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A STUDY ON THE DEVELOPMENT PROSPECTS OF GREEN AND LOW-CARBON CONSTRUCTION: EVIDENCE FROM CHONGQING, CHINA

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Background: With the fast expansion of the social economy and construction industry, environmental pollution, ecological deterioration, and other challenges are becoming more and more serious. The construction industry is a significant contributor to environmental pollution, generating 40% of total solid waste in developed countries and accounting for 30% of global greenhouse gas emissions. Eco-friendly measures must be adopted to design and create environmentally responsible buildings that consume fewer resources throughout their existence. Green construction technologies may be used as an effective technique for implementing sustainability in the construction sector. This growing emphasis on carbon reduction may explain the heightened public awareness and interest in the development of low-carbon buildings. **Objectives:** The objective of this study is to investigate the benefits and application of green and low-carbon technology in developing countries such as China (Chongqing), where construction activities are primarily performed by Chinese companies and Chinese stakeholders. Our primary target is to find sustainable factors that encourages public to employ green and low-carbon building technologies. Considering above facts, the proposed study attempts to provide answers to the following questions: which enablers and challenges contribute to the adoption of green and low-carbon building technology; how to assess sustainable green and low-carbon building technology enablers under data uncertainty; how to find an interdependent relationship among the enablers. **Methods:** A systematic literature review (SLR) offers an overview of the research's scope. In total twenty-eight drivers and fifteen challenges of green and low-carbon building technology and sustainable construction were reported from 91 selected articles, and research questions were assessed and evaluated. Following that, primary data was collected through a two-step process involving a questionnaire survey (analysed using statistical software,) and factor analysis. The sample was collected from registered building companies listed in China's Ministry of Housing (Chongqing). The company's sample size in this study was 100 construction companies out of 400 chosen and 300 contacted persons, consists of professionals who are involve Engineers, truction as stakeholder, Project Managers, Architects, Civil Engineers and local literate people in these companies. Carbon emission values for each category of construction machinery were calculated using a standardized emission factor approach. **Results:** In total, 27 key enablers were identified through literature review and added to questionnaire to monitor the public response. The highest level of agreement, 40.96%, was recorded for "Optimization in energy and construction materials" (E18), indicating strong support for the incorporation and optimization of energy in construction materials. E18 reflects the most appropriate, sustainable, affordable, and trendy option to achieve green construction that offers little or no repercussions making it most voted enabler. Following E18, the factors representing the most valued enablers are "Enhance return on investment" (E25), "Improve safety and health" (E19), and "Environmentally friendly" (E17), with percentages of 39.36%, 39.10%, and 39.89%, respectively. The major challenges were mentioned as "affordability" and "lack of public demand" for green and smart buildings that produced same value of 38.30% highly agreed response. "Lack of knowledge and understanding" of green and low-carbon construction practices also marked as significant challenge with voted value 36.17% strongly agreed response, expressed a relatively low degree of disagreement. Mixed opinions were expressed regarding the "lack of client awareness". The most significant is Tire loader from Shovel and horizontal transport machinery carbon emitting 245.60 Kg/work, Self-raising tower crane from Hoisting and vertical lifting machinery emitting 201.32 Kg/work and grader from Compaction and pavement equipment with total emission 142.75 Kg/work. There is a scarcity of data on the carbon emissions of nonroad construction equipment and the relevant carbon emissions factors of the equipment. **Conclusion:** Government support, including building regulations, planning policies, and financial incentives such as subsidies and tax breaks was found to be a primary enabler, while limited stakeholder awareness and low market demand were major barriers. The study contributes new scientific knowledge by revealing nuanced interactions between enablers and challenges that previous research had not fully explored, particularly in the context of urban construction landscape of the study area.

Keywords: green technologies; low-carbon building; construction material optimization; carbon emissions; sustainability; energy optimization; SDG 13; SDG 11.

INTRODUCTION

With the fast expansion of the social economy and construction industry, environmental pollution, ecological deterioration, and other challenges are becoming more and more serious (Maury-Ramírez et al., 2022). Global industrialization and urbanization have consumed vast amounts of non-renewable energy while emitting enormous quantities of greenhouse gases, resulting in an increase in global temperature and creating several environmental problems. According to Allison (2023), the global construction industry is responsible for significant resource consumption, utilizing 30% of the world's resources, 15% of freshwater, and a quarter of all timber resources. The construction industry is a significant contributor to environmental pollution, generating 40% of total solid waste in developed countries (Datta et al., 2023; Salam et al., 2022), and accounting for 30% of global greenhouse gas emissions (Liu et al., 2023; Salam et al., 2021b). Carbon emission is the most challenging aspect in building construction due to difficulty to define single emission source (Hong et al., 2015). In addition to construction and operating emissions, the production of building components and materials also significantly adds to overall carbon emissions (Chen et al., 2023). It was noted that future climate change and its repercussions will include an increase in global temperature, extreme weather, the degradation of marine and terrestrial ecosystems, a rise in sea level, biodiversity loss, and the extinction of certain species if the effective methods are not implemented to limit or reduce carbon emissions (Singh & Singh, 2012). Carbon dioxide is the most prevalent greenhouse gas and has a major environmental effect. Past researches concluded that by 2050, carbon dioxide emitted by utilizing non-renewable energy sources, will have increased by approximately 50% (de Souza Mendonça et al., 2020; Noor et al., 2025).

