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A-state-of-the-art review of risk management process of green building projects

Lina Wang [a,*], Daniel W.M. Chan [a], Amos Darko [b], Benjamin I. Oluleye [a]

[a] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China
[b] Department of Construction Management, University of Washington, USA

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ABSTRACT

Green buildings (GB) have attracted significant attention for improving sustainability and reducing carbon emissions in the building sector. Like traditional projects, risk management plays a crucial role in green projects. The inadequacy of risk management may lead to diminished workforce performance, delays in project schedules, and poor quality in GB projects. To comprehend risk management in GB projects, it is essential to conduct a state-of-the-art review. This study applied the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method to select 52 records from the database 'Scopus' and 'Web of Science' (WoS). A bibliometric analysis indicated that the emphasis in risk management is on the identification and evaluation of risks in engineering projects. Subsequently, a thematic analysis displayed the research topics related to risk management, including (1) methods for identifying risks, (2) risk identification in special conditions, (3) risk assessment with fuzzy sets, social network analysis (SNA), and interpretive structural modeling (ISM), and (4) risk assessment with other technologies. This study focused on the research gaps within the risk management field, specifically in risk identification methods, risk evaluation methods, and risk-mitigating processes. Finally, with research gaps, this study also proposed related research directions for risk management in GB projects.

1. Introduction

Despite a significant increase in investment and international accomplishments in mitigating energy emissions from buildings, aggregate energy consumption and CO_2 emissions exceeded pre-pandemic levels in 2021 [1]. The energy consumption of the construction ranges from approximately 25% to 40% [2], resulting in considerable environmental pollution from traditional buildings [3]. In this context, green building (GB) was introduced as a means to mitigate adverse environmental effects. According to the World Green Building Council (WorldGBC), GB projects are designed to reduce carbon emissions, lower energy costs, and improve the quality of life for citizens throughout the projects' life-cycle [4]. The GB projects, as prioritized by the United States Environmental Protection Agency, focus on incorporating environmental responsibilities throughout the design, construction, operation, and maintenance stages. The primary goal of GB projects is to minimize adverse environmental effects and create a healthy and comfortable living environment [5]. Compared to traditional projects, GB projects have advantages in environmental, economic, social, and technological aspects. GB projects have attracted high attention from academics and practitioners. However, the distinctive attributes of GB projects may cause new risk management challenges, including risks associated with using novel

* Corresponding author.
E-mail address: linawang@polyu.edu.hk (L. Wang).

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Table 1
Previous reviews and current study of risk management on GB.

Reference	Methods	Database	Objectives	Gaps
[15]	■ systematic review	■ Scopus	■ analyze risk relationships	■ lack of analyzing risk management
[16]	■ systematic review	■ explore design risks	■ lack of enough papers for systematic review	
[17]	■ systematic review	■ Scopus, WoS	■ identify risk, create risk assessment models	■ lack of risk management process
[18]	■ systematic review	■ Scopus, WoS	■ analyze stakeholders roles	■ lack of risk management process
[19]	■ questionnaire		■ analyze cost-benefit risk factors	■ lack of a systematic review of risk management
[20]	■ systematic review	■ WoS, Scopus, Engineering Village, and Science Direct	■ analyze critical risk factors	■ lack of the relationship of risk
[21]	■ systematic review	■ Scopus	■ classify drivers from generic aspects	■ lack of the relationship of drivers
[5]	■ systematic review	■ Scopus, WoS	■ analyze risk interdependencies	■ lack of risk management process
[22]	■ systematic review	■ WoS	■ analyze keyword co-occurrence analysis of risk	■ lack of risk management
[23]	■ systematic review	■ Scopus	■ analyze seismic risk	■ lack of risk management
current study	■ systematic and qualitative review	■ Scopus, WoS		

materials and technologies, and potential social implications. Consequently, the risk management process of GB projects has become a popular topic.

Risk management involves identifying, assessing, and allocating adverse factors to reduce, monitor, and control the possibility or consequences of unfavorable occurrences [6]. Moreover, the inherent uncertainty associated with risk has dual effects: downside risk, also known as a threat, and upside risk, also known as opportunity [7]. The characteristics of risk indicate the importance of risk management for projects. As with traditional projects, risk management plays a crucial role in green construction [8]. The significant risk factors for GB projects are notable due to the sustainability goals and common objectives. Hence, GB projects need higher risk management measures compared to traditional projects. Effective risk management is essential for the successful implementation of green retrofit projects. Concerning the significance of risk management, existing studies have analyzed the risk management of GB projects, such as the factors influencing green retrofit [9], the process of risk identification [10–13], and the framework for risk response [14]. In light of the importance of risk management, some existing research has conducted a literature review to present various topics related to risk management topics. Table 1 presents some reviews about risk management in GB projects. The main themes addressed in the existing review focus on (1) identifying risk factors in GB projects, (2) analyzing relationships of risk factors, and (3) exploring stakeholders with the risk factors in GB projects. Moreover, the existing reviews analyze risk management with systematic reviews from Scopus and Wos, but some gaps need to be addressed. For instance, some reviews only selected Scopus or WoS as the sole database, potentially omitting certain records. Existing research focuses on the identification of risks in special stages, such as the design stage, as well as on risk evaluation and the framework for responding to risks. Most importantly, the majority of reviews focus on identifying risk factors rather than analyzing the risk management process. Nevertheless, a systematic analysis of risk management on GB projects is lacking. Therefore, providing a systematic review of the aspects of the risk management process for GB projects is crucial.

Regarding the significance and the lack of systematic research on the risk management of green retrofit projects, it is essential to construct a systematic review to analyze the present development of risk management, providing a reference for future study of GB projects. Thus, this study aims to accomplish the following objectives:

- What is the status of risk management in GB projects? The status of risk management is displayed by several aspects, such as the distribution of articles by year and country, as well as the popular journals of published articles, etc.
- What is the focus of risk management on GB projects? The focus on risk management includes the processes of identifying and evaluating risks.
- What are the challenges and future research directions for risk management in the GB projects? The research directions are analyzed in terms of the spotting of risk management in GB projects.

The contributions of this paper are threefold: (1) This study presents a bibliometric analysis of risk management conditions. (2) This study provides a thematic analysis of GB projects' risk identification and risk evaluation process. For risk identification,

Table 2
Basic information of selected literature.

