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REVIEW

# Risk management in green building: a review of the current state of research and future directions

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## Abstract

There has been considerable interest in investigating risk factors in Green Building (GB) projects, with increasing debates in recent years. This study aims to investigate tendencies and identify gaps in the GB risk literature, which can define future research guidelines, with an extensive analysis of the latest contributions. A systematic literature review was conducted by analyzing 64 relevant studies from 2006 to 2020. The results revealed that the GB risk topic is somewhat nascent but growing and almost limited to several countries, including Singapore, the USA, Australia, and China. Notably, this research discovered and classified the main themes of GB risk studies: (1) identify risk factors in implementing GB projects, (2) create risk assessment models for GB projects, (3) study according to specific types of GB risks, and (4) investigate risks in green retrofit projects. Also, a comprehensive list of GB risk factors was provided that could be a helpful reference for industry practitioners and future researchers. Furthermore, this research identified gaps in the current literature, such as inconsistency in identifying GB risk factors, lack of investigation of the relationship between GB risks and project outcomes, and lack of exploring in cross-country or developing countries. Finally, this research suggested future research directions to enrich the literature. Thus, this study contributes a valuable platform for both practitioners and researchers to comprehend the development of the GB risk literature.

**Keywords** Risk · Green building · Sustainable construction · Systematic literature review

## 1 Introduction

The construction industry plays an essential role in the development of any country. However, the construction industry also contributes significantly to environmental pollution and global climate change. Kientzel and Kok (2011) stated that construction activities provide significant greenhouse gas emissions and other environmental pollutants. According to

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previous research, the construction industry has a considerable impact on raw materials since consuming 40% of stone and sand, 25% of natural wood, and 16% of water across the globe (Robichaud & Anantatmula, 2011). Similarly, another research also claimed that construction buildings use 70% of timber worldwide (Thilakaratne & Lew, 2011). Also, more than 30% of global energy is consumed by construction buildings (Berardi, 2017). Moreover, traditional buildings increase environmental pollution by generating a large amount of waste during their life cycle (Li et al., 2016).

In this context, Green Buildings (GB) has been recognized as a potential resolution to mitigate adverse effects on the environment of construction activities. In the literature, the concepts "sustainable construction," "green construction," and "high performance" have been frequently used interchangeably. Nevertheless, the concept of "sustainable construction" most comprehensively considers construction buildings' ecological, social, and economic aspects (Kibert, 2016). Notably, "Green Building" is usually used interchangeably with "sustainable construction" (Woolley & Kimmins, 2003). According to Kibert (2016), GBs refer to the buildings' quality and characteristics created using sustainable construction principles and approaches. From the view of Yudelson (2010), GBs are high-performance buildings that have a low influence on the environment and people's health and resource consumption effectively (e.g., water and energy).

According to previous studies, GBs concentrate more on environmental and social aspects than traditional buildings (Ahmad et al., 2019). Research in Australia and New Zealand showed that, compared to traditional buildings, GBs emit 33% of greenhouse gases, consume 33% of electricity and water, and recycle around 96% of demolition waste (Economics, 2014). Another research also demonstrated that GBs could reduce the threats posed by growing urbanization, energy consumption, and emissions (Dean et al., 2016).

Nowadays, the number of GBs has been increasing, and the term "Green Building" has become more popular worldwide. Many developed countries established GB standards, such as LEED (the US), BREAM (the UK), Green Star (Australia), and Greenmark (Singapore). These countries also pioneered the inception of the GB tendency. Also, developing countries have paid attention to GB development, which could be seen through their GB standards and the number of GBs in these countries (Analytics, 2018). Notably, GB standards were developed to apply to various building types, such as residential, commercial, or industrial buildings. So, the term GB refers to a building that satisfies GB standards regardless of the kind of building.

Furthermore, GB-related topics have been attractive to academics. In line with GB development, GB research began in 1990, and the number of studies has risen considerably over the years (Darko & Chan, 2016). These studies have somewhat promoted sustainable development worldwide and thus contributed to protecting the environment. So far, there have been hundreds of articles on the subject of GBs (Darko & Chan, 2016; Goel et al., 2019).

However, the development of sustainable construction still encounters many hindrances such as economic feasibility, awareness, support from project stakeholders, legislation, and resource risks (Gan et al., 2015). Among these, risk factors in implementing GB projects (e.g., inaccurate cost estimation, workforce constraint, and green material unavailability) have been recognized as a significant obstacle by academics and construction practitioners (Ahmad et al., 2019). Risks seem to be a common problem in GB projects as Latham (1994) claimed that "No construction project is risk-free." Indeed, construction projects frequently face various uncertainties, such as finance, technology, and weather (Taroun, 2014). Furthermore, the risks are often dissimilar among different project phases, such as design, construction, and operation (Xia et al., 2018). These findings highlight the complexity and risks that construction projects in general and GB projects, in particular, have to confront. This also implies that risks should be appropriately managed in implementing construction projects (Chapman & Ward, 2004; Du et al., 2016), especially in complicated and distinct construction projects like GB projects.

Similar to conventional projects, GB projects also confront common risk factors in the construction industry. However, though GB projects and conventional projects face similar risk factors, the critical level of these risk factors on each type of project is significantly different due to the distinct features of GB projects (Qin et al., 2016). Moreover, GB projects confront more risks than conventional buildings because of sustainability goals in addition to common goals such as cost, schedule, and safety (Hwang, 2017b; Yang & Zou, 2014). This is not surprising as GBs utilize the latest construction technology and innovative materials to achieve sustainability; thus, these processes are potentially plagued with diverse and complex risks. For example, there are potential problems in using green materials because they may not have undergone adequate testing or a shortage of qualified personnel to use them properly. Also, handling authority regulatory requirements (e.g., contractor selection, using land, and recycling) is frequently not straightforward. Therefore, Risks associated with GB projects (RGB) need to be managed appropriately to achieve success (Guan et al., 2020).

Recently, the RGB topic has received rising interest from academics and construction practitioners (Ahmad et al., 2019; Darko & Chan, 2016). This can be seen through the number of published studies per year. However, RGB studies are still fragmented. Although several studies attempted to review the GB literature, no study has reviewed the RGB literature as far as we know. Previous research reviewed the GB literature in general and investigated several central topics in this area: barriers, benefits, critical success factors, project delivery attributes, and risks (Ahmad et al., 2019). However, due to covering too many issues, such review papers could not provide detailed information about the risks aspect in GB projects, which has emerged as a crucial problem in the development of GB. Given this scenario, investigating the state-of-the-art in the RGB literature is appropriate.

This research aims to explore the body of knowledge associated with risks in GB projects. To accomplish this, this study conducted the systematic literature review (SLR) to detect emerging trends and gaps that might lay the foundation for future research. The results could contribute to the GB literature by providing a comprehensive and transparent view of the RGB literature. Notably, this research identified gaps in the literature by analyzing the methodologies, region, and content of previous studies. Based on the identified gaps, future research directions were also suggested, which might be helpful as references for future research.

To sum up, this review aimed to answer three research questions: (RQ1) What are the features and trends/themes of current studies on the RGB topic? (RQ2) What are the gaps in the current RGB literature? (RQ3) What are the directions for future research?

This research was organized as follows: Sect. 2 presents the research methodology applied to conduct the literature review; Sect. 3 and Sect. 4 analyze the collected data and present results to answer RQ1; Sect. 5 discusses gaps in RGB literature (RQ2) and suggests future research direction (RQ3); and finally, Sect. 6 presents conclusions about contributions and limitations of this research.

## 2 Review methodology

According to previous studies, the literature reviews can help researchers synthesize existing knowledge and identify gaps for future research (Taroun, 2014; Xia et al., 2018). Regarding the literature review methods, the methodology described by Denyer et al. (2003), named "systematic literature review," is acknowledged as valuable by numerous researchers (Danese et al., 2018; Mihalache & Mihalache, 2016; Xia et al., 2018). Notably, SLR could help to reduce errors and complement the traditional unstructured review method (Tranfield et al., 2003). With a replicable, scientific, and transparent process, SLR could enhance traditional methods by:

1. Minimizing bias and errors by the exhaustive literature and providing an audit trace of the procedures and conclusions of reviewers (Tranfield et al., 2003);
2. Improving the rigor of review processes and quality of results. (Mihalache & Mihalache, 2016);
3. Synthesizing and organizing the literature content in a particular domain (Wang & Chugh, 2015).

SLR employs data-extraction procedures to reduce subjective error and bias (Mihalache & Mihalache, 2016). According to Tranfield et al. (2003), SLR methods regularly investigate general information (e.g., research title, authors, and publication information), research context, methodology, and emerging topics coupled with synthesis details. From that, SLR help to expose paradigms of the current knowledge. Also, SLR could be applied in various fields such as construction (Ahmad et al., 2019; Taroun, 2014), entrepreneurial learning (Wang & Chugh, 2015), and Lean management (Danese et al., 2018). In this study, the authors adopted the SLR in three stages, which several authors suggested (Mostafa et al., 2016; Xia et al., 2018). Figure 1 summarizes the process of this SLR through three steps.

### 2.1 Stage 1: planning and computer search

This stage involves planning and searching RGB-related papers by academic databases. The planning of SLR comprises creating research keywords and research protocol (Tranfield et al., 2003). The research keywords were determined based on the research questions reported in Sect. 1, while the research protocol of the SLR is illustrated in Fig. 1. Relevant articles published in the English language were obtained by searching in scientific databases. Review articles, journal articles, book chapters, review conference proceedings, and book reviews were identified using two academic databases, including Web of Science (WOS Core collection database) and Scopus.