Eco-friendly measures must be adopted to design and create environmentally responsible buildings that consume fewer resources throughout their existence. As a result, in recent decades, the construction industry, which is a major emitter of carbon dioxide, has focused more on green construction and sustainable materials.

Furthermore, the most recent Intergovernmental Panel on Climate Change assessment confirms that limiting climate change to 1.5 degrees, agreeing to peak carbon dioxide emissions by 2030, and striving for carbon neutrality by 2060 are all critical to meeting these targets (Liu et al., 2023; Alam et al., 2025b). Direct emissions through building operations are relatively small compared to other sectors and are estimated at 5% of global greenhouse gas emissions, but this number increases to 17% when accounting for indirect emissions from electricity and heat consumption (Baptista et al., 2022). China, recognized at the top of the list among the major seven carbon emitters in the world with increased emissions since 1999. In 2021, as part of its Nationally Determined Contributions (NDCs), China unveiled a strategic plan aimed at reducing its peak CO_2 emissions and ultimately achieving carbon neutrality. This plan includes the release of an Action Plan for Carbon Dioxide Peaking before 2030 and a Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality. Specific objectives and implementing plans are published at the regional level and across all sectors covering energy, industry, urban-rural development, construction, and transportation (Baptista et al., 2022; Alam et al., 2025a).

Green construction technologies may be used as an effective technique for implementing sustainability in the construction sector (Abdelaal & Guo, 2022). Green buildings can potentially reduce GHG emissions and can work best against climate change at the lowest feasible cost. The reduction of carbon emissions throughout a building's lifecycle, as well as the decrease in carbon intensity, has emerged as a prevalent indicator of sustainable construction. This growing emphasis on carbon reduction may explain the heightened public awareness and interest in the development of low-carbon buildings (Luo & Chen, 2020).

Specific buildings sector transformation recommendations by actor group suggests three main core areas for construction shift including, regulate towards zero-carbon building stock, incentivize zero-carbon building stock, facilitate zero-carbon building stock. A generic set of immediate actions that are planned and developed recently to initiate and accelerate the China's transformation of the buildings sector. Green and low-carbon building technology and sustainable construction are recent developments in China (Chongqing) because of curtailed awareness, understanding, and zero-carbon legislation, as compared to other countries such as the United Kingdom, and other European nations (Bui et al., 2021; Alam et al., 2021). Although relevant initiatives such as policies and guidelines, as well as available methods, resources, and tools for designing or constructing of Green, Low-carbon and sustainable construction, are always employed to works and will also be a part of future plans. despite of all, questions such as "To what extent China (Chongqing)'s construction department (stakeholder, worker, and local people) are aware of the current zero carbon initiatives?" and "Whether China (Chongqing) construction stakeholders, worker and local resident ready to adopt and implement Green and Low-carbon building technology and sustainable construction?" remain unanswered.

The objective of this study is to investigate the benefits and application of green and low-carbon technology in developing countries such as China (Chongqing), where construction activities are primarily performed by Chinese companies and Chinese stakeholders. This study briefly discusses the application and challenges of green and low-carbon technology and aimed to fill the awareness gaps by assessing the knowledge of green and low-carbon building technology and sustainable construction. In this study, new buildings that have been planned and built with the maximum operational and embodied carbon reduction throughout the building life cycle are taken into consideration and being examined.

Previous studies have discussed the motivators and challenges for green and low-carbon building technology (Mata et al., 2021). However, no prior study has addressed the enablers of sustainable green and low-carbon building technology in terms of triple bottom line (TBL) approach. Moreover, an integrated modelling approach was needed to categorize the aspects, given priority, and developed into a solid framework. Our study proudly presents an integrated modelling approach to figure out the holistic green building operational and development capabilities to cater the present and future research needs. Our primary target is to find sustainable factors that encourages public to employ green and low-carbon building technologies. According to the majority of scholars, including Siciliano et al. (2021), sustainability encompasses both human and cultural aspects. However, other, such as Pedroso et al. (2021), suggest adopting the Triple Bottom Line (TBL) approach to provide a comprehensive definition of sustainability and effectively address environmental and social impacts. Considering above facts, the proposed study attempts to provide answers to the following questions:

(i) which enablers and challenges contribute to the adoption of green and low-carbon building technology;
(ii) how to assess sustainable green and low-carbon building technology enablers under data uncertainty;
(iii) how to find an interdependent relationship among the enablers.

MATERIALS AND METHODS

Description of the study area

Chongqing is a major city in southwestern China. It is located in the Sichuan Basin and is surrounded by mountains, making it a geographically unique city. Chongqing is situated at the confluence of the Yangtze River (Chongqing) and the Jialing River. Its precise geographical coordinates are approximately 29.5630°N latitude and 106.5516°E longitude (Figure 1). The city's strategic location along the Yangtze River has played a crucial role in its historical and economic building significance. Building construction in Chongqing requires specialized expertise to adapt to the rugged terrain and maintain a balance between modern development and preservation of the region's natural environment. Chongqing is a sprawling city, known for its hilly terrain and mountainous surroundings. Building in the mountainous areas of Chongqing presents several unique challenges, and the local construction techniques need to be adapted to overcome these obstacles.