Reference	Country	Building type	Reference	Country	Building type
[24]	Vietnam	general GB	[25]	Singapore	general GB
[26]		assess risks	[14]	Sri Lanka	retrofit GB
[10]	Singapore	retrofit GB	[27]	Iran	residential GB
[28]		retrofit GB	[29]	Singapore	residential GB
[5]		general GB	[30]	Iran	general GB
[31]	Swedish	general GB	[32]	Finland	general GB
[33]	Hong Kong	general GB	[34]	China	green house
[35]	Ghana	general GB	[36]	Saudi Arabia	retrofit GB
[37]	China	general GB	[38]	Vietnam	general GB
[39]	China	residential GB	[40]	China	general GB
[16]	China	commercial GB	[41]	Hong Kong	general GB
[42]	Singapore	commercial GB	[43]	China	commercial GB
[44]	USA	general GB	[45]	Qatari	general GB
[46]	Vietnam	general GB	[47]		general GB
[48]		general GB	[49]	Hong Kong	general GB
[50]	Saudi Arabia	general GB	[12]	China	residential GB
[51]	China	general GB	[52]	China	general GB
[53]	Singapore	commercial GB	[54]	Australia	University GB
[55]		general GB	[56]	Kuwaiti	general GB
[57]	China	general GB	[15]		general GB
[58]		general GB	[59]	Australia	general GB
[60]	China	resident GB	[61]	India	general GB
[62]	Europe	general GB	[63]	China	commercial GB
[64]	China	general GB	[65]	China	general GB
[66]	China	general GB	[67]	Saudi Arabia	general GB

the risk identification methods and risk identification for special conditions were analyzed with the selected records. The analysis of risk evaluation focuses on risk evaluation models with fuzzy sets, SNA, and ISM. (3) This study identifies research gaps in GB projects based on existing studies of the selected records and presents future research topics for risk management. Therefore, the remainder of this paper is organized as follows: The methodology Section 2 outlines the methodology, which introduces systematic reviews. Subsequently, Section 3 presents an in-depth analysis of risk management from bibliometric and thematic aspects. Section 4 addresses the spotting of risk management in GB projects. Discussions are displayed in Section 5 and the conclusion is presented in Section 6.

2. Research methods

This study comprises two stages aimed at conducting a critical survey and analysis of risk management in GB projects through the analysis of literature. The first stage involves retrieving and screening existing literature, including the database selection, literature retrieval, and literature screening. The systematic review process was displayed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, considering the characteristics of the first stage. This stage contains two steps: (1) Identifying relevant literature on risk management in GB projects from databases, and (2) Selecting related records from the relevant literature using the retrieval and screening methods. After that, the second stage provides the thematic analysis to analyze risk management of the selected literature. With thematic analysis, research challenges and future directions for risk management in GB projects are discussed. The details are listed as follows:

- Stage 1 of this study aims to identify relevant academic articles on risk management in GB projects
  In this paper, the search string is implemented on WoS and Scopus with keywords to identify academic articles. WoS and Scopus cover a wide range of articles, many journals, and a large citation database. The information on Google Scholar is less than WoS and Scopus. The search process was conducted using the 'Topic' in Web of Science and the 'TITLE-ABS-KEY' field on Scopus. The search string is 'green building projects' AND 'risk management' OR 'green building projects' AND 'risk factors'. 'Sustainable projects' and 'risk factors' were considered as alternative words to 'green buildings' and 'risk management'. The inclusion criteria include: (1) The language study was English; (2) The full text was available. (3) The article type was a journal. The search process was completed in Dec 2023 with 545 records. These records were displayed in MS Excel to remove the duplicates. The linked articles are identified and extracted if the defined terms appeared in the titles, abstract, and keywords resulting in a comprehensive database of 52 articles. The inclusion criteria include: (1) Papers focus on GB projects; (2) Papers aim to discuss the risk management process of GB projects. Hence, the flowchart is displayed in Fig. 1. Table 2 displays the basic information of selected records.
- Stage 2 involved a systematic review of the selected papers
  The systematic review management process in GB projects includes two key aspects: (1) The analysis of the risk identification process. The risk identification process encompasses various topics, including methods for identifying risks, risk identification in specific countries, risk identification in special GB projects, and risk identification at different stages. (2) The analysis of the

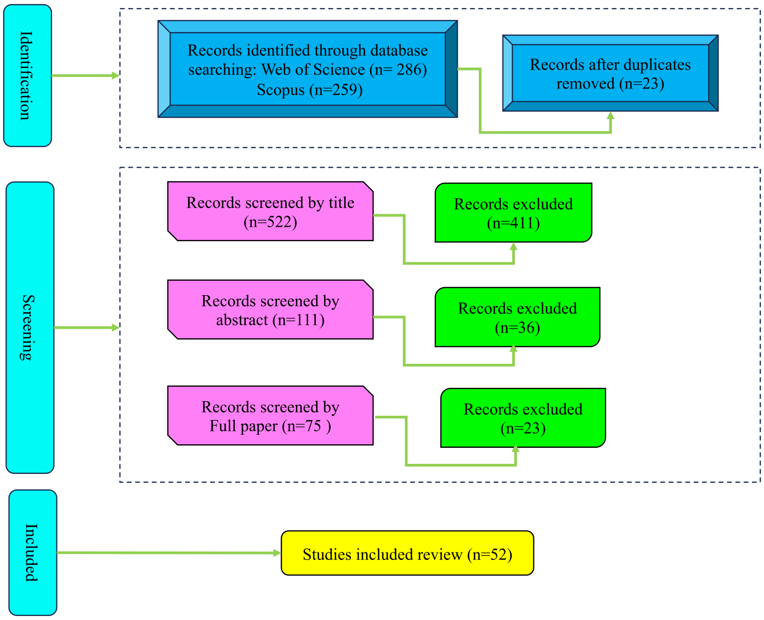


Fig. 1. The PRISMA process of risk management on green retrofit projects.

risk evaluation process. For the risk evaluation process, the topics aim to analyze risk evaluation models with different tools, like fuzzy sets, SNA, ISM, and other technologies. Besides, the risk evaluation models with SNA or ISM display the relationship between stakeholders and risk factors. Given the thematic analysis of risk management in GB projects, the challenges of risk management for GB projects and future research directions are presented.

3. Systematic literature review results

3.1. Bibliometric analysis

The bibliometric analysis provides explanations of existing records by visualizing forms to map the knowledge domain and relationships among journals, articles, and keywords, which is a significant technique in the field of scientometry [68]. VoSViewer is a popular tool for mapping networks by loading datasets, computing information, and analyzing co-citations. In this study, the bibliometric analysis displays the risk management process from the frequency of articles, keywords, research areas, journals, and countries by analyzing selected records with VoSViewer.

Fig. 2 presents the top 8 research areas, like green sustainable science technology (GSST), engineering, environmental science (ES), construction building technology (CBT), engineering environmental (EE), management, energy, and social sciences (SS). The top 3 areas of records focus on engineering (25.9%), ES (22.8%), and management (13%). Fig. 3 displays the frequency of publications on risk management on GB projects from 2011 to 2023. The most published year is 2022, with 15 records. Although there is a minor drop in 2021, more than 50% of the 52 records were published from 2020 to 2023.

