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Green finance gap in green buildings: A scoping review and future research needs

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Abstract

Green buildings, although critical to climate change mitigation, have a huge investment deficit. Green finance provides a viable option for bridging the green buildings investment gap. Despite the benefits of green finance in green buildings (GF-in-GBs), limited attention has been paid to this research area. To provide an overview of and map the area for the first time, this study conducted a systematic scoping review. Systematic searches across the five databases of Scopus, the Web of Science, ScienceDirect, Google Scholar, and normal Google identified a total of 28 relevant studies, including both the grey and academic literature. Study selection and data charting were conducted independently by two reviewers using standardized forms, with disagreements resolved through discussions. General and methodological characteristics of GF-in-GBs research were mapped. Results indicated that this is a highly under-researched and under-invested area. Asia has so far however contributed most. Previous studies embraced a variety of research designs, but most were content or report analysis-based, with limited empirical work. Based on identified gaps this study suggested future research directions, including (1) green incentives for GF-in-GBs, (2) GF-in-GBs rating software, (3) AI-enabled GF-in-GBs performance assessment software, and (4) intelligent GF-in-GBs cost-benefit analysis framework. The findings of this study provide an

understanding of the status quo and future needs of GF-in-GBs, which would help researchers, policymakers and practitioners improve and promote the implementation of green finance for promoting green buildings to combat climate change.

Keywords: Sustainability; climate change; green buildings; green finance; scoping review.

1. Introduction

Climate change is a global challenge. Buildings fuel this challenge by accounting for 35% and 38% of global energy use and carbon emissions, respectively [1], highlighting the need for green buildings. Green buildings are "buildings that, in their design, construction or operation, reduce or eliminate negative impacts, and can create positive impacts, on our climate and natural environment. They preserve precious natural resources and improve our quality of life" [2].

Due to their sustainability benefits, green buildings have attracted significant global attention, leading to a number of studies [3]. Green buildings, however, account for only a fraction of the total US$24.7 trillion investment opportunity by 2030 [4]. Moreover, in 2019, for example, global investment in green buildings accounted for only US$148 billion of the total US$5.6 trillion investment in buildings [1]. To close this green building investment gap there is a need to leverage innovative financing such as green finance to accelerate the development of green buildings. Thus, governments around the world are promoting the development of green finance in green buildings (GF-in-GBs) [5].

Green finance refers to financial instruments that support the transition to a climate-resilient economy by enabling such initiatives as environmental protection through greenhouse gas (GHG) emissions and energy use reduction, and development of climate-resilient infrastructure [6]. As above, GF-in-GBs provides a great opportunity for filling the green buildings investment gap. It could also help address the green buildings cost barriers [7,8]. However, it lacks a systematic review of existing knowledge. Previous reviews focused on either green buildings [3,8–10] [or green finance [11–13] in isolation. No review has yet tackled the implementation of GF-in-GBs, causing a lack of understanding of the status quo and future needs. Such understanding is necessary

– for researchers, policymakers, and practitioners to improve and promote GF-in-GBs. This study aims to conduct a scoping review of the implementation of GF-in-GBs. It addresses the following research question: what are the status quo and future needs of GF-in-GBs? To address this question, the following research objectives are set:

1. To conduct a systematic search for the published literature, including both the grey and academic literature;
2. To chart the characteristics of and the methodologies used in the identified studies;
3. To uncover the gaps and limitations of the research field; and
4. To propose recommendations for advancing the field and enhancing the applicability of the research to practice.

2. The concept of green finance

Climate finance, on one hand, finances climate change mitigation and adaptation initiatives. *Green* finance, on the other hand, has a broader scope, covering both climate finance, and all other financial products and services aimed at other, wider range of environmental objectives as well, including industrial pollution control, and natural resources and biodiversity conservation [6,14]. In fact while the roots of green finance can be traced back to the 1970s [15], green finance started gaining its popularity in 2010 when the Green Climate Fund was established by 194 countries to provide financial aid to developing countries to mitigate and adapt to climate change [12]. And following the adoption of the Paris Agreement, Sustainable Development Goals (SDGs), and Sendai Framework for Disaster Risk Reduction in 2015 [16], green finance was identified to be essential in financing *climate change action* [17]. It involves various financial institutions, both public and private, and such asset classes as green bonds, green loans, green funds, green banks, green credits, climate finance, climate bonds, environmental finance, carbon finance, sustainable finance, sustainability bonds, socially responsible investment (SRI), and responsible or environmental, social and governance (ESG) finance [21]. Table 1 offers a typology that describes different green finance types and their applications. It is clear that green finance is applicable to