This study used a mixed research approach, providing both inferential and descriptive research results. To achieve the objective of this research, data survey and systematic literature review was conducted to identify the enablers and problems confronting Green and Low-carbon Building Technology and sustainable construction practices both globally and in China (Chongqing).

Systematic literature review

A systematic literature review (SLR) offers an overview of the research's scope. The key rationale for using SLR is that it gives a systematic method for extracting data. Three primary phases of the SLR technique were used for literature review. For the planning of this review, literature was selected using digital libraries. Search results from "IEEE Xplore," "ACM Digital Library," "Springer Link," "ISI Web of Science", "Science Direct," and "Google Scholar" were used for selecting articles from journals, conferences, and workshops. Well-defined research questions, search strings and keywords were chosen in the selection of articles. The keywords from the selected articles are illustrated in (Figure 2). The publications selected were published between 2015 and 2021.

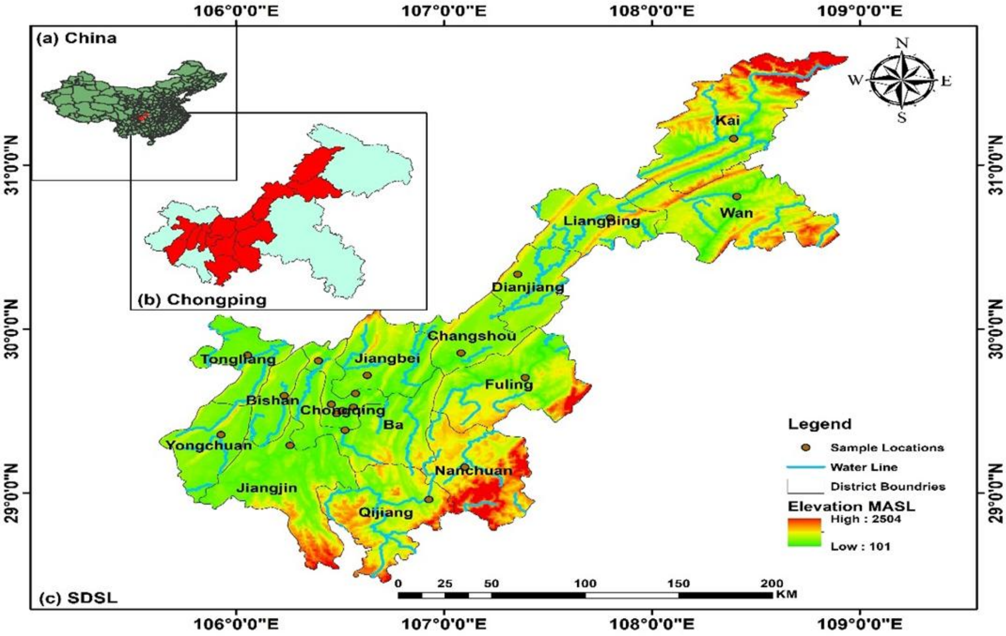

Figure 1. GIS map showing the selected locations

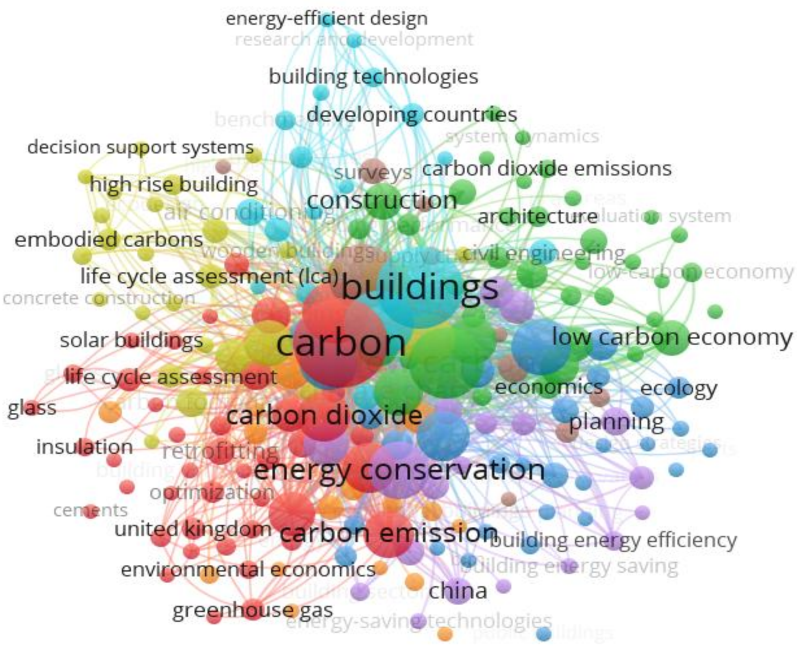

Figure 2. An illustration of keyword from the selected articles

Inclusion criteria was set as formal papers include only journals, conferences, and books targeting the research that defines the relationship between green buildings and sustainability, drivers or challenges, motivation for the implementation, and case study, content analysis, questionnaire survey etc. Exclusion criteria, on the other hand, where irrelevant publications do not define green and low-carbon building technology or enablers and challenges, publications other than the English language and conference paper ranking less than A, were employed to exclude irrelevant literature from selected data. Five question-based checklists described by Kitchenham (2012) was developed to check the quality of selected articles.

