rating systems to enhance robustness and transferability.

Funding

No external funding was received for this study.

Ethical Approval Declaration

The study was conducted in accordance with established standards for research integrity and ethics.

Informed Consent Statement

All participants provided informed consent before participating in the study.

Data Availability Statement

Data can be made available upon request to the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.

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