79 green buildings as a climate change mitigation action within the buildings sector. In sections that
80 follow, this study reviews the application of GF-in-GBs and offers recommendations to improve
81 its future research, policy, and practice.

Table 1

A typology of green finance.

Green finance types	Definitions	Applications[a]	References
Carbon finance	Trading and investment activities relating to financial policies for reducing GHG emissions, including the trading and investment of carbon emission rights and their derivates, investments and financing for the development of low-carbon projects, and other financial intermediary activities	Low carbon projects, such as the reducing emissions from deforestation and forest degradation (REDD+) projects	[18–20]
Climate finance	Financing that supports the transition to a climate-resilient economy by enabling mitigation actions, especially the reduction of GHG emissions, and adaptation initiatives towards promoting the climate resilience of infrastructure as well as social and economic assets in general	Climate change mitigation, including GHG emissions reduction projects, such as clean energy and energy efficiency projects; and climate change adaptation projects, such as building flood defences to warming waters	[14,21]
Climate bonds	Fixed-income financial instruments that are linked with climate change solutions. They are issued in order to raise finance for climate change solutions for mitigation- or adaptation-related projects	Same applications as for climate finance above	[21,22]
Green bonds	Any type of bond instrument where the proceeds are exclusively applied to the finance or re-finance of projects with clear environmental benefits	Green projects, such as renewable energy, energy efficiency, pollution prevention and control, terrestrial and aquatic biodiversity conservation, clean transportation, sustainable water and wastewater management, climate change adaptation, eco-efficient and/or circular economy, and green building projects	[14,23]
Green loans	Any type of loan instrument made available exclusively to finance or re-finance, in whole or in part, new and/or existing eligible green projects	Same applications as for green bonds above	[24]
Green funds	Funds (equity or debt financing) that provide clients with platforms through which environmentally friendly businesses and organisations are supported with long-term funding	Climate change and environmentally friendly projects, such as energy efficiency, agriculture and waste management projects	[21]
Green credits	Basically refers to the green deposit and loan industry, mortgage and project loans	Green industries, constrain investment in pollution and overcapacity industries, and withdraw financing from prohibited industries that have been primarily targeted for their negative environmental impact	[25,26]
Green/sustainable banking	Green banking facilitates private investments in domestic low-carbon, climate-resilient infrastructure and other green sectors such as water and waste management	Meeting ambitious emissions targets, creating jobs, supporting local community development, mobilizing private capital, energy-efficient street lighting, lowering the cost of capital, rooftop solar photovoltaic systems, developing green technology markets, and commercial and residential energy retrofits	[27]
Environmental finance	Finance and investment targeting the ecological environment (air, soil, water, etc.) or to deliver quality environmental while mitigating environmental risks	Renewable energy, energy efficiency, green buildings, sustainable transport, waste and wastewater, agriculture and land use, forestry, ecological resources, infrastructure, energy and built environment, and environmental technologies, solar technologies, and solar home systems	[28–30]
Responsible or ESG finance	Strategies and practices that incorporate environmental, social, and governance factors in investment decisions and active ownership with a view to minimise risks and maximise returns	Pollution prevention and control; natural resources and biodiversity conservation; climate transition; climate change mitigation and adaptation; social issues and outcomes; and governance	[6]

SRI	Investing with the aim to achieve financial returns while respecting specific ethical, environmental, and/or social criteria	SRI projects, including community investing, alternative/clean energy technologies, affordable housing and loans, human rights, political and social activism, and religious value	[6,31]
Sustainable finance	Incorporates climate, green, and social finance while also adding wider considerations concerning the longer-term economic sustainability of the organisations that are being funded, as well as the role and stability of the overall financial system in which they operate	All projects financed under climate, green, and social projects	[6]
Sustainability bonds	Any type of bond instrument where the proceeds or an equivalent amount will be exclusively applied to finance or re-finance a combination of both green and social projects	Same applications as for sustainable finance above	[32]

84 [a] Please note that the project applications listed are not exhaustive.