Initially, 673 articles were selected, however, for the final selection of papers, the tollgate technique provided by Afzal et al. (2009) was used. A total of 91 articles were selected, accounting for approximately 13.52% of the total primary study, as mentioned in (Figure 3). A score was also assigned to each selected article after applying QA criteria. The Kendall coefficient of concordance statistical test (W) was used to evaluate each selected article. In total twenty-eight drivers and fifteen challenges of green and low-carbon building technology and sustainable construction were reported from 91 selected articles, and research questions were assessed and evaluated.

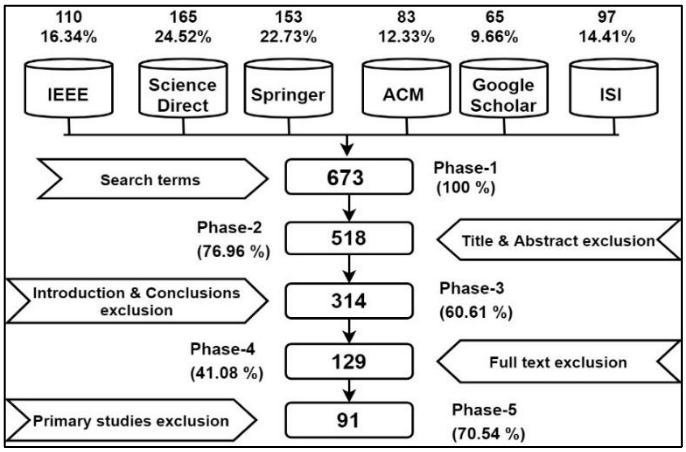

Figure 3. Final selected studies by using the tollgate approach

The triple bottom line (TBL) is a sustainability-focused accounting methodology was also incorporated that contains bottom-line categories for social, environmental, and financial issues. Implementation of Fuzzy DEMATEL approach by decision makers in construction was also checked as it is an effective Multiple-Criteria Decision-Making (MCDM) approach for tackling real-world issues in complicated decision-making systems for identifying direct and indirect linkages between system criteria and their interdependencies, allowing decision-makers to better recognize the consequences of these criteria on output.

Data survey

Following that, primary data was collected through a two-step process involving a questionnaire survey (analysed using statistical software,) and factor analysis. Factor analysis was required for the empirical reduction and categorization of challenges into critical groupings.

The sample was collected from registered building companies listed in China's Ministry of Housing (Chongqing). The company's sample size in this study was 100 construction companies out of 400 chosen and 300 contacted persons, consists of professionals who are involve Engineers, truction as stakeholder, Project Managers, Architects, Civil Engineers and local literate people in these companies, which accounts for the whole population of companies for collecting information purposes as they were selected due to their active involvement in making green and low carbon strategic decisions. A questionnaire-based study with multiple parts was developed to collect data and capture key factors of low-carbon building development in the Chinese city of (Chongqing).

The survey questionnaire consisted of three sections and was administered to professionals directly involved in green and low-carbon construction activities in Chongqing, including engineers, project managers, architects, and technical staff selected through purposive sampling to ensure relevant expertise. The first section collected basic demographic and professional information, such as age, educational background, organizational affiliation, and years of job experience. In the second section, respondents evaluated the perceived impact of 27 enablers and 15 challenges related to low-carbon building practices, using a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"); all factors and tasks assessed by the respondents are presented and discussed in detail in the Results section. The third section measured corporate willingness to adopt and promote low-carbon construction. A total of 420 questionnaires were distributed through field investigations between September and March 2022, yielding 402 responses, of which 376 were valid, resulting in a 95.71% response rate and a 93.53% valid response rate.

Estimating carbon emissions from construction machinery

Carbon emission values for each category of construction machinery were calculated using a standardized emission factor approach. Specifically, the emission factors (Kg/work) were derived by combining the rated power, load capacity, or operational specifications of each machine with established carbon emission coefficients obtained from national guidelines and previously validated literature on construction equipment energy consumption. These coefficients were then multiplied by the corresponding unit of work performed by each machine type to estimate carbon emissions under typical operating conditions. All machinery specifications, including power rating, loading mass, bucket capacity, compacting capacity, and lifting capacity, were sourced from manufacturer data sheets and verified through project documentation to ensure accuracy. The complete list of equipment categories, specifications, and resulting emission factors is presented in the Results section where the final emission outcomes are discussed.