Fig. 4 shows the publication numbers of the existing records in different countries. Compared to other countries, China, Australia, and Singapore are the most productive countries for risk management in GB projects. A large percentage of records are published by scholars from China, Australia, and Singapore. Besides, with the VoSviewer tool, the related criteria are settled as (1) The type of analysis and the unit of analysis are settled as 'bibliographic coupling' and 'countries'. (2) The number of records of a country meets ($n \geq 3$). Based on these criteria, the country's map is displayed in Fig. 5. Take China as an example, the weight of risk management documents published by Chinese scholars is 13, the average publication year is 2019, and the total link strength is 552.

Table 3 presents the top 10 journals that publish risk management on GB projects. A large percentage of articles are published in the Journal of Cleaner Production (26.9%), Sustainability [Switzerland] (15.4%), Building and Environment (7.7%), Buildings (7.7%), Engineering Construction and Architectural Management (7.7%), and Sustainable Cities and Society (7.7%). The publication journals display the popularity of risk management on GB projects. Fig. 6 displays the co-occurrence of risk management keywords with the selected records. There are two clusters in Fig. 6: The left cluster is the risk identification one with pink lines and the right cluster is risk assessment with green lines, which indicates the thematic analysis topics. Regarding the co-occurrence of risk management, Table 4 presents keyword networks from total link strength (TLS), average publication year (APY), and average citations (AC).

After analyzing the full text of the selected records, existing research prefers to identify risk factors by different stages or various types. With the Pareto chart, Fig. 7(a) displays the significance of different stage risks. The frequency of construction risk factors is

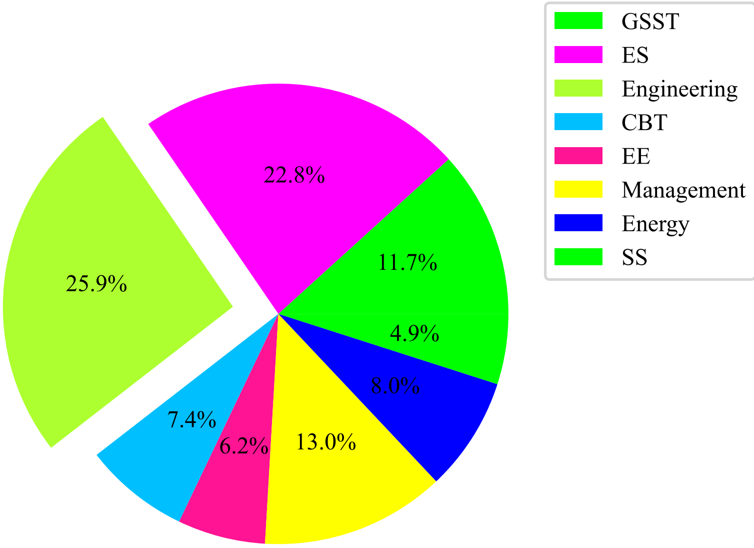


Fig. 2. Top areas of RM with GB projects.

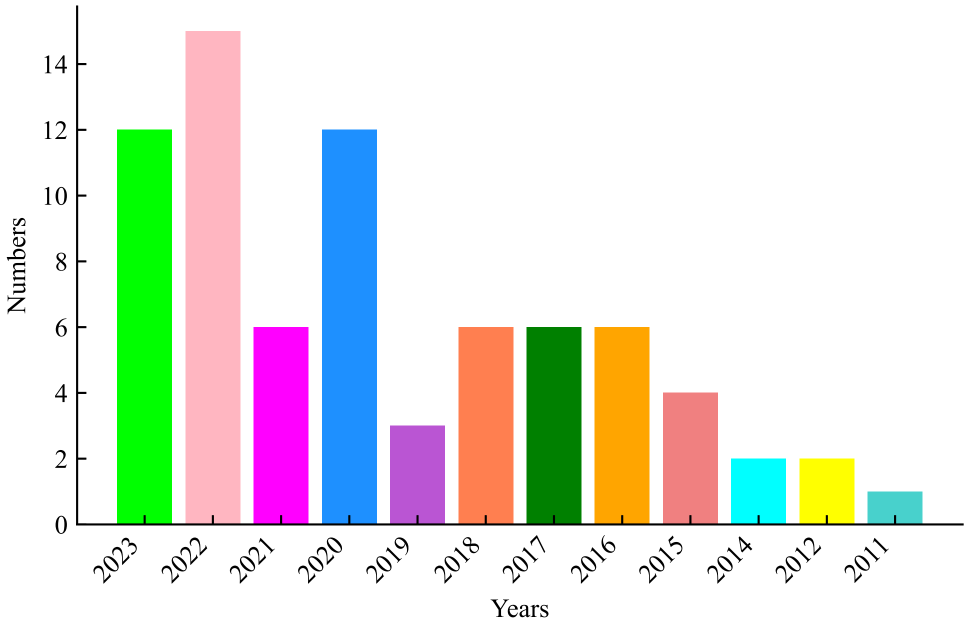


Fig. 3. Frequency of publication of GBRM with years.

nearly 140, the same as design stage risk factors. Therefore, the critical risks of stages are the construction, design, and operation stages. Similarity, Fig. 7(b) indicates the frequency of risk with different types. The significant types included financial, management, technical, environmental, and material risks.

3.2. Thematic analysis

Regarding the significance of risk management for GB projects, the main research topics focus on the risk identification process and risk evaluation process (see Fig. 6). For the risk identification process, the main topics of the selected records include risk identification methods, risk identification for special countries, risk identification for special GB projects, and risk identification for special stages. For the risk evaluation process, the main research topics contain risk evaluation models, like evaluating risk factors with fuzzy sets, evaluating risk networks with SNA, and evaluating risk relationships with ISM.

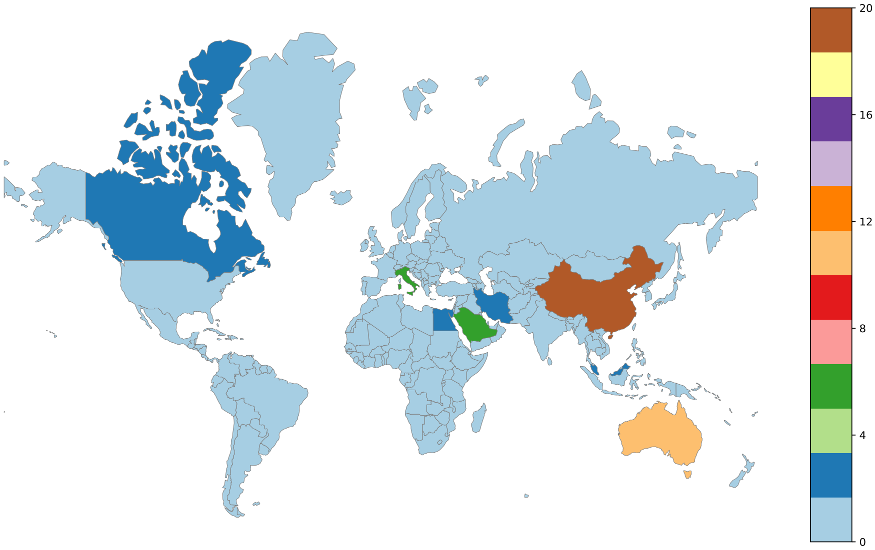


Fig. 4. Frequency of publication of GBRM with countries.