3. Research methodology

This study used the scoping review methodology to investigate the status quo and future needs of GF-in-GBs research. Scoping review is an effective methodology for assessing progress made in a research domain, based on which further studies are developed [33]. It has been used in many previous studies [34,35]. To conduct the scoping review, a set of guidelines, as shown in Table 2, were first developed. The guidelines established the scope of the study, data sources and information to be gathered from the reviewed studies. The scope of the study defined the duration of the review, and language, access and literature types of the studies. Data were collected from the various, multiple sources of Scopus, the Web of Science (WoS), ScienceDirect, Google Scholar, and normal Google search (for the grey literature). Information gathered from the studies included the titles, authors, publication years, keywords, publication countries/regions, study aims, methodologies, results, and recommendations for further studies.

Table 2
The scoping review guidelines.

Scope	Data sources	Information gathered
• Duration of the review: four months • Access to the full text • English language • Academic publications (academic literature) and policy or practice-based reports (grey literature)	• Scopus • WoS • ScienceDirect • Google Scholar • Normal Google search (for the grey literature)	• Titles, authors, publication years • Keywords • Publication countries/regions • Study aims • Methodologies • Results • Recommendations

After establishing the scope of the study, data sources and information to be gathered, this study used the established five-step scoping review process [36]: (1) inclusion and exclusion criteria, (2) systematic search strategy, (3) selection of studies, (4) data extraction, and (5) data synthesis. Fig. 1 shows the scoping review process, details of which are discussed next.