The rationale for using these databases is their reputation and the relevant publications. Scopus is considered to have a broader scientific publishing range than WOS (Falagas et al., 2008). However, the WOS core collection database has many reputed journals and covers articles for a more extensive range of years, as Scopus is limited to papers published after 1995 (Falagas et al., 2008). Notably, WOS and Scopus were used in most previous review research associated with GBs (Ahmad et al., 2019; Zhao et al., 2019).

The search rule conducted in the title/abstract/keyword of the articles in the databases was ("green building" OR "sustainable building" OR "low-carbon building" OR "zero-energy building" OR "high-performance building" OR "green construction" OR

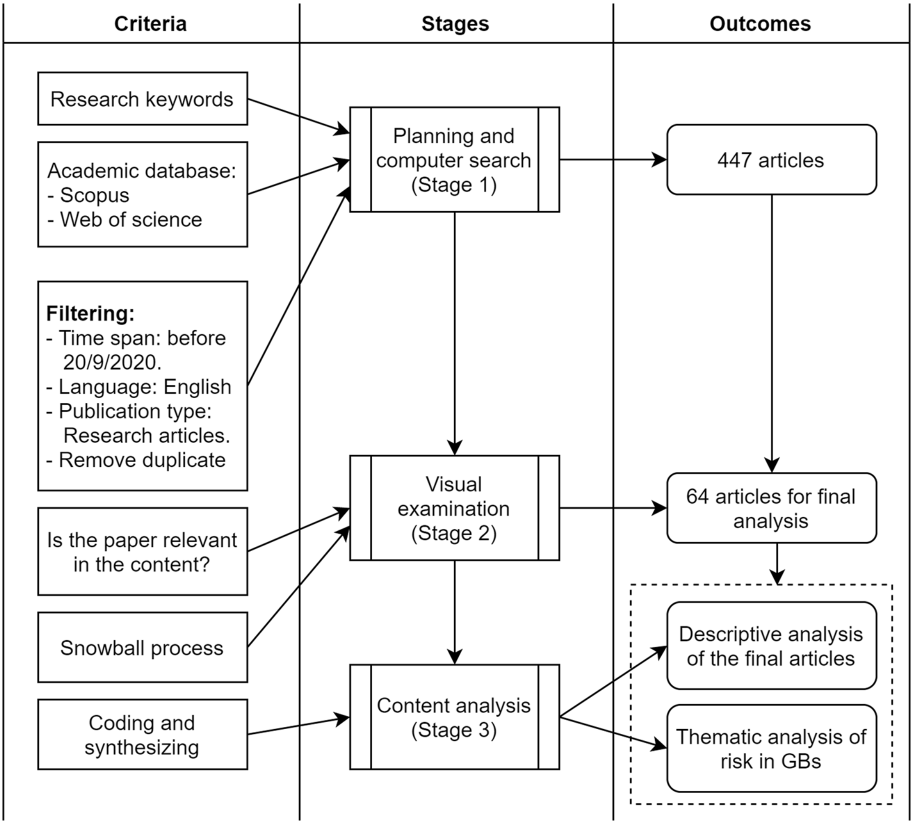


**Fig. 1** Summarize the stages of SLR in this study

"sustainable construction" OR "low-carbon construction" OR "zero-energy construction" OR "high-performance construction") AND ("risk"). The scope of the search was restricted before 20th September 2020. As a result of this stage, after removing duplicated papers by the automatic tool in these scientific databases, a total of 447 documents were collected for further analysis.

## 2.2 Stage 2: visual examination

This state relates to removing irrelevant papers. The inclusion and exclusion criteria are illustrated in Table 1.

Firstly, the authors read the titles, keywords, and abstracts to exclude unrelated papers that did not consider risks or construction sustainability in GB projects. For example, the papers that only examined the benefits or indoor environment of GBs were removed. After this step, 162 articles were retained.

Secondly, the content of remain articles was examined to choose the most relevant papers. The papers would be excluded for two reasons: they did not consider risks in GB projects or were not found in prestige journals/conference proceedings (in Scimago). As a result, the number of papers was narrowed down to 54.

**Table 1** Inclusion and exclusion criteria

| | Inclusion/exclusion | Rationale |
|---|---|---|
| 1. Selection of journals | • Peer-reviewed English language journals, book chapters, and peer-reviewed conference proceedings | • Because this topic is still developing, the number of research is relatively limited<br>• These criteria ensure to find out every previous research on this topic |
| | • The journals in Scopus or Web of Science (Core collection database)<br>• The journals that have scope somewhat fit with the RGB topic | • The aim was to identify reliable journals on different topics with high scientific value and research interest in the RGB field |
| 2. Selection of time range | • Before 20th September 2020 | • The period was long enough to find the latest studies on the RGB topic |
| 3. Selection of articles | • The papers use the research keywords in their title, abstract, and keywords | • As the interest field is relatively nascent, the authors supposed these keywords sufficient to capture every study on this topic |
| | • Exclusion criteria: The papers do not concern RGB (by full reading papers) | |

Finally, all selected papers were read carefully again. Based on their references, the authors found ten interesting articles somewhat related to the RGB topic but not included in the 54 original articles. These papers were not found in the searching process because they did not contain the searching keywords in their title and abstract. Among the ten papers, five papers are review papers about GB literature, while the other papers studied barriers in GBs. Thus, these studies did not directly explore RGB and only considered risks in their contents. However, they are still somewhat associated with the RGB topic. Finally, 64 papers were selected for content analysis (Fig. 1). These articles comprise 55 journal articles and nine conference articles from 2006 to 2020.

### 2.3 Stage 3: the content analysis

Finally, the content analysis technique was carried out to analyze the collected papers. This method could identify the focus of the subject matter and discover emerging patterns in the current RGB literature (Elo & Kyngäs, 2008). This process has two parts: descriptive analysis and thematic analysis (Xia et al., 2018).

In the descriptive part, the authors carefully read all collected papers to detect and organize the necessary information according to features such as "year of the publication," "country of the research," "authors," and "research methodology." During this process, the authors also created the codebook based on the content of the reviewed papers. The initial codes could be edited and updated depending on the discovery in the analysis process (Xia et al., 2018). Table 2 presents the final codebook adopted in the descriptive analysis process.

In the thematic analysis step, the authors implemented an in-depth investigation of the collected papers' contents. Thus, the thematic analysis could find out the themes and

**Table 2** The codebook for content analysis

| No | Code | Description |
|---|---|---|
| 1 | Year | Year of publication |
| 2 | Article title | Title of the article |
| 3 | Journal title | Publication |
| 4 | Journal ranking | Based on the assessment of Scimago Journal Ranking (H-index, impact factor, quartiles) |
| 5 | Research design | Survey, case study, mathematical modeling, conceptual study, and critical literature review |
| 6 | Data collection methods | Questionnaires, interviews, and document review |
| 7 | Research method | Quantitative and qualitative method |
| 8 | Region | Countries where collected data |
| 9 | Author | Name of the authors |
| 10 | Author's country | The countries were affiliated with the authors |
| 11 | Risk type | Categorization of risks according to their characteristics |
| 12 | Project phase | Design, construction, operation phase |
| 13 | Research objectives/questions | Research objectives and questions identified in the paper |
| 14 | Major findings | Significant findings indicated in the paper |
| 15 | Contributions | Contributions identified in the paper |
| 16 | Limitations | Limitations clearly stated in the paper |

methodologies used in the RGB literature. Because this step aims to identify the RGB studies themes in the literature, the authors only analyzed 59 RGB articles. The remaining five review papers were used as references and helped check the results. Notably, the current research gaps were also identified based on analyzing the findings and limitations of the reviewed studies.

## 3 Descriptive analyses

In this section, the authors present the descriptive analysis of the 64 collected papers. These papers were analyzed according to the codebooks illustrated in Table 2. The results can provide an overview of the current RGB studies and thus answer the research question RQ1.

### 3.1 General considerations

This section describes the findings acquired from analyzing the codebooks: "Journal title," "Journal ranking," and "Year of the publication." The reliability of collected papers was considered via H-index and Quartiles of the corresponding journals based on the Scimago Journal Rankings assessment (Danese et al., 2018). Also, the number of published papers in each journal was counted.

Firstly, the results showed that most articles are from reputation journals with good Quartiles and high H-index. The Q1 and Q2 ranking journals accounted for approximately 72% (46/64). Most journals have just published one or two RGB papers. However, there are still some journals that have a significant number of RGB publications. Among these journals, the Journal of Cleaner Production had the most publications (13 articles). Sustainability was in the second position with six articles. The third position was the Journal of Construction Engineering and Management, with four papers. This result proves that the collected articles are reliable and suitable for further analysis.