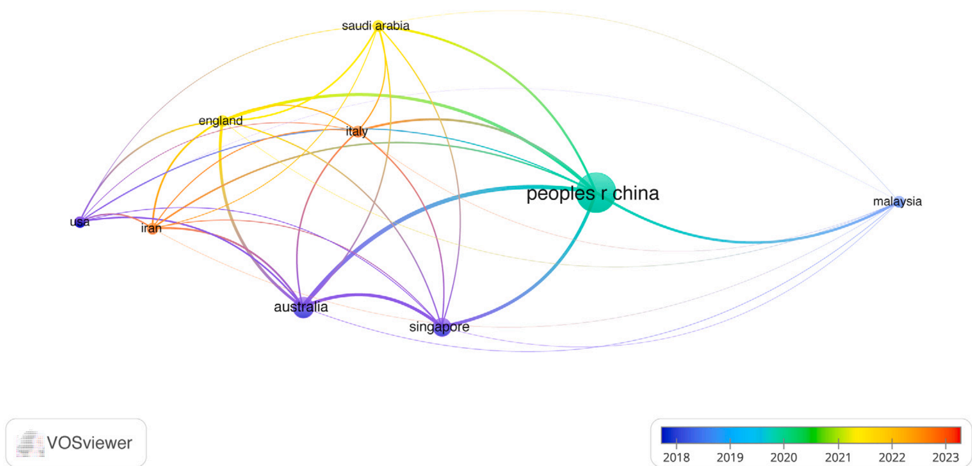


Fig. 5. Co-occurrence analysis of countries in GB projects.

Table 3
Top 10 Journals of selected articles.

No.	Publication titles	Record count	% of 52
1	Journal of Cleaner Production	14	26.9%
2	Sustainability	8	15.4%
3	Building and Environment	4	7.7%
4	Buildings	4	7.7%
5	Engineering Construction and Architectural Management	4	7.7%
6	Sustainable Cities and Society	4	7.7%
7	International Journal of Construction Management	3	5.8%
8	Journal of Building Engineering	3	5.7%
9	Energy and Buildings	2	3.8%
10	Advances in Civil Engineering	1	1.9%

3.2.1. The risk identification process in the GB projects

(1) The methods of identifying risk factors

After reviewing the selected records, the popular risk identification methods focus on quality and quantity methods, like literature review, questionnaire, interview, case study, and focus group discussion. The risk identification process generally contains two steps: Construct an initial risk list with a literature review to get an initial risk list, and then identify critical risk factors through interviews,

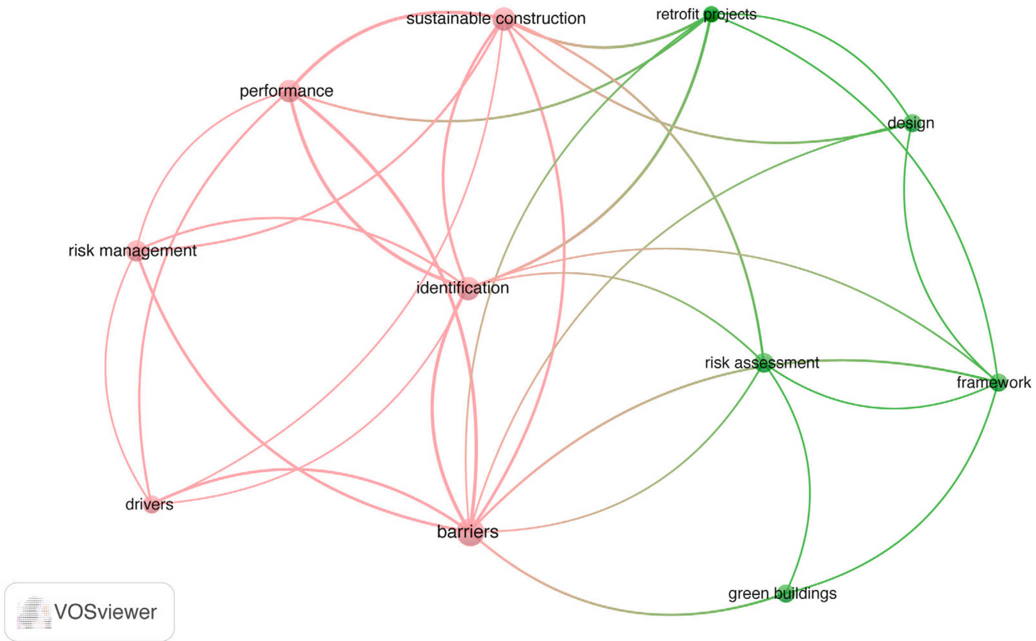
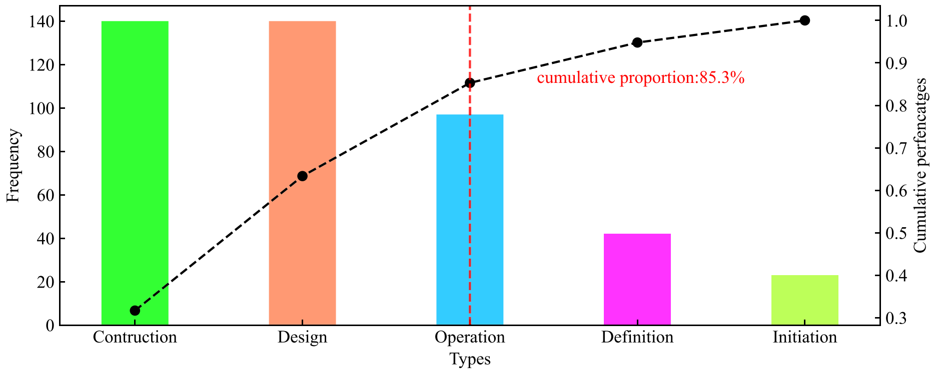
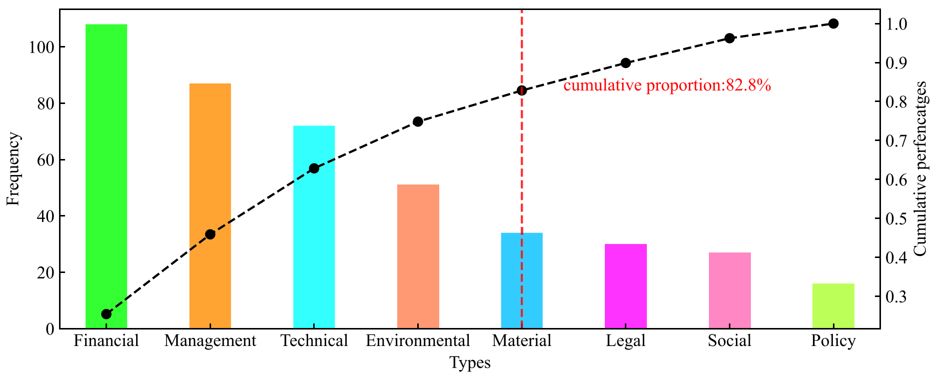


Fig. 6. Co-occurrence of risk management with GB projects. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



(a) Stage risks of GB projects



(b) Types risks of GB projects

Fig. 7. Pareto charts of risks with stages and types on GB projects.