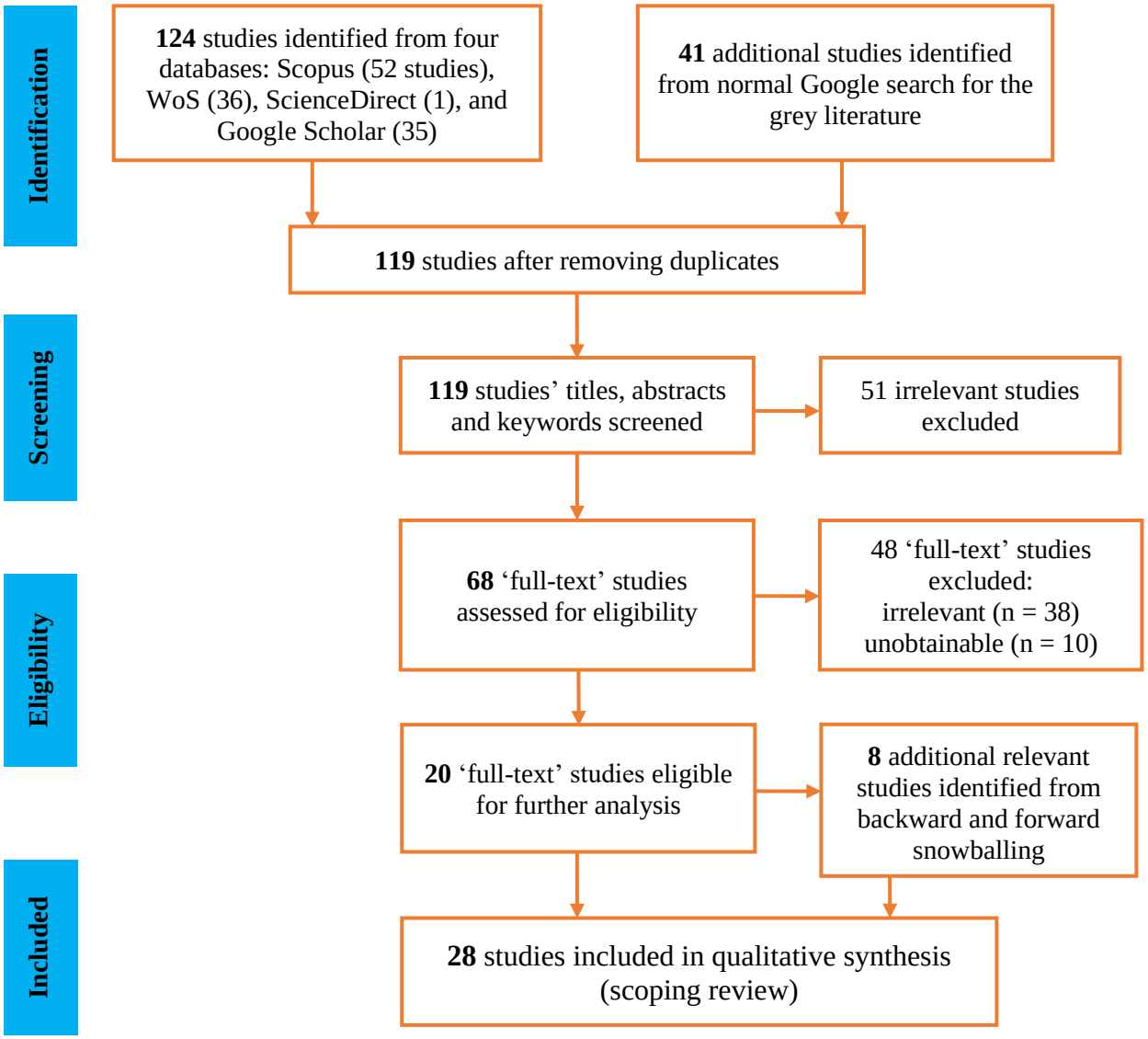

Fig. 1. Flowchart of the study selection process.

3.1. Inclusion and exclusion criteria

The study was limited to academic publications (articles, conference papers, book chapters, and review studies) and practice-based reports on GF-in-GBs from reputable international bodies, such as the UNEP and International Finance Corporation (IFC). Such studies could afford relevant information from the international perspective. Book reviews, press coverage, encyclopedias, interviews, website information, commentaries, and non-English language studies were excluded, while the literature search and review was conducted from January to April 2021.

3.2. Systematic search strategy

In this study, data retrieval of previous studies is crucial, as it determines the body of knowledge on which the study conclusions are based. Hence, the literature search strategy and databases were carefully selected. To achieve the most relevant results regarding the research question, data were collected from the four academic databases of Scopus, WoS, ScienceDirect, and Google Scholar. To ensure a representative and wider coverage of the literature, the search was pre-tested in various databases so that the most relevant databases were chosen for the review. Furthermore, the selected databases have been used in recent similar scoping reviews [34,37]. Moreover, to increase the validity and reliability of the data, it is essential to include all the widely recognized keywords in the study area in the literature search. While this study intends to include these keywords, it is infeasible to include all potential keywords in one study [3]. A combination of keywords from related previous reviews on both green finance [11–13] and green buildings [3,9,10] were, however, used to collect the bibliographic data from the five databases. Table 3 presents the search query strings used to achieve a high level of precision and specificity. The search was performed on the title, abstract, and keywords sections of studies, with no limitations on date range, ensuring that as many as possible relevant available studies were identified. Moreover, it is worth noting that the literature searches were last updated on 26 April 2021, and the number of available studies may increase at the end of the year.

Table 3
Literature search strategy.

No.	Keywords
1	"Green finance" OR "Climate finance" OR "Sustainable finance" OR "Carbon finance" OR "Environmental finance" OR "Carbon financing" OR "Sustainable financing" OR "Green bonds" OR "Climate bonds" OR "Green investing" OR "Eco-investing" OR "Carbon investing" OR "Green credit" OR "Green loans" OR "Green securities"
2	"Green buildings" OR "Green building" OR "Green technology" OR "Green technologies" OR "Green housing" OR "Green retrofit" OR "Green retrofits" OR "Green project" OR "Green projects" OR "Green construction" OR "Sustainable buildings" OR "Sustainable building" OR "Sustainable housing" OR "Sustainable project" OR "Sustainable projects" OR "Sustainable construction" OR "High performance buildings" OR "High performance building" OR "High performance project" OR "High performance projects" OR "High performance construction" OR "High-performance buildings" OR "High-performance building" OR "High-performance project" OR "High-performance projects" OR "High-performance construction"
3	"Green financing" OR "Green finance" OR "Climate finance" OR "Sustainable finance" OR "carbon finance" OR "Environmental finance"
4	"Green building" OR "Green construction" OR "Sustainable building" OR "Sustainable construction"
5	Combination of 1 and 2
6	Combination of 3 and 4