Secondly, to assess the research tendency, Fig. 2 illustrates the number of published articles per year from 2006 to 2020. As shown, the number of papers per year was relatively few. This result is not surprising as this SLR focused on a specific topic of the current GB

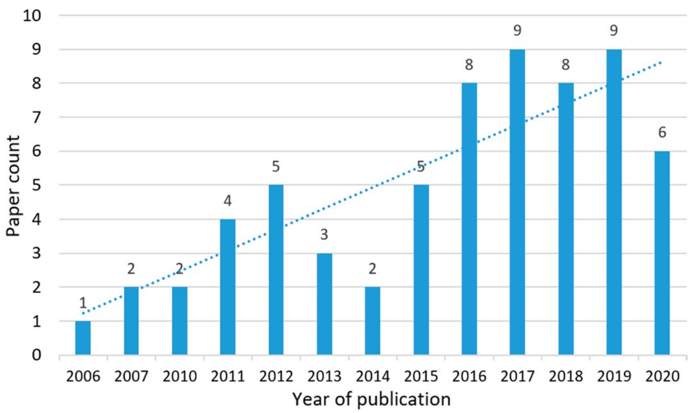


**Fig. 2** Distribution of RGB studies over the years (2006–2020)

literature. Moreover, the RGB research field only began in 2006 and has just received more attention since 2011. Interestingly, Fig. 2 shows a growing tendency, with the highest number of publications in 2016–2019 ($n \geq 8$ papers per year). Therefore, this finding implies that the RGB topic is an emerging issue and on the rise.

### 3.2 Country of the research

This section examined the countries where data was collected in previous studies. The authors only considered 59 RGB papers because the remaining five review papers were not associated with any specific country. Figure 3 illustrates the distribution of selected publications by countries and regions over the world. Some conclusions could be withdrawn from this figure:

Firstly, Fig. 3 reveals that most studies used data collected in a single country. Only one study (Yang et al., 2016) gathered data in two countries (China and Australia). Notably, another article attempted to collect data from 56 countries on all continents (Rafindadi et al., 2014). However, this study's main limitation is that the sample size was small, as admitted by the authors. This could lead to research hypotheses tests being biased.

Secondly, the result indicates that China, the USA, Singapore, and Australia are the most prevalent countries. China and the USA were in the two first positions with nine papers, while Australia and Singapore shared the following places with six studies. In general, this result confirms the claim that most RGB studies are still country-specific (Ahmad et al., 2019).

Finally, research involving developing countries is relatively limited. We can mention some countries such as Sri Lanka, Ghana, and India, with only one article in each country (Fig. 3). This phenomenon is understandable since the RGB topic has just attracted attention for only more than a decade recently, and GB is somewhat still a new concept in

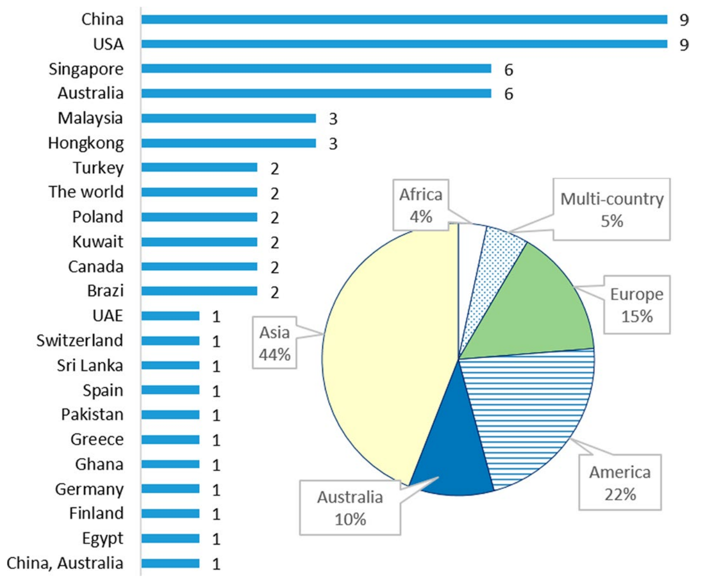


**Fig. 3** Distribution of selected publication (59 papers) by countries and regions

developing countries (Nguyen et al., 2017). Regarding continents, Asia had the most studies (44%), while studies involving Africa and cross-countries were very few (4% and 5%, respectively).

In summary, findings imply that RM research in GB projects was an attractive topic for many researchers worldwide. However, RGB studies are region-specific, and the distribution is mainly in several developed countries. Thus, caution as applying RGB research from country to country, especially from developed countries to developing countries.

## 4 Research methodology

In this section, the methodologies used in the RGB literature were investigated to identify the research tendency as well as limitations of previous studies. As we know, in construction projects, risk management (RM) usually includes the main steps: identify & classify, assess & analyze, risk response, and monitor risks (PMI, 2017). However, the review results show that most previous studies identified and assessed GB risks factors, besides some research attempted to create risk assessment (RA) models. This implies that previous research mainly concentrated on the risk identification and assessment stages of the RM process. This finding is understandable since the RGB topic has only received attention since 2011 and is still developing. Also, risk analysis and assessment are considered the most critical steps of the RM process because they provide information for risk decision-making (Aven, 2016). Figure 4 presents a breakdown of the research methods and data collection methods of RGB studies. More details of the research methodologies used in each collected paper can be found in the appendix (Table 7).

Research method: over half of studies (55.9%; $n=33$) used quantitative methods, nearly 12% of studies (11.9%; $n=7$) applied qualitative methods, and other studies (32.2%; $n=19$) adopted mixed methods (Fig. 4). The quantitative analysis methodologies mainly included: descriptive analysis, inferential statistics (e.g., ANOVA test and *t*-test), and modeling methods. Qualitative approaches mainly included: content analysis and pattern matching.

Research design: survey, case study, mathematical modeling, conceptual study, and the critical literature reviews were adopted. Figure 4 shows that around two-thirds of the studies (66.1%; $n=39$) used the survey-based approach, and slightly over a fifth (20.3%; $n=12$) utilized the case study-based approach. Also, nearly a quarter of the studies (23.7%;

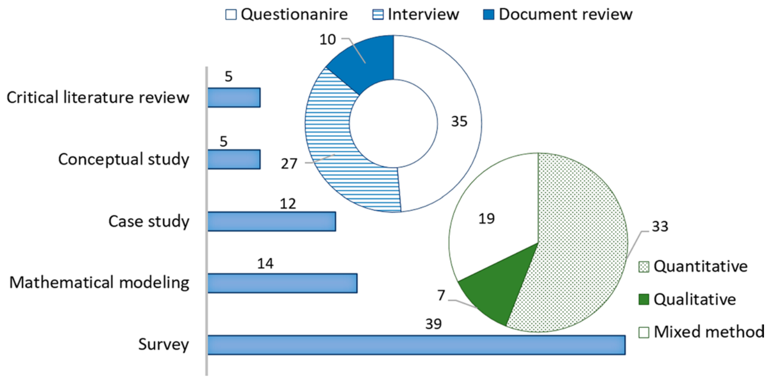


**Fig. 4** Research methods and collection methods used in the RGB literature

$n = 14$) applied mathematical modeling (e.g., fuzzy algorithms and social network analysis), several studies (8.5%; $n = 5$) adopted conceptual study, and a small fraction of the studies (8.5%; $n = 5$) were the critical literature review (Fig. 4).

Data Collection Methods: Questionnaires, interviews, and document reviews were adopted in previous RGB research. According to Fig. 4, over a half of the studies (59.3%; $n = 35$) used questionnaire surveys, just over a sixth of the studies adopted document review (16.9%; $n = 10$), and around 45% of the studies utilized interviews (45.8%, $n = 27$).

## 5 Thematic analyses of current risks in GB projects

According to PMI (2017), a risk factor is "an uncertain event or set of circumstances that, should it occur, will affect the achievement of one or more of the project's objectives." Nevertheless, risks are not wholly negative because it is also an opportunity to measure the potential gain. The relationship between risks and associated opportunities depends on many elements, such as contexts, practitioners, and culture (Taroun, 2014).

However, the RGB literature mainly considers the negative effect of risks on GB projects. This is also the general limitation in risk studies in the construction literature (Taroun, 2014). In this section, the content of 59 reviewed studies was analyzed to determine themes and research trends in the RGB literature. The result showed that previous studies attempted to dissect multiple aspects of the RGB topic (Table 3).

### 5.1 Identify risk factors in implementing GB projects

In the first paradigm, researchers attempted to identify and evaluate risk factors in GB implementation. Regarding identifying risks, the common method is conducting the literature review. Some studies then adopted expert interviews to support the risk identification process; however, the number of experts in the most discussions was minimal. Moreover, most studies only considered a specific phase or did not explicitly state project stages, which could confuse practitioners. Also, very few studies considered risks in the project life cycle, including the design, construction, and operation phase. In terms of assessing risk, the favored method is conducting a questionnaires survey and calculating risk levels by multiplying risk impacts with occurrence probability. Notably, some studies attempted to investigate measures to mitigate GB risks. However, these measures are still general, thus needing more research in future. Also, comparing risks between GBs and conventional buildings is an exciting direction that several researchers examined.

For instance, Hwang et al. (2017a) explored risks in residential GB projects in Singapore. The findings showed the most critical risk factors were “complex procedure to obtain approval,” “overlooked high initial cost,” “unclear requirements of owners,” “employment constraint,” and “lack of availability of green material and equipment.” This study also compared RA between GB projects and traditional ones. As a result, the authors concluded that residential GB projects are riskier than traditional residential projects. Also, this research provided a risk mitigation framework for residential GB projects.