Table 4
Analysis of the keyword network.

Rank	Keyword	Occurrences	TLS	AVG	AC
1	barriers	14	57	2019	61
2	sustainable construction	10	43	2020	32
3	identification	10	40	2020	39
4	performance	9	39	2019	58
5	risk management	8	30	2020	25
6	framework	6	29	2020	37
7	retrofit projects	5	27	2022	15
8	design	6	25	2019	40
9	drivers	6	25	2018	115
10	risk assessment	7	25	2020	25
11	green buildings	6	22	2018	75

questionnaires, or case studies. For instance, Koc et al. constructed an initial list with 69 risk factors through a literature review and then identified 32 risk factors through a focus group discussion [26]. Hwang et al. analyzed risk factors using a comprehensive literature review and structured interviews. The findings not only indicated critical risk factors but also revealed that design change risks and poor construction quality on GB projects are less critical compared to traditional projects [42]. With the BIM platform, the combination of WBS and resource breakdown structure was applied to identify risk factors [69]. Nguyen et al. investigated risk factors by analyzing a questionnaire. Their study presents a list of risk factors at different stages and ranks the most influential risks, such as human resource and technical risks in the construction stage, performance risks during the operation stage, and human resource risks in the design stage [38]. Chan et al. analyzed critical barriers through a literature review and questionnaire, identifying the most significant obstacles such as increased costs, a lack of government incentives, and insufficient financing schemes [35]. Meanwhile, the study revealed significant barriers related to government, human resources, knowledge, market, and cost. Taking Iran as a case study, Kamranfar et al. analyzed risk factors from economic, environmental, cultural, social, and other perspectives through a literature review, questionnaire survey, and interviews. They revealed the significance of economic factors [30]. Unlike most studies, Shen and Li identified risk factors through text mining. The text mining result involved the application of machine learning methods to classify risk factors by analyzing differences among the government, experts, industry practitioners, and the public [66]. To be more specific, Fig. 8 displays the details of risk identification methods.

(2) Identifying risk factors in special countries

The significance of the risk identification process is evident in selected records that focus on identifying risk factors in specific countries. For example, Nguyen et al. conducted a literature review to identify risk factors and then analyzed their influence using a questionnaire in Vietnam. The results indicate that human resource and technical risks are more critical than others during the construction stage, while performance plays the most significant role in the operational stage [38]. Huang et al. conducted a systematic literature review to identify the risk factors of GB projects in China. The review highlighted planning and decision-making risks, design-related risks, construction-related risks, and operation-related risks [57]. In Singapore, a study analyzed 20 risk factors associated with green retrofit projects through a literature review and a questionnaire. The risk factors included pre-retrofit tenants' cooperation risk, regulatory risk, financial risk, etc [10].

(3) Identifying risk factors in special GB projects

In the context of energy retrofitting for residential GB projects, various risks were examined through interviews and a questionnaire to analyze risk factors from the perspectives of stakeholders (including government, homeowners, designers, and contractors) and to classify risk factors based on the projects' life cycle [13]. Hwang et al. conducted a literature review, interviews, and a questionnaire to identify risk factors associated with green commercial buildings. The study revealed several critical risk factors, including inflation, currency and interest rate volatility related to green materials, the durability of green materials, and damages caused by human error [42]. A questionnaire was conducted to collect information on the risk factors impacting green retrofit projects in Sri Lanka, including financial risk, market risk, legislative risk, etc. [14].

(4) Identifying risk factors in special stages of GB projects

The design stage plays a crucial role in GB projects, particularly in managing design changes, design errors, and design materials. Therefore, the selected records focus on identifying risk factors specific to certain countries and consider the risk factors associated with special-stage GB projects. For instance, Li et al. identified four types of design risks through a literature review. These include design risk factors related to design technical, design management, design behavior, and green certification risk [16]. When it comes to design requirements and construction materials in GB projects, it is important to identify more risks compared to traditional projects. Wan et al. collected risk factors associated with energy performance contracts through a literature review [70]. These factors were classified into political, economic, financial, etc. Wan et al. also developed a three-stage risk allocation model for commercial buildings in China based on risk aspects. Nguyen et al. developed an initial risk list through a literature review and subsequently enhanced the list using a questionnaire. The questionnaire addressed human resources and technical risks during the construction stage, performance risks during the operation stage, and risks during the design stage [8].

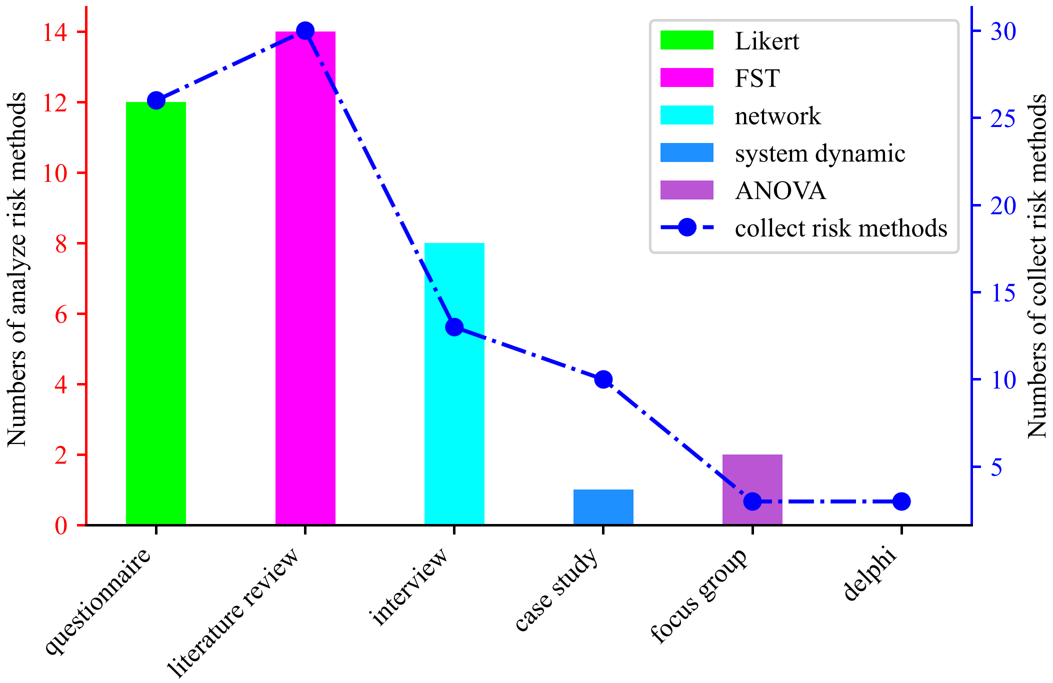


Fig. 8. Frequency of risk identification methods.