In addition to the academic literature searches in Scopus, WoS, ScienceDirect, and Google Scholar, a normal Google search for the grey literature of practice-based reports and documents was also conducted using the combination of the search query strings 3 and 4 (Table 3). Finally, 124 studies were identified from Scopus (52 studies), WoS (36), ScienceDirect (1), and Google Scholar (35) while 41 additional studies were identified from the normal Google search. Using the backward and forward snowballing technique, another eight additional studies were found through references list search [37].

3.3. Selection of studies

Titles, abstracts, and keywords were independently screened by two of the authors (APCC and AD) to identify those studies that met the eligibility criteria. The other author (CD) doublechecked to double confirm the eligibility of the studies, then retrieved their full texts to produce a final set of eligible studies for the review. Regarding the grey literature search, paid-for advertised reports were discounted and the first 10 pages of Google results were searched [38]. For some organizations, such as the UNEP, multiple reports that address very similar issues have been published. In such case, after a review, discussion and agreement between APCC and AD, one or two reports that covered the key issues addressed by the other reports were chosen. To meet the inclusion criteria, a study must have *GF-in-GBs* as its focus. Therefore, studies such as techno-economic studies that have been conducted on green buildings were excluded from the review. Specifically, studies that focused on the economic (e.g., capital and operational costs [45–48], sales [9,45], occupancy rates [9,45] and rental income [9,45]) analyses of green buildings, for instance, were excluded. This is because they do not investigate the dynamics surrounding the implementation of GF-in-GBs.

After the screening process to remove all duplicates and irrelevant studies, 28 relevant studies were finally identified for the scoping review (see Fig. 1). This small sample size may be attributed to the fact that GF-in-GBs is an emerging, very young research area with *few* studies, thus the choice of the scoping review methodology for this study. Similar to systematic reviews, scoping

reviews have no requirement on the acceptable minimum sample size, causing the "prevalence of 'empty reviews' in the Cochrane Library" [39]. However all reviews should follow a rigorous scientific methodological approach [40]. According to [40], the median or modal average sample size of systematic reviews (scoping review in this case) is 15 studies. Moreover, previous similar scoping reviews have been conducted with smaller sample sizes of seven [41] and 24 [36] studies. The sample size of 28 studies for the present study could, therefore, be deemed acceptable.

3.4. Data extraction

CD extracted information from each study and entered them into a Microsoft Excel spreadsheet. The information extracted were author, year, title, keywords, country or region, aim, methodology, results, recommendations, and funding details of the study, as shown in the supplementary file. Results were then descriptively synthesized by assessing the thesis and antithesis of the studies. APCC and AD scrutinized the data extracted to ensure quality. The Zotero reference manager was used to ensure that citations and documents were properly accounted for during the process.

3.5. Data synthesis

This review outlines the scope of GF-in-GBs research and development. The status-quo was investigated by examining the main themes, keywords, and focuses of the reviewed studies. In addition, promising areas for future research were identified and analyzed. Furthermore, the differences between the academic and grey literature were identified and evaluated to inform the next generation of GF-in-GBs research and development.