RESULTS

Enablers of green and low carbon building

The study examined the success factors associated with green and low carbon building technology while considering the perspective of key stakeholders, with a specific focus on the factors that facilitate the technology's implementation and widespread adoption. In total, 27 key enablers were identified through literature review and added to questionnaire to monitor the public response. All enablers scored above 30% strongly agreed responses except "attained higher rental rates" that only scored 28.72% strongly agreed response. The lowest mean value for it supports the housing affordability index in China, making it the lowest among all. Higher rental prices may increase periodic charge per unit for the use of a property thus can be detrimental to the public and market. The highest level of agreement, 40.96%, was recorded for E18, indicating strong support for the incorporation and optimization of energy in construction materials. E18 reflects the most appropriate, sustainable, affordable, and trendy option to achieve green construction that offers little or no repercussions making it most voted enabler. Following E18 in (Table 1), the factors representing the most valued enablers are E25, E19, and E17, with percentages of 39.36%, 39.10%, and 39.89%, respectively. These percentages favour a focus on "enhanced return on investment", "improvement in safety and health", and further "environmentally friendly" approaches.

Table 1. Success factors of green and low carbon building in (Chongqing) China

No.	Enablers	Strongly disagree, %	Disagree, %	Neutral, %	Agree, %	Strongly agree, %
E1	Development in building regulations	4.79	5.85	18.35	37.77	33.24
E2	Increase the public's trust	3.99	6.12	20.48	34.57	34.84
E3	Enable renewable energy	6.38	4.52	18.35	32.45	38.30
E4	Planning policy	3.99	4.52	20.21	36.70	34.57
E5	Smart building	4.79	5.05	18.62	33.78	37.77
E6	Lower project capital costs	3.19	6.91	23.67	28.19	38.03
E7	Corporate social responsibility	5.32	3.99	21.28	33.51	35.90
E8	Minimize operation and maintenance cost	3.72	7.98	19.41	30.05	38.83
E9	Collaborative innovation	3.46	5.85	22.87	32.45	35.37
E10	Improve inhabitant comfort	4.79	5.85	18.35	34.04	36.97
E11	Green construction awareness	4.26	6.65	17.02	34.04	38.03
E12	Green construction process necessitates	3.46	7.18	19.41	32.45	37.50
E13	Corporate green culture	5.59	5.32	21.01	32.18	35.90
E14	Expand investment	2.93	6.12	21.81	35.37	33.78
E15	Increase property value	3.19	7.18	18.09	34.57	36.97
E16	Improve overall innovation	5.59	5.05	18.62	32.45	38.30
E17	Environmentally friendly	5.59	4.26	18.35	31.91	39.89
E18	Optimization in energy and construction materials	2.93	7.18	17.29	31.65	40.96
E19	Improve safety and health	4.52	5.59	18.88	31.91	39.10
E20	Achieve lower total ownership costs	5.59	6.12	19.15	32.45	36.70
E21	Government subsidies and tax breaks	2.66	5.59	20.48	33.78	37.50
E22	Attain higher rental rates	4.26	5.59	25.53	35.90	28.72
E23	Waste minimization	4.52	5.05	21.81	31.38	37.23
E24	Minimize sanitation expenses	2.93	7.98	19.15	34.57	35.37
E25	Enhance return on investment	5.59	4.52	18.09	32.45	39.36
E26	Minimize environmental impact	3.99	6.91	19.95	32.98	36.17
E27	Increase carbon objectivity	4.79	5.3	19.68	35.37	35.64

The "development in building regulation" also received a positive response of 33.24% highly agreed, indicating that it plays a crucial role in promoting green and low-carbon building practices. The respondents were well recognized with the importance of robust building regulations in promoting green and low-carbon building practices. Similarly, the respondents recognized the importance of building trust among the public to encourage the adoption of green and low-carbon building technology. Public perception and awareness of the benefits of sustainable construction play a vital role in encouraging individuals to support and embrace environmentally friendly building practices. The respondents also acknowledged the significance of "enabling renewable energy" sources in reducing carbon emissions and promoting sustainable energy use within buildings and produced strongly agreed response of 38.30% while only 6.38% strongly disagree with E3. Interestingly the highest strongly disagreed response was also recorded against E3 i.e. 6.38% and reason behind it was intentions towards collaborative initiatives instead just to focus on energy sector solely. Integrating renewable energy technologies, such as solar panels and wind turbines, can contribute to achieving energy efficiency and carbon neutrality. "Planning policies" were majorly 34.57% recognized as an important success factor in promoting green and low-carbon building practices. "Smart building" technologies, which optimize energy consumption, enhance operational efficiency, and provide intelligent monitoring and control systems, were identified as a significant enabler and produces valued responses near to highest 37.77% while the strongly disagreed responses were more intentioned toward policy establishment and implementation instead to transforms the traditional building designs despite admitting the fact that smart building technologies offer opportunities for reducing energy wastage, improving resource management, and enhancing occupant comfort and well-being.