3.2.2. The risk assessment models in the GB projects

The selected records primarily focus on fuzzy sets, SNA, and ISM to develop risk assessment models. These three methods focus on different aspects. For instance, the risk assessment model using fuzzy sets to display risks' probabilities and impacts. With SNA or ISM, risk assessment models pay attention to relationships between risks and stakeholders.

(1) The risk assessment model with fuzzy sets

According to Ref. [8], the evaluation of risk factors using fuzzy set theory, which takes into account the probability of occurrence (P), the magnitude of impact (I), and risk manageability (M) ($risk\ assessment = \sqrt[3]{P \times I \times M}$). The fuzzy synthetic evaluation model was used to calculate the most significant risk factors based on the degree of risk groups, which were determined by the occurrence probability and impact level, as well as the overall risk. For example, Zhao et al. utilized a fuzzy synthetic evaluation method to assess the risk factors associated with Singaporean green projects, considering the likelihood of occurrence, magnitude of impact, and risk criticality. Their findings indicate that inaccurate cost estimation stands out as the most significant risk [25]. After identifying risk factors through a literature review and interviews, Issa et al. constructed a risk analysis model using the fuzzy logic method. This model considers the presence of risk factors, their impact on the process, and their influence on performance [36]. A fuzzy AHP and TOPSIS were utilized to examine the roles of stakeholders concerning risk factors, including risk impact, risk probability, and manageability. This analysis identified the most significant risk factors and their associated stakeholders [26]. In addition to general risk factors, green finance is a prominent subject in GB projects. For instance, Dai et al. utilized the fuzzy VIKOR method to evaluate the significant risks, demonstrating that the expansion of financing tools is essential in mitigating green financial risks [37]. Regarding the benefits of green roofs in social, environmental, and personal contexts, Tabatabase et al. utilized the Monte Carlo-DEMATEL method to examine the interrelationships of risk factors. Then subsequently ranked these risk factors using a fuzzy parsimonious analytic network, which effectively displays the most significant barriers and opportunities for green roofs [58]. Huo et al. constructed a risk evaluation model using the C-OWA operator and a grey cluster analysis to assess the risk factors associated with green retrofit projects. The model provides risk management strategies based on different levels of risk [12]. Nguyen et al. employed a fuzzy synthetic evaluation method to analyze risk factors, demonstrating the significance of these factors and highlighting key issues such as the lack of experience among GB designers and human resources risks during the design stage [24]. Ref. [49] developed a holistic Z-numbers risk management model to systematically assess occupational health and safety risk factors using a five-level strategy, which displays the significance of fall hazards to safety. This model highlights the importance of fall hazards about safety risks. Dalirazar and Sabzi classified barriers using the PESTLE technique into political, economic, social, technological, legal, and environmental factors. Their analysis revealed that the most significant barriers are social and economic, such as 'high initial costs', 'lack of demand for sustainable buildings', and 'long payback period and investment risks' [55].

(2) The risk assessment model with social network analysis

The SNA utilizes mathematical techniques to assess risk factors from a network-oriented viewpoint. In an SNA, risk factors are depicted as nodes, different patterns are used to represent stakeholders, and distinct stages are indicated by different colors. For instance, Wang et al. utilized SNA to detect risk networks in the initial phases. Their findings suggest that the primary risk factor is the 'low communication efficiency between partners', while the key stakeholder is the 'contractor' [51]. Yang, et al. developed an SNA to evaluate the relationship between risks and stakeholders, illustrating risk mitigation measures such as addressing critical risks, mitigating risks by cutting off the main interactions, and mitigating risks by improving communication among stakeholders [54]. Ref. [57] applied SNA to illustrate networks of risk occurrence and risk harm across various life stages and respondents. This approach not only indicates the connections between risk factors and networks but also reveals the relationships among respondents' age, risk occurrence networks, and risk harm networks. Ma et al. applied SNA to display the significant risk factors associated with stakeholders, demonstrating that the most critical risk factors are related to contractors [40].

(3) The risk assessment model with interpretive structural modeling

A hybrid system dynamics ISM approach was developed to analyze the influence between risk factors and project behavior in the design stage of GB projects [71]. Regarding the lack of analysis of the interdependencies of GB risk, Guan et al. analyzed risk interdependencies using ISM, considering the life cycle and multiple project risks. The study revealed that the most significant factors are the unclear requirements of project implementation, ambiguous contracts, and design errors [5]. An integrated method combining the fuzzy-ANP-ISM method was developed to assess the manageability of supply chain risks in GB projects, as opposed to focusing on the severity of impacts or the probability of occurrence [27]. Regarding the significance of design risks to the performance of the operation stage, Li et al. applied structural equation modeling to analyze risk factors and performance during the operation stage, revealing a positive correlation between design risks and performance [16]. Wuni et al. constructed a hierarchical analysis structural model among various risk factors, which provides suggestions for risk allocation [15].

(4) Risk assessment process with other technologies

Given the constrained efficiency of assessing risks with individual expertise and accessible design information, there is a need to establish a framework for managing risk knowledge using ontology and semantic web technology within the context of the BIM environment. For instance, integrating ontology and semantic web technologies with BIM was applied to manage construction hazards, including identifying risk factors, reasoning about risk paths, and recommending risk prevention plans [72]. The risk register and Revit program were integrated to combine risk information with the Dynamo program, allowing for the display of risk data such as risk score and risk status [73]. With the ontology theory and the Revit software, Shen et al. constructed a monitoring system for evaluating the performance of safety risk management in prefabricated buildings [74]. Several risk management databases have been constructed to analyze the benefits of BIM, such as the risk database of BIM-cloud [75], BIM-3D GIS framework [76], and BIM-based MiC risk management [77].

4. Discussions

This systematic literature review aims to study the risk management process of GB projects. Following a bibliometric analysis and thematic analysis of risk management in the selected records, two key findings regarding risk management in GB projects have been identified: risk identification and risk evaluation. The discussions of risk identification and risk evaluation process are presented as follows:

(1) Risk identification of GB projects discussions

As depicted in Fig. 7, the predominant risk identification methods consist of questionnaires and literature reviews, accounting for more than half of selected records. This indicates that most of the selected records utilized a systematic literature review to develop a risk list, subsequently collecting critical risk factors through questionnaires or interviews. Consequently, the risk identification methods are challenges for the development of risk management in GB projects.