Another article investigated risks involving commercial GB projects in Singapore (Hwang et al., 2017b). The result revealed the most significant risk factors in commercial GB projects were “inflation,” “currency and interest rate volatility worsened by the import of green materials,” “damages caused by human error,” “durability of green materials,” and “shortage of green materials.” Compared to conventional commercial

**Table 3** Content analysis of the RGB articles

| Topics | Typical issues that previous research solved |
|---|---|
| Identify risk factors in implementing GB projects | • Study the evolution of risks in GB projects (3)<br>• Identify risk factors in GB projects (16)<br>• Evaluate risk factors in GB projects (15)<br>• Compare risks between GB projects and conventional construction projects (2)<br>• Consider risks in the life cycle of GB projects (3) |
| Create risk assessment models for GB projects | • The modeling methods of RA: fuzzy theory (2), social network analysis (3), interpretive structural modeling (1), project risk management framework (1), Functional resonance analysis method (1)<br>• Consider stakeholder-associated analysis (3)<br>• Consider risk interdependency (1) |
| Study according to specific types of GB risks | • Examine safety risks in GB projects (8). Some modeling methods were used: Fuzzy TOPIS (1), risk plane analysis (1), and holistic Z-number-based RM framework (1)<br>• Investigate financial-related risks in GB projects (5). Several modeling methods were used: analytical hierarchy process (1) and Monte Carlo simulation (1)<br>• Examine risks in the GB supply chain (1)<br>• Material-related risks (2)<br>• Risks of applying energy-efficient and renewable technology (2)<br>• Examine legal risks involving design, construction, and operation (3)<br>• Schedule-related risks (1) |
| Investigate risks in green retrofit projects | • Identify and assess risk factors in green retrofit projects (7)<br>• Compare risks between green retrofit projects and traditional ones (2) |

Numbers in brackets denote the number of articles handling related issues

projects, commercial GB projects were reported to face fewer risks regarding "poor construction quality" and "design change." This result is not surprising since GB projects have a strict management procedure. So the change and quality management in GB projects are better than traditional construction projects, thereby mitigating risks in design change and construction quality. However, the adoption of green ideas, materials, and technologies still puts more risks on commercial GB projects, such as facing new risks or other risks that become more critical. This study also attempted to investigate measures to mitigate risks in commercial GB projects.

Similarly, one study identified and assessed risks in GB projects in the UAE (El-Sayegh et al., 2018). The result revealed that the top five critical risk factors were "shortage of clients' funding," "insufficient or incorrect sustainable design information," "unreasonably tight schedule for sustainable construction," "design changes," and "poor scope definition in sustainable construction." In the same vein, Ismael and Shealy (2018) investigated risk factors associated with GB projects in Kuwait. The finding indicated that "inexperienced designers and contractors with GB practices" and "high initial costs" are the most severe risks in the Kuwait context.

Tao and Xiang-Yuan (2018) identified and assessed risk factors in GB projects in China based on sustainability perspectives. This result showed the two most critical risk factors were “the public’s satisfaction with GB projects is meager” and “lack of experienced managers in the operation phase.” Similarly, Qin et al. (2016) assessed and prioritized risks of the life cycle of GB projects in China based on the occurrence likelihood and impact level. The findings revealed that stakeholders have different risk preferences in GB projects, which could be helpful for practitioners to create RM strategies for specific parties.

Notably, Rafindadi et al. (2014) investigated risks in GB projects based on stakeholders’ perceptions in 56 different countries. Interestingly, the outcome revealed no significant difference among stakeholders’ perspectives of sustainable project risks. This conclusion contrasts with another research claiming that RA is a subjective process and depends on stakeholders’ perspectives in GB projects (Qin et al., 2016). This conflict implies that the difference in RA among stakeholders in GB projects may depend on each country’s context. However, the authors of both studies admitted the identical limitation in their studies: the sample sizes were relatively small (115 in Rafindadi’s research and 74 in Qin’s research). Indeed, this problem could lead to biased results; thus, these outcomes should be assessed and generalized conservatively.

The risk factors identified in the previous studies are provided in the appendix of this paper (Table 6). Table A presents the list of risk factors and their corresponding references. Notably, the authors categorized these risk factors based on phases of GB projects: Feasibility & Design, Construction, and Handover & Operation. Also, the risk factors in each phase were grouped based on their characteristics. This list of risks may be a helpful reference for GB practitioners and future research.

### 5.2 Create risk assessment models for GB projects

In the second paradigm, some studies attempted to create RA models for profoundly assessing GB project risk levels. A number of methods were used to develop RA models, the most prominent of which are fuzzy set theory, social network analysis, and interpretive structural modeling.

In Singapore, one article proposed a RA model adopting the fuzzy synthetic evaluation method for GB projects (Zhao et al., 2016). In this model, the authors first determined the occurrence probability and impact level of risk factors. The critical level of risk factors was then determined by multiplying the occurrence probability and impact level. After that, the fuzzy synthetic evaluation was adopted to determine the critical level of risk groups and overall risk. The advantage of fuzzy synthetic evaluation is dealing with multiple attributes and levels of assessment. Furthermore, this model allows experts to assess risk factors using linguistic terms. Thereby, this can reduce vagueness and subjectivity in the evaluation process. The result exhibited that "inaccurate cost estimation" is the most significant risk factor, while the most vital risk group is "cost overrun risk." The research also reveals that the overall risk in GB projects is high, which implies that RM is necessary for GB projects in Singapore.

Also applying fuzzy set theory but with a different approach, another study attempted to build a model that comprehensively evaluated risks in GB projects in China (Bao et al., 2013). In this research, the authors adopted the fuzzy comprehensive evaluation to assess GB risks. This research first identifies the main risk index in GB projects and their relative weight using the expert scoring method and analytic hierarchy process (AHP). After that, this research conducted a RA process based on the fuzzy assessment method with

20 experts. According to the authors, this model could provide concrete fundamentals in decision-making in the RM process of GB projects.

Yang et al. (2016) proposed the interactive networks model of risks related to various stakeholders in GB projects to comprehend the critical GB risk networks. The data for case studies were collected from GB projects in China and Australia using group workshops and interviews. Social network analysis was then used to analyze the collected data. The result revealed that "reputation risk" is significant in both countries, while "the ethical risk" is more crucial in China. Notably, the outcome indicated that the government has a vital role in enhancing GB knowledge and awareness in China. Also, this study provided a clear picture of the interaction between stakeholders and the RA process in GB projects.

Likewise, Yang and Zou (2014) proposed a social network analysis model based on stakeholder-associated risk analysis to evaluate and analyze risks in GB projects in China. According to the authors, this research could improve stakeholder communication in GB projects. Additionally, the model can simulate and test the effectiveness of risk mitigation measures. Thereby, this study might enhance the understanding, assessing, and mitigating risks in GB projects effectively.

With the same approach, Wu et al. (2018) investigated the crucial evaluation indicators of mega GB projects in China from stakeholders' perspectives. Associations between evaluation indicators and stakeholders were examined by social network analysis. The result indicated that the government and designers play an essential role and significantly impact other stakeholders. Notably, adopting "energy saving" and "intelligent technologies" is crucial in mega GB projects. Also, this research could improve the effectiveness of the management strategies and save costs and human resources, thereby helping to enhance the sustainability level of mega GB projects.

In another perspective, Guan et al. (2020) investigated risk interdependencies in GB projects using interpretive structural modeling. This model utilized 22 risk factors, 16 constraint factors, and 11 objectives identified by reviewing the literature. Also, this research determined phases of GB projects that are affected by specific risk factors. Next, a hierarchical network structure was developed to illustrate cause-effect relationships between constraint factors, risks, and objectives. After that, this model determined the importance of risk/constraint factors linked to project objectives. Notably, this research also analyzed the drive/dependence powers of risk interdependency elements. The result revealed the importance level of risk factors/ constraints with the goals of GB projects and indicated crucial constraints/risk factors in implementing GB projects. This model could contribute in-depth knowledge to GB practitioners, thereby enhancing the RM process's effectiveness in GB projects.

## 5.3 Study according to specific types of GB risks

In this paradigm, the RGB studies only examined a specific risk aspect in GB projects such as safety, financial, material, legal, and energy risk. Such research could give construction practitioners insight into a particular issue they pay attention to in the RM process.

### 5.3.1 Study safety risks in GB projects

In the USA, some investigations discovered that LEED-certificated buildings account for a higher injury rate compared to conventional buildings (Dewlaney et al., 2012; Fortunato III et al., 2012). Indeed, workers typically have to perform dangerous tasks in GB projects, such as installing green roofs, photovoltaic, and innovative wastewater technologies. Therefore, investigating safety risks in sustainable construction is critical and has recently attracted researchers.

Koulinas et al. (2019) proposed a safety RA process in worksites using Fuzzy TOPIS (the technique for order of preference by similarity to ideal solution) and PRAT (the proportional RA technique) for GB projects in Greece. According to the authors, this model could enhance the health, safety, and well-being of workers in sustainable construction worksites. This model was validated by applying to a construction project in Greece as compared the model's results with actual fatal and non-fatal accident data from 2014 to 2016. Therefore, risk managers could use this integrated multi-criteria approach to assess safety risks and make decisions within a constrained budget to improve workplace health and safety.

Another article quantified the percentage increase in safety risks caused by the design approaches and construction method executed to achieve LEED-certified in the US (Dewlaney et al., 2012). This study suggested that these design elements and construction methods required to achieve LEED certification could pose injury risks. The most notable influences are a 36% rise in lacerations, strains, and sprains due to recycling construction materials. Another significant impact is a 24% rise in the possibility of falling to lower levels when installing renewable energy on the roof. Other effects are a 19% rise in eye strain as installing reflective roof membranes and a 14% rise in exposure to harmful substances as installing wastewater technologies. These results could enhance the understanding of the safety impacts of design approaches and construction methods, thereby may help to mitigate safety risks.