Furthermore, "lowering project capital costs" was identified as a significant success factor for green and low-carbon building technology. A substantial portion of respondents (38.03%) highly acknowledged the importance of this factor. They believed that it could increase interest in the adoption of safe, technologically advanced, and highly affordable options, consequently leading to a greater reduction in emissions. Cost-effectiveness is a key consideration for stakeholders when deciding to adopt sustainable construction practices. Strategies such as life cycle costing and innovative financing mechanisms can help overcome initial cost barriers. The concept of "corporate social responsibility" was found to be a crucial enabler in promoting the adoption of green and low-carbon building technology. The study revealed that 35.90% of the respondents strongly agreed with this concept, while 5.32% strongly disagreed, and 21.28% provided neutral responses. Companies that prioritize sustainability and incorporate environmental and social considerations into their operations can positively influence the construction industry. The significance of "reducing maintenance and operation costs" for sustainable buildings is also emphasized. Energy-efficient designs, low-maintenance materials, and optimized building management systems also marked as key enablers contributing to reducing long-term operational expenses and enhancing the economic viability of green construction. In the same way, respondents agreed that "improving inhabitant comfort" is a crucial factor in promoting the adoption of green and low-carbon building technology. Sustainable buildings should prioritize factors such as indoor air quality, thermal comfort, acoustics, and access to natural light to create healthy and pleasant living and working environments.

In summary, the study identified several success factors for green and low-carbon building technology as shown in (Table 1). These factors encompassed a range of areas, including regulatory frameworks, public perception, renewable energy integration, planning policies, smart building technologies, cost considerations, corporate responsibility, collaboration, occupant comfort, and awareness of green construction practices. These findings provide valuable insights for policymakers, industry professionals, and stakeholders in promoting and implementing sustainable construction practices.

Challenges of green and low carbon building

The study also aimed to identify and analyse the challenges associated with green and low-carbon building technology. (Table 2) presents major challenges of green and low carbon buildings in (Chongqing) China collected from respondents.

Table 2. Challenges of green and low carbon buildings in (Chongqing) China

No.	Challenges	Strongly disagree, %	Disagree, %	Neutral, %	Agree, %	Strongly agree, %
C1	Lack of knowledge and understanding	3.99	7.45	21.01	31.38	36.17
C2	Lack of awareness of stakeholders	5.85	5.85	19.95	35.90	32.45
C3	Lack of demand	3.19	5.59	17.29	35.64	38.30
C4	Affordability	3.19	5.59	17.29	35.64	38.30
C5	Lack of client demand	5.32	5.85	18.88	34.84	35.11
C6	Lack of client awareness	2.39	8.24	26.06	28.99	34.31
C7	Lack of established alternative	4.52	6.65	21.01	32.18	35.64
C8	Lack of business case understanding	4.26	6.91	22.87	31.38	34.57
C9	Insufficiency of government regulations and legislation	4.52	8.24	18.88	35.90	32.45
C10	Lack of technology knowledge	4.52	6.38	23.40	32.71	32.98
C11	High initial construction cost	4.79	6.91	19.68	34.31	34.31
C12	Cost of green products	4.26	7.18	18.88	36.44	33.24
C13	Sustainability unawareness	4.79	7.71	16.49	33.51	37.50
C14	Absence of leadership and decision-making process	3.46	8.24	20.21	31.38	36.70

The major challenges were mentioned as "affordability" and "lack of public demand" for green and smart buildings that produced same value of 38.30% highly agreed response. The primary considerations were given to these two factors namely public interest and affordability across various socioeconomic classes. About 21.01% of the respondents provided neutral responses regarding the high demand for green buildings, which signifies current trends and their appeal to the public compared to traditional structures. This indicates that green buildings are not viewed as significant challenges in this context. "Lack of knowledge and understanding" of green and low-carbon construction practices also marked as significant challenge with voted value 36.17% strongly agreed response, expressed a relatively low degree of disagreement. This shows that stakeholders have an acceptable level of knowledge and comprehension, while more efforts may be required to fill any remaining gaps. Respondents reported a moderate level of disagreement on "stakeholders' lack of awareness". This suggests that, while stakeholders are aware, there is still potential for improvement in terms of raising awareness and involving every relevant stakeholder. Most respondents agreed that there is a lack of client demand for green and low-carbon buildings and valued as 35.11% and 34.84% strongly agreed and agreed responses, making it a significant challenge in the industry, as the adoption of sustainable construction practices heavily relies on market demand and willingness to prioritize environmental considerations while some respondents also disagreed to some extent 5.85%, that there is a lack of client demand as trendy and innovative buildings are on higher demand in China. This suggests that there is a reasonable level of interest and demand from clients for sustainable construction practices. However, efforts should still be made to further promote the benefits and advantages of green buildings to clients. Mixed opinions were expressed regarding the "lack of client awareness". While there was a significant percentage of 34.31% and 28.99% strongly agreed or agreed respondents indicating agreement that client's awareness need to be elevated to increase demand for successful incorporation of green buildings. This highlights the need for targeted awareness campaigns and education to improve client awareness and understanding. The challenges "insufficiency of government regulations and legislation" (C9) and "lack of awareness of stakeholders" (C2) received the lowest values, with 32.45% strongly agreeing with these statements. This suggests that the national formulation and implementation of the green building agenda is already a government priority, with sufficient policies, regulations, and legislative frameworks in place. Consequently, stakeholders are generally well-informed about green sustainability concepts and do not express significant disagreement with them.