Moreover, the selected records identify risks not only in specific countries and special GB projects but also at different stages. These records highlight the differences in risk factors within Vietnam, China, and Singapore. Nevertheless, the process of identifying risk in other countries, such as the U.S., U.K., Australia, and others, is deficient. Moreover, the selected records predominantly identify risk factors during the design and operation stages. Furthermore, this study also revealed specific GB projects in the selected records, such as GB commercial projects, GB residential projects, green retrofit projects, and others.

(2) Risk evaluation of GB projects discussions

The study revealed risk evaluation models with different methods. These models consider the probability of occurrence, the severity of impact, and risk management. Notably, most risk assessment models assess information with fuzzy sets, whereas the utilization of linguistic fuzzy sets in risk assessment models is relatively infrequent. Furthermore, the study also revealed that the risk evaluation model prefers to apply decision-making models, like TOPSIS or VIKOR. However, there is a limited number of studies that utilize linear programming in risk evaluation models to enhance the efficiency of risk management.

In light of the significance of risk and stakeholders in the risk management process, some selected records illustrated the relationship between stakeholders and risk factors. For instance, the selected records revealed the relationship between critical risk factors and contractors. Considering the significance of design risk factors in GB projects, the selected records studied the relationship between design risks and the performance of GB projects. Nevertheless, there is a lack of exploration regarding the relationship of specific risks at different stages or the relationship of the same stakeholder at different stages.

It is noteworthy that existing research has demonstrated the risk identification process through various risk identification methods and specific risk factors. This study simultaneously presents risk evaluation models based on fuzzy sets and explores the relationship between risks and stakeholders. Therefore, future research directions should concentrate on identifying risks, evaluating risks, and risk mitigation processes to enhance the efficiency of risk management.

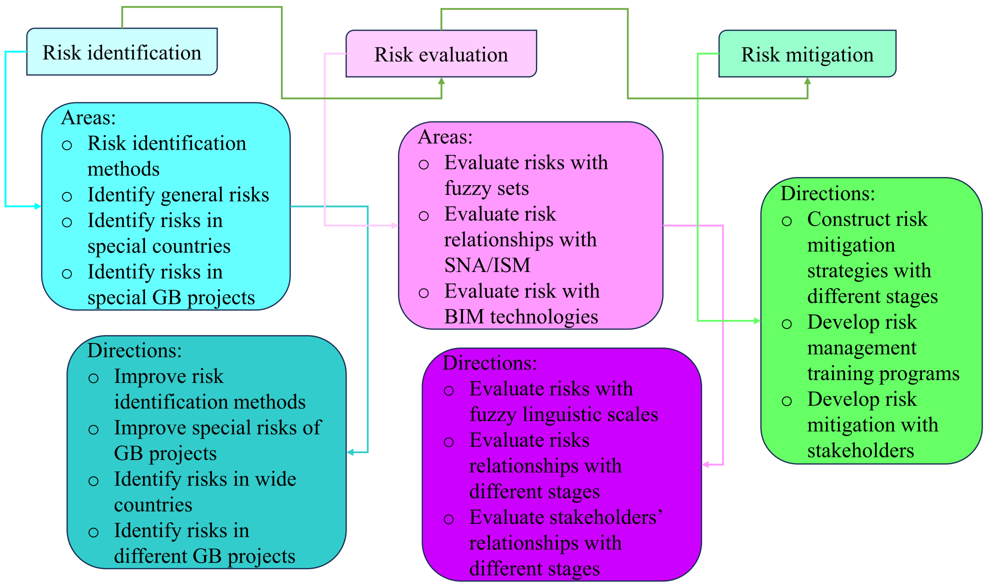


Fig. 9. Framework of research areas and directions for risk management.

5. Research gaps and future directions of risk management on GB projects

Regarding the thematic analysis in Section 3, this part analyzes research gaps and directions with a framework in the existing research areas (see Fig. 9).

5.1. Research gaps of existing risk management in GB projects

(1) The spotting of risk identification on GB projects

Existing studies primarily emphasize quality methods such as questionnaires, literature reviews, and case studies for risk identification. Quantitative methods are often overlooked, potentially resulting in inconsistent risk identification compared to the actual situation.

The lack of extensive research on the financial risks associated with GB projects represents a notable gap in the existing literature. Financial risks in the context of GB projects typically encompass increased costs, longer payback periods, and the unpredictability of future energy prices resulting from the adoption of novel technologies and materials. Insufficient research on financial risks poses challenges for project stakeholders in effectively managing these risks. Consequently, further research is required to analyze the financial risks of GB projects.

The necessary research on social and environmental risks in GB projects needs attention. The GB projects are associated with social and environmental risks, such as energy efficiency, human comfort, and environmental impact. Research on social and environmental risks can assist professionals in developing effective risk assessment models and associated risk allocation models in GB projects [78]. Furthermore, further research into social and environmental risks provides suggestions for enhancing the social impacts of GB projects.

(2) The spotting of the risk assessment process on GB projects

The primary focus of risk assessment for the selected records is on the risk assessment models. Therefore, the gaps in risk assessment focus on risk assessment models and the assessment of specific risks. Existing studies utilize risk assessment models that represent information using fuzzy sets associated with fuzzy variables rather than fuzzy linguistic scales. Nevertheless, GB projects involve new technologies, materials, and design approaches that may require the use of fuzzy linguistic scales for expression. The absence of fuzzy linguistic scales presents a challenge in developing risk assessment models for supporting managers, designers, and constructors in analyzing risk factors. Identifying specific risks is crucial for GB projects, and developing a specific risk assessment model is necessary to enhance risk evaluation processes.

Moreover, the limited variety of risk assessment models may represent another deficiency in developing risk assessment. In selected records, the risk assessment models involve the analysis of risk networks and the evaluation of risk significance using methods such as SNA, ISM, fuzzy sets, and others. When it comes to risk network models, the majority of studies concentrate on the network between stakeholders and risks. Limited records illustrate the relationship between the risk occurrence network and the risk harm network [57]. Moreover, the lack of risk assessment for special risks is a notable deficiency in GB projects. In light of the attributes of GB projects, the adoption of novel technologies and materials could potentially give rise to distinct risk factors, including health risks [49], green supply risks [27], and green finance risks [37]. Therefore, it is necessary to address the absence of specific risk assessment models to enhance the risk management developments of GB projects.

(3) The spotting of risk handling process

The absence of risk-handling studies for the selected records represents a significant research gap in the risk management process of GB projects. The extensive knowledge of risk mitigation from traditional construction projects provides valuable research directions for GB projects. Insufficient research on risk mitigation strategies includes risk treatment at different stages, strategies for addressing risks with different stakeholders, and alternatives for mitigating specific risks.

Firstly, there is a significant research gap in the strategies for managing risks at different stages. Similar to traditional projects, the strategies for managing risks may vary for each stage. Especially, the risk-handling strategies should be addressed carefully during the design, construction, and operation stages (see Fig. 8). For instance, the utilization of new technologies and environmentally friendly materials entails the need for strategies to address special design requirements and modifications. The update of new technologies, various operation scenarios, and safety risks during operations are essential, highlighting the significance of implementing strategies for managing risks.