Likewise, other research identified and assessed the safety and health risks related to design factors and construction methods performed to achieve LEED certification (Fortunato et al., 2012). This article showed some remarkable results. Firstly, workers in LEED construction projects work for longer periods at height, with electricity, near unstable soils, and heavy equipment compared to workers in traditional projects. Secondly, workers have to conduct risky tasks such as installing green roofs and installing photovoltaic panels. Finally, there are some influences on worker safety and health since using low volatile organic compound adhesives and sealants.

Similarly, Karakhan and Gambatese (2017) assessed, quantified, and classified occupational health and safety (OHS) risk related to the construction, operation, and maintenance of GB projects in the USA. This research also compared OHS risks in GB projects with conventional projects. The result showed that although many GBs are neutral toward health and safety risks, some GB projects related to the rise in OHS risks compared to traditional projects. Subsequently, this research integrated the RA model into a risk plane analysis to classify safety risks linked to specific LEED credits. According to the authors, this study can help practitioners by showing how sustainable designs can affect safety risks in GB projects.

In Hong Kong, some authors developed a Holistic Z-number-based RM framework is to investigate critical safety risks associated with GB projects (Xueqing Zhang & Mohandes, 2020). This research identified and evaluated safety risks as well as pinpointed green-oriented requirements. The result revealed that the three most critical safety risks were related to fall hazards. Also, according to the authors, this model could enhance GB projects' occupational health and safety. Additionally, the result provided a comprehensive list of mitigation measures to control safety risks in GB projects.

### 5.3.2 Study financial-related risks in GB projects

Being cost-effective is a crucial objective in any project in the construction industry. Management costs in GB projects are especially essential because GB projects are regularly considered big and complicated construction projects. Therefore, several studies attempted to examine risks in the finance aspect in GB projects (Ranaweera & Crawford, 2010; Tabatabaee et al., 2019).

For example, Gurgun et al. (2016) identified risk factors and their impact on the cost of GB projects in the USA. The result revealed that the risks associated with consultants and contractors have the highest impact on project cost. This research also exposed the ranking of the risk factors that might help practitioners mitigate the risk impact on cost in future GB projects.

In Malaysia, another study determined the importance of economic motivation factors and identified risks for developing GBs using the Analytical Hierarchy Process (AHP) method (Ghazali et al., 2017). The result revealed that “lack of government incentive” and “high capital cost” were critical factors that significantly influenced the decision-making for implementing GB projects in Malaysia. This research also reported the number of GBs increasing in Malaysia owing to government support and incentives.

With a different approach, research in Poland attempted to simulate cost variance in the GB project based on Monte Carlo simulation (Górecki et al., 2020). The result supposed that the changing probability distributions of cost elements might involve economic, technological, and organizational features. This approach could help GB practitioners deal with cost-related risks in a more accessible way.

## 6 Research other kinds of risk in GB projects

There are several other types of risk in GB projects that previous research examined, such as material, supply chain, and legal risks. However, there has been a shortage of studies on these topics since just one or two studies per topic.

For example, in Turkey, the authors identified the material-related risk factors that often affect contractors during the construction phase in GB projects (Polat et al., 2017). This research evaluated and ranked the impacts of material-related risks on cost and time performances. The result revealed that "negligence of constructability in green designs" is the most critical risk factor, and the most influential groups are "design-related" and "contractor-related."

In Australia, Zou and Couani (2012) identified significant risk factors in the GB supply chain. The result exposed that risks in GB development are varied and unevenly distributed throughout the supply chain. However, there are still some common risk factors that could occur in any part of the supply chain, such as “lack of commitment in the supply chain to go green” and “higher investment costs.” This research also unveiled that GB performance (e.g., cost, schedule, and quality) could be considerably improved by adopting research, training, supply chain coordination, sharing information, previous experience, and applicate technology.

The conflicts among stakeholders are unavoidable because of GB projects’ inherent complexity. Therefore, some researchers attempted to examine legal risks in GB projects. For example, some authors identified and evaluated risk factors in Turkey that could lead to claims in GB projects (Mohammadi & Birgonul, 2016). This research could improve industry practitioners' awareness of legal risks, thereby helping prevent claims in GB projects. In another perspective, Abdul-Malak and Khalife (2020) investigated the risks of GB certification failures in GB projects. This research examined how these risks are addressed in contract terms and inquired experts about dealing with them based on their perspective and experience. The result proposed the preferred methods used in the case of GB certification failure and suggested a framework for owners to deal with sustainability certification-failure risks.

Regarding energy performance, Zhang et al. (2012) explored risk factors when adopting energy-efficient and renewable technology (EERTs) in green office buildings in Australia. The result showed that the risk factor "uncertain governmental policies" has the highest impact. Also, "lack of access to funds" and "the presence of system constraints" are the most prevalent risk factors in EERTs projects. Notably, this study revealed that EERTs owners are the most affected stakeholder, and most risks happen in the operation stage.

### 6.1 Investigate risks in green retrofit projects

For sustainable development in the construction industry, besides creating new GBs, the renovation of existing buildings into GBs also has an important role. Admittedly, existing non-green buildings are still much more outnumbering GBs and have significant adverse effects on the environment. Hence, the benefits of GBs will not have significant impacts if the number of existing non-green buildings still wholly dominates. Therefore, several researchers have paid attention to investigating risks in green retrofit projects recently (Zheng et al., 2019).

In Sri Lanka, Ranawaka and Mallawaarachchi (2018) evaluated risk factors related to green retrofit projects to establish a risk response framework. The result revealed the most severe risk factors: cost, inflation, energy-saving uncertainty, warranty risk, schedule, and design changes. This study also proposed strategies to mitigate risks in implementing green retrofit projects in Sri Lanka.

In another approach, Hwang et al. (2015) dealt with risks in green retrofit projects in Singapore by the following steps: (1) identified risk factors in green retrofit projects; and then (2) analyzed critical risk factors; finally, (3) compared the essential risk factors between green retrofit and traditional retrofit projects. The findings indicated that "post-retrofit tenants' cooperation risk" is the most severe risk factor. According to the authors, in general, risks become more acute in green retrofit projects than traditional ones. Additionally, this research proposed 28 measures to mitigate risks in green retrofit projects that gained considerable agreement from participants.

In Malaysia, Lee et al. (2020) reviewed risk factors in the design stage of green retrofit projects in commercial buildings by conducting a comprehensive literature review. The result showed that technical/quality and financial risk are the most critical risk groups in the design stage. The study also quantified these risks to help practitioners enhance design performance in green retrofit projects.

## 7 Discussion for gaps and future research

Previous studies investigated several crucial aspects of GB risks, such as identifying risk factors, creating RA models, safety risks, and financial risks. However, the RGB topic is still developing and needs more studies to enrich the literature. Therefore, this section would answer research questions RQ2 (about the gaps) and RQ3 (about the research directions) based on discussing findings and limitations of previous studies.

### 7.1 The gaps

There are some contradictory opinions about risks in implementing GB projects. Some views considered that GBs could help investors/owners reduce risks during project implementation owing to strict management procedures from preparation to operation (Dahiru et al., 2014; Edwards, 2006). Contrastingly, from the perspective of construction practitioners and some academics (Hwang et al., 2017a; Zhao et al., 2016), implementing GB projects is riskier than traditional construction projects due to adopting high technical requirements and novel construction procedures. This finding implies that RGB is still a controversial topic and needs more in-depth studies to enrich the literature.

Table 4 illustrates gaps in the RGB literature and corresponding analysis results supporting these gaps. In the reference variable column, "research theory" refers to gaps in the methodology of previous studies; "research context" indicates gaps associated with countries/regions where research was implemented; and "research issues" imply gaps related to issues that previous studies have not investigated yet.

Firstly, the identification of GB risk factors was less consistent in RGB literature. These significant differences could be seen through the list of GB risk factors identified in previous studies (Hwang et al., 2017b; Ismael & Shealy, 2018). One plausible explanation for this phenomenon is that GB risks regularly depend on the specific context of each country. However, another reason might come from the approaches of previous studies, such as the participation of GB practitioners in identifying risk was not significant. Consequently, GB risk factors were identified based mainly on the literature review and subjective ideas of authors. Also, many previous studies do not state clearly which construction stages were used to identify GB risks. Indeed, this problem can confuse practitioners and academics in the identify risks process in GB projects because risk factors are varied and unevenly distributed throughout the lifecycle of GB projects (Khaddour, 2021).

Secondly, GB risk classifications were ambiguous among previous studies. This phenomenon is not surprising since GB risk classification also relied mainly on the subjective ideas of authors. Notably, no studies have classified GB risks based on empirical research as far as we know. This problem can restrain future research from developing RA models due to unclear about the hierarchy of risks in GB projects and might cause many difficulties for construction practitioners in the RM process in GB projects.

Moreover, most RGB studies used traditional methods to calculate risk level (i.e., multiply risk impacts with risk probability) without considering other risk features (e.g., risk controllability and risk attitude) mentioned in the risk literature (Dikmen et al., 2018). This led to RA models in the GB literature being less comprehensive compared to the risk literature in general. Another limitation is that the sample size for quantitative methods in most previous RGB studies was small. This problem could restrain previous studies from adopting sophisticated statistics techniques (e.g., Factor analysis and Clusters analysis). However, this is understandable since GB practitioners are still significantly fewer than construction practitioners in general.