Furthermore, the study identified several other challenges associated with green and low-carbon building technology. These challenges include the "lack of technology knowledge", "high initial construction costs", "cost of green products", "sustainability unawareness", "absence of leadership and decision-making processes", and "technical ability and IT-skills" as highlighted in (Table 2). These findings provide valuable insights for policymakers, industry professionals, and stakeholders in addressing these challenges and promoting the widespread adoption of green and low-carbon building practices.

Carbon emission from construction equipment

The carbon emission factor represents the amount of carbon emissions produced per unit of work performed by the machinery. As the Chongqing city of China is a mountainous region, so the carbon emission from the green and low carbon building will be reasonably high (Tan et al., 2017). The findings of the study can be used to estimate and analyse the carbon footprint of construction projects, assess the environmental impact of machinery usage, and inform decision-making processes for adopting more sustainable and low-carbon alternatives in the construction industry. The most significant is Tire loader from Shovel and horizontal transport machinery emitting 245.60 Kg/work, Self-raising tower crane from Hoisting and vertical lifting machinery emitting 201.32 Kg/work and grader from Compaction and pavement equipment with total emission 142.75 Kg/work. It is important to note that these emission factors are specific to the machinery models and specifications (Table 3). The actual carbon emissions can vary depending on factors such as equipment maintenance, fuel efficiency, and operational practices.

Table 3. Carbone emission from construction machinery

Type	Machinery	Specification and model		Carbon emission factor, Kg/work
Shovel and horizontal transport machinery	Crawler dozer	Power	75 kW	190.56
	Tire loader	Bucket capacity	2 m3	245.60
	Truck	Loading mass	4 t	93.41
	Truck (large)	Loading mass	8 t	138.8
	Dump truck	Loading mass	8 t	160.3
	Lift truck	Loading mass	8 t	193.64
	Mortar transport truck	Loading capacity	4000 L	95.65
	Dumper	Loading mass	1 t	26.21
Hoisting and vertical lifting machinery	Crawler electrical crane	Lifting capacity	5 t	64.13
	Crawler crane	Lifting capacity	15 t	131.43
	Truck-mounted crane	Lifting capacity	5 t	89.56
	Truck-mounted crane (large)	Lifting capacity	8 t	111.23
	Self-raising tower crane	Lifting capacity	1500 kNm	201.32
Compaction and pavement equipment	Smooth-wheeled roller	Working weight	8 t	81.56
	Vibratory roller (large)	Working weight	6 t	76.15
	Compactor (electricity)	Compacting capacity	20 – 62 kNm	22.32
	Grader	Power	90 kW	142.75
Rebar and pre-stress machinery	Rebar bending machine	Diameter	40 mm	16.24
	Rebar cutting machine	Diameter	40 mm	36.65
	Rebar straightening machine	Diameter	14 mm	18.34

There is a scarcity of data on the carbon emissions of nonroad construction equipment and the relevant carbon emissions factors of the equipment. The IPCC Guidelines for National GHG Inventories (Change, 2006), provided the equipment energy consumption and related carbon emissions components utilized in this work. The emissions factors for key types of construction equipment and machinery were computed based on actual construction machinery usage and construction machinery one work-shift expenses in Chongqing city.

DISCUSSION

In this study several enablers and challenges were discussed regarding the sustainable construction and carbon emission of green and low carbon building technology in (Chongqing), China. China is currently paying great attention to environmental concerns throughout the enormous increase of urbanization and has established "green and low carbon" as a fundamental growth direction. The primary goal is to create "green and low carbon" cities, which calls for collaboration from many different governmental and social sectors, as these are the main sources of carbon emissions in China. Promoting green and low-carbon building practices in Chongqing, China requires the implementation of various enablers that can drive sustainable construction. For example, green construction awareness plays a crucial role in promoting sustainable practices among stakeholders, including developers, contractors, architects, and homeowners. Relation between increasing awareness about the environmental benefits of green building and the available technologies and strategies, stakeholders can make informed decisions and actively contribute to reducing carbon emissions. Education campaigns, workshops, and seminars can be effective tools/enablers to raise green construction awareness and encourage the adoption of sustainable practices (Darko & Chan, 2017; Salam et al., 2021a).

Green and low-carbon buildings often have higher property values due to their energy efficiency, lower operational costs, and positive environmental impact. In (Chongqing) China, increasing property values can serve as an incentive for developers and homeowners to invest in sustainable construction practices. Studies have shown that green buildings exhibit several advantages, including higher rental rates, reduced vacancy levels, and an appeal to environmentally conscious tenants. Consequently, these factors contribute to economic benefits for stakeholders (Taltavull et al., 2017).

Developing a corporate green culture and expanding investment are also essential for driving sustainable construction practices in (Chongqing) China. When construction companies prioritize sustainability and environmental responsibility, they can actively seek green building certifications, implement sustainable construction processes, and adopt innovative technologies that reduce carbon emissions. This cultural shift within organizations can result in long-term sustainability commitments and contribute to the overall green transformation of the construction industry (Wang et al., 2022).