Furthermore, it is crucial to identify and mitigate risks by considering the roles of stakeholders. Unequal distribution of benefits among stakeholders can result in the adoption of varying risk allocation strategies. Hence, it is essential to implement appropriate risk-handling strategies to effectively allocate risks by considering the perspectives of stakeholders. Furthermore, addressing the research gap in allocation strategies for specific risks is essential. The absence of risk assessment models for specific risks has resulted in a dearth of research on effective mitigation strategies for these specific risks in GB projects.

(4) The spotting of risk management in various countries

Moreover, various factors will need to be addressed in the future by different countries. Several critical factors must be addressed for the development of GB projects in developing countries. Like Sri Lanka, it is essential to analyze the critical risk factors of green retrofit projects, such as construction cost, inflation, project completion delays, as well as productivity and quality risks [14]. Assylbekov et al. identified the absence of expertise, government support, and the high cost of sustainable materials and products as crucial factors in risk management for GB projects in Kazakhstan [79]. Liu et al. believed that the lack of financial support, knowledge, information, professional training, and regulations needs to be effectively addressed in GB projects in China [80]. In the context of Vietnam, the barriers are divided into social cognitive, economic cost, legislative institutional, and technical knowledge barriers [81]. Nguyen et al. identified barriers in Vietnam related to workforce, technical aspects, and performance across the design, construction, and operation stages [38].

The most significant critical risk factors for developed countries include economic, institutional, and technical design. Like Australia's GB projects, the primary challenges include high investment costs and uncertain future legislative benefits, inadequate enforcement of green-washing regulations, and the absence of life-cycle management factors for GB projects [82]. The critical risk factors for the growth of GB in Singapore include the adoption of new construction techniques and the ambiguous demands of clients [83].

5.2. Research directions of existing risk management in GB projects

In terms of research gaps of risk management in GB projects, the related research directions are displayed in three aspects:

(1) The direction of identifying specific risk factors

For GB projects, the specific risk factors include two types: financial risk and social and environmental risk. The high cost of GB projects has become a prominent issue despite their green material usage, low energy consumption, and reduction of carbon emissions. Consequently, it is imperative to address the financial risks associated with GB projects, including huge costs of materials, long payback periods, and uncertain energy prices. Therefore, further research should focus on the financial risk of GB projects. Moreover, the environmental friendliness of GB projects represents a notable advantage, underscoring the importance of environmental risk factors. Therefore, further research should also focus on the social and environmental risks of GB projects, including human emotions, social effects, and unintended environmental effects.

(2)The direction of developing risk evaluation models

Considering the constraints of risk assessment models, it is imperative to develop effective risk evaluation models. Given the presence of uncertain conditions, the existing risk evaluation model expresses information with fuzzy sets. Assessing the effectiveness of environmentally friendly materials, green design strategies, and longer payback with fuzzy sets in GB projects becomes difficult. In this regard, it is effective to construct thorough risk assessment models with fuzzy linguistic scales, such as the probabilistic linguistic term set [84], the linguistic term with weakened hedges [85], and fuzzy Petri nets [86]. The probabilistic linguistic term set considers information from linguistic terms and probability theory. The linguistic term with weakened hedges analyzes risk information using linguistic terms and weakened hedges, while fuzzy Petri nets analyze information with fuzzy logic rules. This approach not only considers stakeholders' perspectives but also reduces the impact of uncertain information on the risk management process.

Moreover, existing research evaluates risk networks with SNA or ISM by considering relationships between risk factors and stakeholders. The significance of risks and stakeholders in GB projects may vary with the use of novel materials, new design plans, and green technologies. Therefore, further research needs to study the relationship between the same risk factors and stakeholders at different stages. This includes analyzing the relationship between design risk during the design and construction stages, the relationship of financial risk between the construction stage and operation stage, and the relationship of different stakeholders at different stages.

(3) The direction of mitigating risk factors

In light of the research gap concerning risk mitigation in GB projects, there is a need to develop effective risk mitigation strategies. The related risk factors of the utilization of new technologies and the procurement of green materials need to be addressed. Furthermore, it is crucial to develop risk management training programs. These programs can assist stakeholders in comprehending the implementation of new technologies or materials in GB projects, thereby enabling them to effectively manage associated risk factors. Hence, risk mitigation strategies should address not only general risk factors but also the mitigation of specific risk factors.

6. Conclusions

This study conducted a systematic literature review of risk management in GB projects, which included a bibliometric analysis and content analysis. The bibliometric analysis addressed Q1 by analyzing the frequency of selected articles, research areas, journals, and countries. The response to Q2 is displayed through a thematic analysis, which presents topics from the process of risk identification and risk evaluation. The research gaps and research directions are revealed based on thematic analysis, providing the answer to Q3. The key findings and related contributions of this study are summarized as follows:

(1) The bibliometric analysis analyzed risk management in GB projects using 52 selected records and specific keywords. As indicated by keywords and research areas, engineering, and environmental studies are two widely researched areas. Furthermore, risk identification and assessment were significant research topics (see Fig. 5). However, there is a need to explore co-occurrences of risk management, such as design risks, retrofit projects, and barriers. Therefore, it is essential to study the significance of risks in the design stage and green retrofit projects.

(2) This study conducted a thematic analysis of GB projects' risk identification and risk evaluation. Initially, risk factors for GB projects are identified through quality methods such as literature reviews and questionnaires. Considering the characteristics of these identification methods, it is imperative for future research to study efficient risk identification methods. Moreover, specific risk factors for special GB projects, such as design risk, social risk, and supply chain risk in green commercial or retrofit projects, have been identified. Subsequently, this study analyzed the information expression of risk evaluation models, such as fuzzy sets, SNA, and ISM tools. The evaluation models are constructed to assess risk factors and demonstrate the relationship between risk factors and stakeholders.

Some limitations need to be addressed. In the bibliometric analysis aspects, the selected records were restricted to English-language academic papers, excluding non-academic reports. The bibliometric analysis was limited to two databases, namely Web of Science and Scopus. Besides, the keyword analysis did not consider centrality networks and clustering. Moreover, from the perspective of thematic analysis, this study may not provide a more thorough analysis of risk management in GB projects. For instance, the classification of critical risk factors needs to be addressed. Nevertheless, the limitations and prospects of risk management in GB projects have been investigated in this research. These findings contribute to an improved understanding and management of risk factors in GB projects by researchers and practitioners.

CRediT authorship contribution statement

Lina Wang: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **Daniel W.M. Chan:** Supervision, Writing – review & editing. **Amos Darko:** Supervision, Writing – review & editing. **Benjamin I. Oluleye:** Writing – review & editing.

Declaration of competing interest

We confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

Data availability

No data was used for the research described in the article.

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