Furthermore, creating RA models in the GB literature is still a developing research direction. Several methods were used to build RA models in GB projects, such as fuzzy synthetic evaluation, fuzzy comprehensive evaluation, social network analysis, and interpretive structural modeling. Thus, future research can apply the latest modeling methods

**Table 4** Main gaps and supporting data raised from the literature

| Reference variable | Main gaps | Supporting data |
|---|---|---|
| Research theory | • Limited studies used existing robust theories to identify and classify risk factors<br>• Limited studies adopted the latest methods to assess risks | • Only nine papers identified risks in GB projects. In which, the method of some studies was still loose<br>• The result of identifying risk factors among the previous papers was less consistent<br>• No study classified risk factors based on empirical data<br>• Almost all articles only considered a specific phase of GB projects or did not specify which stages. Only three papers examined risks in the project life cycle, but the results were still somewhat limited<br>• Most studies calculated risk levels by multiplying risk impacts with risk probability |
| Research context | • Lack of studies was conducted in developing countries and cross-countries<br>• Need more studies based on data from less-explored countries | • Only one research was conducted cross-countries (China and Australia)<br>• One study attempted to collect data from 56 countries. However, the sample size of this research was small, so the result was still limited<br>• Previous studies collected data mainly in Singapore, China, Australia, and the USA<br>• Only several studies were conducted in developing countries (e.g., Ghana, India, and Sri Lanka). However, these studies were not in-depth enough, and the results were relatively limited |
| Research issues | • Limited studies investigated the influence of elements on the RA process, such as practitioners' characteristics and project features<br>• Lack of studies explored the relationship between RA and project outcomes, such as project performance and customer satisfaction | • Only three papers considered the effect of stakeholders on risk analysis<br>• Many studies in risk literature supposed that RA is a subjective process and depends on assessors' viewpoints and roles. However, no study tested these hypotheses in RGB literature<br>• Only one article considered the relationship between RA and project outcomes. This reveals significant gaps in the RGB literature because all project stakeholders care about project outcomes |

to develop RA models in GB projects. Also, considering the positive side of GB risks is an exciting direction as most previous studies only consider the negative effect of risks in GB projects.

Notably, the current RGB studies were highly country-specific and almost limited to developed economies, such as the USA, China, Singapore, and Australia (Ahmad et al., 2019). The content analysis results also showed that very few studies had investigated risks in GB projects in cross-countries or developing countries. According to Nguyen et al. (2017), unlike in developed countries, GB is still a new concept in developing countries. This implies that GB risks in developing countries may be more critical than those in developed ones. Also, environmental pollution is a big problem in many developing countries, mainly due to over urbanization in some big cities (Liang et al., 2019). Hence, the lack of RGB studies can be a significant obstacle to growing sustainable construction in developing countries.

In addition, there are gaps in addressing the novel RGB literature issues that future research could exploit. Indeed, though previous studies attempted to dissect various aspects of risks in GB projects, many issues still need to be investigated.

For example, some researchers suggested that RA highly depends on practitioners' experience, role, and viewpoints (Dikmen et al., 2018; Hayat, 2017; Xia et al., 2017). However, the RGB literature currently lacks studies investigating the effect of practitioners' characteristics on the RA process in GB projects. Indeed, such research could enrich this topic's debate and help practitioners comprehend GB risks adequately, thereby having better risk response strategies as implementing GB projects.

Also, lack studies that explore the relationship between RM and project outcomes. Indeed, many studies supposed that project performance is the critical goal in construction projects and somewhat is the RM process's consequence (Ogwueleka, 2011; Wiguna & Scott, 2006). Moreover, GBs are vulnerable to cost overruns and delayed schedules due to the complexities of implementation processes (Raouf & Al-Ghamdi, 2019). Therefore, research in this direction is needed to enrich the GB literature and provide more insight into risks in GB projects.

## 8 Research directions

This section proposes future research directions on the RGB topic based on the identified gaps to answer RQ3 (Table 5). This suggests opportunities for future research. The first research directions relate to applying consolidated theories to identify, classify, and evaluate GB risks in the RGB literature.

Regarding identifying and classifying risks, a list of risk factors in implementing GB projects should be created carefully based on the comprehensive literature reviews. After that, some qualitative methods such as interviews and brainstorming could be helpful to confirm this list and complement new GB risk factors that frequently depend on the specific research context. In the next step, quantitative research should be used to validate the final list of risks. Some quantitative techniques could be adopted in this situation, such as Factor analysis, Principal Component Analysis (PCA), and Clusters analysis. Such methods can help discover latent factors and classify risk factors as well.

In evaluating risks, adopting the latest methods to assess GB risks is also a promising direction for future RGB studies. For instance, future research should consider adding other risk features (e.g., risk manageability and risk attitude of practitioners)

**Table 5** Future directions in RGB field

| Future research directions | Academic and RM relevance |
| --- | --- |
| *Gap 1. Research theory:* | |
| To encourage future RGB research based on robust theories to identify, classify, and evaluate GB risk factors<br>Examples:<br>• Identify risks in implementing GB projects by both qualitative and quantitative methods<br>• Classify risk factors based on empirical data and statistical techniques such as Factor analysis, Principal component analysis, and Cluster analysis<br>• Consider risks in the life cycle of GB projects<br>• Identify measures for risk mitigation based on empirical research<br>• Assess risk factors by adopting the latest methods rather than just using traditional methods<br>• Apply robust modeling methods to create RA models for GB projects | • Provide a deeper understanding of the RM process in implementing GB projects<br>• Provide reliable risk factors and guidelines for risk mitigations for practitioners in the RM process<br>• Assess risk factors more precisely |
| *Gap 2. Research context:* | |
| • Conduct cross-country studies<br>• Replicate successful studies or conduct new research in less-explored countries, especially developing countries<br>• Compare risks between two or more countries, particularly between developed and developing countries | • Improve the effectiveness of the RM process in more countries<br>• Help to spread GBs over the world, especially in developing countries |
| *Gap 3. Research issues:* | |
| • Conduct studies to examine some features' effect on the RA process, such as practitioners' characteristics, project features, and research contexts<br>• Investigate the relationship between RM and the project outcomes, such as project performance, customer satisfaction, and collaboration | • Provide insight into this field<br>• Contribute to the body of knowledge<br>• Promote the adoption of RM in the construction industry in general and in GB projects in particular |

besides traditional elements, including impact level and occurrence probability (Dikmen et al., 2018; Taroun, 2014). This can help assess risk more comprehensively, thereby providing more insight into the RGB topic. Furthermore, adopting some robust modeling methods such as Fuzzy AHP, Bayesian Belief Network, design structure matrix, and cognitive argument to create RA models in GB projects are also potential directions (Taroun, 2014). Such research can examine GB risks more in-depth and also enrich the RGB literature.

Like conventional construction projects, GB projects also comprised three main stages: design, construction, and operation phase. Moreover, risks in different stages are often various. Notably, unlike traditional construction projects, risk factors in GB projects' design and operation stages are also critical (Qin et al., 2016; Hwang et al., 2017b). Thus, investigating risks in GB projects' life cycle is needed and a promising direction for future research. Such studies can facilitate construction practitioners in the RM process. Also, finding solutions for risk mitigation is an exciting research direction for future research. Even though several studies attempted to identify measures to mitigate GB risks (Hwang et al., 2017a, 2017b), the outcomes are still limited and need more in-depth studies.

The second directions relate to previous research contexts: RGB studies are highly region-specific and almost limited in Singapore, Australia, China, and the USA (Ahmad et al., 2019).

This finding suggests the need to conduct RGB studies in less-explored countries. Such studies could help practitioners improve the RM effectiveness of GB projects in more countries, thereby promoting GB development globally. Especially in developing countries, where the polluted environment has become a progressively severe problem due to urbanization (Liang et al., 2019), the need for RGB studies is even more critical. Also, research in this direction could contribute to the body of knowledge of the RGB literature and benefit future research.

Additionally, future research should compare GB risks between two or more countries, especially between developed and developing countries. This is an exciting direction because there is always a distance between developed and developing countries. In our view, such studies can provide more insight into RGB literature and are particularly useful for practitioners or organizations that work across multiple countries.

The last research directions relate to issues not addressed in previous RGB studies.

For example, future studies should examine the effect of some elements (e.g., practitioners' characteristics, project features, and research context) on the RA process in GB projects. There are some practitioners' characteristics that future research should examine, such as project role, industry experience, GB-related knowledge, risk-related knowledge, and risk attitude. Regarding project features, future studies should consider project type (e.g., commercial, residential, industrial, and educational GB buildings), type of delivery/contract (e.g., design-build and design-bid-build), and project complexity level. Additionally, features of research contexts should also be considered, such as country, region, and culture. Such research can give academics and practitioners more insight into the RGB field and enrich the literature.

Furthermore, exploring the relationship between RM and project outcomes is also an attractive direction for future RGB studies. Indeed, there are various kinds of project outcomes in construction projects that researchers can exploit, such as project performance (e.g., cost performance, time performance, and quality), customer satisfaction, and stakeholders' collaboration. Depending on the specific role in GB projects, practitioners may have interests in different types of outcomes. Therefore, such studies can contribute helpful knowledge for practitioners to handle GB risks more effectively and become a premise for more in-depth studies on the RGB topic.

## 9 Conclusion

Risks in implementing GB projects are widely considered a critical obstacle of GB development globally. Many studies attempted to investigate risks linked to GB projects in recent years. However, no study has reviewed RGB studies to provide an overview picture of the current literature as far as we know. Acknowledge the importance of this issue; this study conducted a systematic literature review of the RGB literature by identifying and analyzing 64 articles published until September 2020 in reputable journals.