Challenges on the other hand are also an inevitable part of transitioning towards green and low-carbon buildings in (Chongqing), China. Understanding and addressing these challenges is crucial for the successful adoption of sustainable construction practices. One of the challenges is the limited availability and lack of established alternatives to conventional construction methods and materials. The market may have limited options for sustainable building materials, technologies, and construction practices. This can hinder the adoption of green and low-carbon building practices (Liu & Hu, 2019). Many stakeholders in the construction industry may not fully understand the financial and economic benefits associated with green and low-carbon buildings. The lack of awareness and understanding of the business case for sustainable construction practices can hinder investment and decision-making in favour of such projects (Sánchez Cordero et al., 2019; Salam et al., 2024). Inadequacy of specific regulations and limited knowledge and understanding related to green and low-carbon buildings can act as a barrier to their widespread adoption. Clear policies, regulations, and incentives from the government are essential to create an enabling environment for sustainable construction practices (Lu et al., 2019).

It is important to recognize the challenges faced by green and low-carbon building and work towards overcoming them through targeted policies, capacity building, knowledge dissemination, and industry collaboration. Governments, industry associations, educational institutions, and stakeholders need to work together to address these challenges and create an enabling environment for green and low-carbon building practices in (Chongqing), China.

Thus, this study, through a combination of modelling and literature review, made the following contributions to the area of knowledge being studied:

1) The authors conducted a detailed evaluation of previous studies on sustainable green and low-carbon building technologies and identified specific research gaps. These gaps include a lack of integrated assessment combining both quantitative modelling of carbon emissions and qualitative evaluation of implementation enablers and challenges. Additionally, most prior studies have focused on general sustainability measures without providing region-specific insights for Chongqing, China, limiting their applicability in local policy and practice. This study addresses these gaps by providing a localized, evidence-based analysis that integrates modelling results with literature synthesis, offering a comprehensive understanding of both technical and practical aspects of green and low-carbon building adoption.

2) Based on an in-depth investigation of the literature and the results obtained in this study, several gaps were identified in the implementation of sustainable green logistics in Chongqing. While previous studies emphasized general enablers, this study quantified the influence of each factor, revealing that economic enablers scored an average of 4.2, social enablers 3.8, and environmental enablers 4.5 on a 5-point scale. These results indicate that although environmental initiatives are relatively well-adopted, significant gaps remain in integrating economic and social considerations effectively.

3) The current study, using SLR (a robust statistical method for classifying implementation factors under uncertainty), identified key enablers and challenges of green and low-carbon building practices in the study area. Based on the results, gaps were observed in stakeholder engagement (scoring 3.2/5), technology adoption (scoring 2.8/5), and policy support (scoring 3.0/5), indicating areas where current practices are insufficient. These findings highlight specific targets for improving implementation effectiveness and reducing carbon emissions in local building projects.

4) Using a mean value approach, the factors were prioritized, revealing that lack of policy incentives (mean 4.32) and high initial construction costs (mean 4.18) are the primary barriers, while stakeholder awareness (mean 4.45) and technological readiness (mean 4.37) are the strongest enablers. These results address the specific gap in quantifying and ranking enablers and challenges in green and low-carbon building practices in the study area, providing a clear, evidence-based framework for future implementation.

CONCLUSION

This study successfully achieved its goal of assessing the enablers, challenges, and carbon emissions associated with green and low-carbon building practices in Chongqing, China. Through comprehensive analysis, it identified the critical factors that facilitate and hinder the adoption of sustainable building technologies. Notably, government support, including building regulations, planning policies, and financial incentives such as subsidies and tax breaks was found to be a primary enabler, while limited stakeholder awareness and low market demand were major barriers. By systematically integrating these insights, the study provides a clearer understanding of how policy frameworks, economic mechanisms, and social factors collectively influence the implementation of green building initiatives in the region.

The study contributes new scientific knowledge by revealing nuanced interactions between enablers and challenges that previous research had not fully explored, particularly in the context of urban construction landscape of the study area. The study fills the gap in empirical evidence regarding region-specific drivers and obstacles of low-carbon buildings, offering actionable recommendations to accelerate sustainable construction adoption. The findings open prospects for future research and practice by highlighting the need for targeted awareness campaigns, multi-stakeholder collaboration, and policy optimization. Ultimately, this work provides a foundation for policymakers, industry professionals, and researchers to advance green and low-carbon building practices, promote environmental sustainability, and support the broader transition toward a low-carbon urban economy.

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Author's statements

Contributions

Conceptualization: F.A.; Data curation: M.Y., D.B.; Investigation: B.A., R.S.; Methodology: F.A., A.S., D.B.; Supervision: F.A., D.B.; Validation: F.A., D.B.; Writing – original draft: B.A., R.S.; Writing – review & editing: F.A., D.B., A.S. Approval of the version of the manuscript to be published by all co-authors including corresponding author.

Declaration of conflicting interest

All authors of this manuscript are agree to the terms and policies of the journal and they have no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

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Data availability statement

All authors of this manuscript confirmed that the data supporting the findings of this study are available within the manuscript and all the required data are available and easily accessible.

AI Disclosure

The authors declare that generative AI was not used to assist in writing this manuscript.

Ethical approval declarations

Informed consent was obtained from all individual participants included in the study. All applicable international, national, and/or institutional guidelines for the care of both humans and/ or animal studies were followed in this research work. All guidelines regarding ethical committees and Internal Review Boards were also followed in this study.

Additional information

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