As the first contribution, this paper provided a clear view and research trends of RGB literature by classifying and comparing previous studies according to the year published, research context, methodology, and theme. Regarding tendency, the RGB topic had received significant attention from both academics and practitioners in recent years, demonstrated by the increasing number of publications over the years. In terms of explored regions, the result indicated that most studies refer to single countries and are almost limited to several developed economies such as Singapore, Australia, the USA, and China. The number of research in developing countries is very few. About contents, this research identified four main themes in the current RGB literature: (1) identify and evaluate risks in implementing GB projects; (2) create RA model in GB projects; (3) study according to specific types of GB risks; (4) investigating risks in green retrofit projects. Notably, most RGB studies belong to the first and second paradigms that imply this topic is still developing.

The second contribution is to identify gaps in the RGB literature by analyzing previous studies' findings and limitations and comparing them with the risk literature. The result showed gaps in the current RGB literature related to the research theory, research context/countries, and research issues not investigated. The finding indicated that the RGB field is still nascent and a promising research area.

Finally, this study suggested future research directions based on the identified research gaps. The potential research directions include adopting the latest methodologies, dealing with emerging issues (e.g., project outcomes, interactions among features), and investigating less-explored contexts (e.g., cross-country or developing countries). Such studies can enhance the breadth and depth of RGB literature.

To conclude, we present the strength and limitations of this research. Regarding strength, this research conducted a clear and rigorous systematic literature review with a wide range of reliable documents. In terms of limitations, the number of collected papers was relatively low (64 articles). Therefore, this research could not provide a more in-depth and comprehensive review of the RM process in GB projects because most previous studies only concentrate on identifying and assessing risks. However, this limitation may be acceptable and inevitable since the RGB topic is still nascent. Also, the gaps and suggestions for future research were identified based on the literature analysis results and partially on the authors' subjective views. Consequently, the proposed research directions may lack creativity and innovation. Nevertheless, we believe our work could be a springboard to find future research directions to enrich the RGB literature.

## Appendix

See Tables 6 and 7.

**Table 6** List of risk factors in the RGB literature

| Code | Risk factors in GB projects | References |
|---|---|---|
| D | Feasibility and design phase of GB project | |
| *D1* | *Market* | |
| 1 | Lack of market demand/lack of expressed client interest | [3], [4], [7], [8], [14], [15], [17], [18] |
| 2 | Fluctuation in exchange rates by the import of green materials | [1–3], [7], [11] |
| 3 | Lack of public awareness regarding the benefits for sustainability | [4], [5], [7], [14], [17], [18] |
| 4 | Lack of knowledge of GB costs/perception of higher GB cost | [7], [15], [17] |
| 5 | Resistance to change from conventional to green practices and technology by occupants | [7], [17] |
| 6 | Increasing the tax rate | [1], [5], [10], [14] |
| *D2* | *Law & policies* | |
| 7 | Change in local regulations/governmental policies | [3], [4], [6], [7], [9], [11], [14], [15], [18] |
| 8 | Green building policy change | [2], [5–8], [11], [14] |
| 9 | Intellectual property protection (e.g., special design/construction method) | [3] |
| 10 | Insufficient/inconsistent incentives and rewards from the government | [4], [5], [7], [17] |
| 11 | Incomplete regulations and laws for GBs | [8], [17] |
| 12 | Government bureaucracy | [1], [2], [8], [11] |
| *D3* | *Financial/cost* | |
| 13 | Poor estimations of GBs' long-term return on investment | [7], [8], [10], [12–14] |
| 14 | Lack of financial viability of the project | [3], [7], [10–12], [14] |
| 15 | Fluctuations in exchange rates by the import of green materials | [1–3], [7], [10], [11] |
| 16 | Increasing inflation rate/price inflation of construction materials | [1–3], [5], [7–11], [15], [18] |
| 17 | Lengthy payback period | [4], [5], [17] |
| 18 | Overlooked high initial cost | [2], [4], [7] |
| 19 | Inaccurate investment estimate of GBs | [6], [8], [10], [11], [13] |
| *D4* | *Technical/quality* | |
| 20 | Unclear requirements of clients/poor definition of scope and change in scope | [1–3], [7], [10], [11], [15] |
| 21 | High target for green building certificate rating | [7], [8] |
| 22 | Special requests from clients about specified green technologies to be used | [3] |

**Table 6** (continued)

| Code | Risk factors in GB projects | References |
|---|---|---|
| 23 | Inappropriate interventions of clients | [1–3], [11] |
| 24 | Technical complexity | [1], [17] |
| 25 | Improper project feasibility and planning (setting expectations too high) | [2], [3], [9–11] |
| 26 | Insufficient site investigation not tailored to local conditions | [7], [8], [18] |
| 27 | Risks of green design innovation | [7], [8], [16] |
| *D5* | *Management* | |
| 28 | Unclear contract conditions for dispute resolution | [1], [2], [9], [10], [14], [15] |
| 29 | Inaccurate orientation of project’s green-goal | [7], [8], [11] |
| 30 | Complex planning approval and permit procedures | [1], [7], [16] |
| 31 | Delay in the insurance of documents | [1], [15] |
| 32 | Unclear responsibility of green certification | [8] |
| 33 | Delays caused by frequent meetings with green specialists | [3], [11] |
| *D6* | *Human resources* | |
| 34 | Project management consultant/project teams without the relevant knowledge | [1], [6], [11], [13], [14], [17], [18] |
| 35 | Inefficient communication and coordination | [1], [2], [5], [7], [14] |
| 36 | Designer consultant having lack of GB design experience | [4–9], [11], [13], [16], [17] |
| 37 | Owners lack green construction management experience with GBs | [6], [8], [9], [11], [14], [18] |
| C | Construction Phase of GB projects | |
| *C1* | *Financial/cost* | |
| 38 | Inaccurate cost estimation | [1], [2], [4], [5], [7], [8], [10] |
| 39 | Labor and materials price fluctuations | [1], [10], [11], [15], [16] |
| 40 | Difficulties in project budgeting due to unfamiliarity with green projects | [3], [11] |
| 41 | High cost of sustainable materials and equipment | [3], [4], [8], [11], [14], [16], [18] |
| 42 | Owner’s unexpected cost increases | [5], [8], [13] |
| *C2* | *Legal risk* | |

**Table 6** (continued)

| Code | Risk factors in GB projects | References |
|---|---|---|
| 43 | Unclear contract conditions for claims and litigations | [1–3], [9] |
| 44 | Delay payments on the contract | [1], [5], [7] |
| 45 | Difficulty in comprehending green specifications in contract details | [3] |
| 46 | Lack of corresponding contracts for GBs | [8] |
| 47 | Claims arising from green requirements | [7], [8], [14] |
| 48 | Delays in resolving disputes | [4] |
| *C3* | *Technical/quality* | |
| 49 | Lack of documents and information for new green technologies | [3], [8], [17] |
| 50 | Unclear detailed design or specifications | [1–3], [11] |
| 51 | Poor design/design errors | [1], [2], [5], [9–11], [13] |
| 52 | Design changes during construction | [1], [3–5], [11] |
| 53 | Unfamiliarity with new technology rates | [1], [2], [5], [7], [16], [17] |
| 54 | Unfamiliarity of job requirements | [2], [16] |
| 55 | Unfamiliarity with green materials | [2], [16] |
| 56 | Unfamiliarity with the construction process | [2], [16] |
| 57 | Improper quality control and defective work | [3], [7], [10], [11], [13] |
| 58 | Incremental time caused by sustainable construction | [4], [5], [8], [17] |
| *C4* | *Management* | |
| 59 | Poor communication among projects stakeholders in the construction process of GB projects | [1], [5], [7] |
| 60 | Difficulty in the selection of contractors/subcontractors providing GB construction services | [4], [6], [7], [11], [15], [17] |
| 61 | Loose control over subcontractors | [2] |
| 62 | Poor communication among projects stakeholders | [2], [3], [5], [7], [14] |
| 63 | Slow approval processes due to sustainable specifications | [1], [4], [7], [15], [16] |
| 64 | Lack of corresponding insurance products for GBs | [3], [8], [14] |
| 65 | Sustainability measures not considered early by stakeholders | [4] |

**Table 6** (continued)

| Code | Risk factors in GB projects | References |
|---|---|---|
| *C5* | *Safety and environmental risk* | |
| 66 | Strict safety and health regulations | [1], [2], [6] |
| 67 | Construction accidents | [1], [3], [9], [10], [13], [18] |
| 68 | High demand for environmental protection in construction site | [2], [6–8] |
| 69 | Handling recycled materials puts construction workers at safety risks | [4] |
| 70 | Changes in the weather | [3], [9], [10] |
| 71 | Unforeseen adverse site condition and geographical conditions | [3], [9], [10], [13] |
| 72 | Air, sound, and water pollution | [3], [5], [13] |
| *C6* | *Material and equipment problems* | |
| 73 | Material quality problems | [1], [4], [5], [9], [16] |
| 74 | Import/export restrictions | [2], [14] |
| 75 | Lack of availability of green materials and equipment | [1–5], [7–14] |
| 76 | Uncertainty with durability/reliability of green materials, technology, and equipment | [3–5], [7], [10–13], [15], [16] |
| 77 | Change in material types and specifications during construction | [4] |
| *C7* | *Human resources* | |
| 78 | Unskilled workers | [1–8], [11], [14], [16–18] |
| 79 | Constraints on laborer employment | [1], [2], [12], [14] |
| 80 | Lack of qualified professionals with experience and expertise for GBs | [1–4], [7], [8], [11], [13], [16], [17] |
| 81 | Lack of management staff | [1], [2], [11], [13], [17], [18] |
| 82 | Resident engineers poor supervision ability for GBs | [8], [9] |
| 83 | Contractors/subcontractors lack knowledge and experience of GBs | [1], [2], [4–9], [11], [15–17] |
| 84 | Owners lack green construction management experience with GBs | [8], [9], [11], [18] |
| O | Handover and operation phase of GB projects | |
| *O1* | *Certification* | |
| 85 | Loss of financing or losing loans for not achieving certification | [4], [13], [15] |

**Table 6** (continued)

| Code | Risk factors in GB projects | References |
|---|---|---|
| 86 | Project evaluation results did not reach the expected GB standard | [4–8], [11], [18] |
| 87 | Green certification cost increase | [8] |
| 88 | GB evaluation standard changes | [4], [5], [8] |
| 89 | GB assessment results deviation | [8], [12] |
| 90 | Disputes due to the unclear division of green certification responsibilities | [7], [8] |
| *O2* | *Technical/quality* | |
| 91 | Energy-saving uncertainty | [2], [5], [6], [12], [14], [15], [18] |
| 92 | Lack of standard test method for green certification evaluation | [5], [8] |
| 93 | Unstable operation performance for GB/Lack of stability in GB operation performance | [7], [8], [15], [18] |
| 94 | Green products upgrading | [7], [8] |
| 95 | Challenges for operating renewable energy systems | [4] |
| *O3* | *Management* | |
| 96 | Warranties to homeowners of green building | [2], [5] |
| 97 | Inappropriate user behavior | [6], [9] |
| 98 | Lack of cooperation between parties involved in the trial operation stage | [8] |
| 99 | Lack of experienced managers for building's operational phase | [7], [18] |
| 100 | Lack of experienced property company | [7–9] |
| 101 | Unclear responsibility in later upgrade/Green products upgrading | [7], [8] |
| 102 | Inadequate GB maintenance/lack of adequate GB maintenance | [7], [8] |

[1] Zhao et al. (2016); [2] Hwang et al. (2017a); [3] Hwang et al. (2017b); [4] Ismael and Shealy (2018); [5] Ranawaka and Mallawaarachchi (2018); [6] Yang et al. (2016); [7] Ahmad et al. (2019); [8] Qin et al. (2016); [9] Rafindadi et al. (2014); [10] Guan et al. (2020); [11] El-Sayegh et al. (2018); [12] Hwang et al. (2015); [13] Krechowicz (2017); [14] Zhao et al. (2015); [15] Zou and Couani (2012); [16] Polat et al. (2017); [17] Chan et al. (2017); [18] Tao and Xiang-Yuan (2018)

**Table 7** Methodologies of reviewed studies

| N. | Source | Research design | | | | | Data collection methods | | | Research method | | Country |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Survey | Case study | Mathematical modeling | Conceptual study | C. literature review | Questionnaire | Interview | Document review | Quantitative | Qualitative | |
| 1 | Zerkin (2006) | x | | | | | | x | | | x | USA |
| 2 | Evans et al. (2007) | | | | x | | | x | | | x | Australia |
| 3 | Lützkendorf and Lorenz (2007) | x | | | | | x | | | x | | Germany |
| 4 | Lam et al. (2010) | x | | | | | x | | | x | | Hongkong |
| 5 | Ranaweera and Crawford (2010) | | x | | | | | | x | x | | Australia |
| 6 | Häkkinen and Belloni (2011) | | x | | | | | x | | | x | Finland |
| 7 | Zhang et al. (2011) | x | x | | | | x | x | | | | China |
| 8 | Tollin (2011) | | | | x | | | | x | | x | USA |
| 9 | Menassa (2011) | | x | | | | | | x | x | | USA |
| 10 | Zhang et al. (2012) | x | | | | | x | | | x | | Australia |
| 11 | Zou and Couani (2012) | x | | | | | x | | | x | | Australia |
| 12 | Kohler and Hassler (2012) | | x | | | | | | x | x | | Switzerland |
| 13 | Dewlaney et al. (2012) | x | | | | | | x | | | | USA |
| 14 | Fortunato III et al. (2012) | | x | | | | | x | | | | USA |
| 15 | Omar et al. (2013) | | x | | | | | x | | | | USA |
| 16 | Bao et al. (2013) | | x | x | | | | x | | x | | China |
| 17 | MacAskill and Guthrie (2013) | | | | x | | | | x | | x | USA |
| 18 | Yang and Zou (2014) | | x | x | | | | x | | | | Australia |
| 19 | Rafindadi et al. (2014) | x | | | | | x | | | x | | The world |
| 20 | Zhao et al. (2015) | x | | | | | x | | | x | | Singapore |
| 21 | Rosa et al. (2015) | | | x | | | | x | | x | | Brazil |

**Table 7** (continued)

| N. | Source | Research design | | | | | Data collection methods | | | Research method | | Country |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Survey | Case study | Math-ematical modeling | Con-ceptual study | C. literature review | Questionnaire | Interview | Docu-ment review | Quantitative | Qualitative | |
| 22 | Gan et al. (2015) | x | | | | | x | x | | | | China |
| 23 | AlSanad (2015) | x | | | | | x | | | x | | Kuwait |
| 24 | Hwang et al. (2015) | x | | | | | x | x | | x | x | Singapore |
| 25 | Zhao et al. (2016) | x | | x | | | x | x | | x | x | Singapore |
| 26 | Yang et al. (2016) | x | | x | | | x | x | | x | x | China, Australia |
| 27 | Afshari et al. (2016) | x | | | | | | x | | | x | Canada |
| 28 | McArthur and Jofeh (2016) | | x | x | | | | x | | x | x | Canada |
| 29 | Qin et al. (2016) | x | | | | | x | | | x | | China |
| 30 | Darko and Chan (2016) | | | | | x | | | x | | x | |
| 31 | Mohammadi and Birgonul (2016) | x | | | | | x | x | | x | x | Turkey |
| 32 | Gurgun et al. (2016) | x | | | | | x | | | x | | USA |
| 33 | Chan et al. (2017) | x | | | | | x | | | x | | Hongkong |
| 34 | Rosa et al. (2017) | | | x | | | | x | | x | | Brazil |
| 35 | Zhang et al. (2017) | x | | | | | x | | | x | | China |
| 36 | Ghazali et al. (2017) | x | | | | | x | | | x | | Malaysia |
| 37 | Krechowicz (2017) | x | | | | | | x | | x | x | Poland |
| 38 | Hwang et al. (2017a) | x | | | | | x | x | | x | x | Singapore |
| 39 | Hwang et al. (2017b) | x | | | | | x | x | | x | x | Singapore |
| 40 | Polat et al. (2017) | x | | | | | x | | | x | | Turkey |
| 41 | Karakhan and Gambatese (2017) | | x | | | | | | x | x | | USA |
| 42 | Hwang et al. (2018) | x | | | | | x | x | | x | x | Singapore |

**Table 7** (continued)

| N. | Source | Research design | | | | | Data collection methods | | | Research method | | Country |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Survey | Case study | Mathematical modeling | Conceptual study | C. literature review | Questionnaire | Interview | Document review | Quantitative | Qualitative | |
| 43 | Chan et al. (2018) | x | | | | | x | | | x | | Ghana |
| 44 | Wu et al. (2018) | | | x | | | | x | | x | | China |
| 45 | Tao and Xiang-Yuan (2018) | x | | | | | x | | | x | | China |
| 46 | Othman and Abdelwahab (2018) | x | | | | | x | x | | x | x | Egypt |
| 47 | Ranawaka and Mallawaarachchi (2018) | x | | | | | x | | | x | | Sri Lanka |
| 48 | El-Sayegh et al. (2018) | x | | | | | x | | | x | | UAE |
| 49 | Ismael and Shealy (2018) | x | | | | | x | x | | x | x | Kuwait |
| 50 | Ahmad et al. (2019) | | | | | x | | | x | | x | |
| 51 | Zhao et al. (2019) | | | | | x | | | x | | x | |
| 52 | Zheng et al. (2019) | x | | x | | | x | | | x | | China |
| 53 | Koulinas et al. (2019) | | x | x | | | | | x | x | | Greece |
| 54 | Goel et al. (2019) | | | | | x | | | x | | x | |
| 55 | Tabatabaee et al. (2019) | x | | x | | | x | | | x | | Malaysia |
| 56 | Javed et al. (2019) | x | | | | | x | x | | x | x | Pakistan |
| 57 | Raouf and Al-Ghamdi (2019) | | | | | x | | | x | | x | |
| 58 | Carretero-Ayuso and Rodríguez-Jiménez (2019) | x | | | | | x | | | x | | Spain |
| 59 | Guan et al. (2020) | | | x | | | | | x | x | | Australia |
| 60 | Xiao et al. (2020) | | | x | x | | | | x | x | | China |

**Table 7** (continued)

| N. | Source | Research design | | | | | Data collection methods | | | Research method | | Country |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Survey | Case study | Mathematical modeling | Conceptual study | C. literature review | Questionnaire | Interview | Document review | Quantitative | Qualitative | |
| 61 | Zhang and Mohandes (2020) | x | | | | | x | x | | x | x | Hongkong |
| 62 | Abdul-Malak and Khalife (2020) | x | | | | | x | | | x | | Multi-country |
| 63 | Lee et al. (2020) | | | | x | | | | x | | x | Malaysia |
| 64 | Górecki and Díaz-Madroñero (2020) | x | | x | | | x | | | x | | Poland |

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.



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