4. Results

4.1. General characteristics and status-quo of GF-in-GBs research

It was found that the first study on GF-in-GBs was the 2011 study of Martin [42] on "Home purchase counselling: The untapped green financing tool". This implies that GF-in-GBs research has been around for about only a decade now, although both the green finance and green building research fields in general were born in the 1970s [9,15]. The finding could be explained by the fact that green finance started gaining its popularity only in 2010 [12], as noted earlier in Section

2. Fig. 2 shows the number of studies published from 2011 to 2021. It reveals a fluctuating trend with no steady growth since 2011. There were several 'ups and downs' and, more interestingly, no studies published at all in some years, 2012 and 2015. It could be that the popularity of green finance had still not significantly manifest in green buildings during these years. 2019 and 2020, however, saw the highest number of studies, but still as small as eight and seven studies, respectively, with 2021 likely to see an upsurge at the end of the year. There are some interesting observations from the research findings. First, the findings indicate that this is an emerging, very young research area with promising opportunities for future research given the few existing studies. Such future research should enable policymakers and practitioners to take advantage of the projected trillion-dollar investments opportunities by 2030 [4] to finance and hence promote green buildings to combat climate change. Second, it is not surprising the more recent years saw the highest number of studies because there has been much global attention to both green finance and green buildings in these years owing to the global Climate Emergency Declarations [43]. But still the number of studies is far from satisfactory and does not reflect the significance of both the Climate Emergency Declarations and GF-in-GBs. There is indeed a need for further GF-in-GBs research. Given the urgent need to address the green buildings investment gap [1] and cost barriers [7,8] to greatly promote green buildings for fighting climate change, GF-in-GBs research, policy, and practice are expected to grow significantly in the coming years.

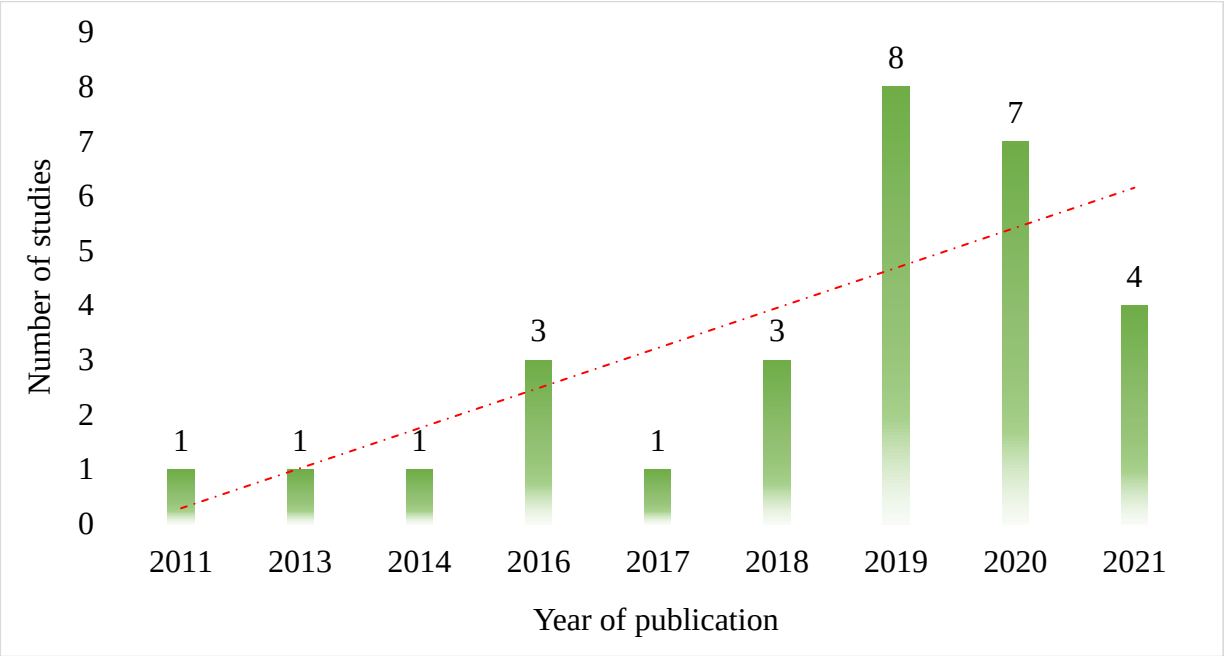

Fig. 2. Number of studies published from 2011 to April 2021. The number of 2021 studies may increase at the end of the year.

In terms of the number and percentage of studies by continents (Fig. 3), Asia contributed most, 13 studies (46.4%), followed by Africa and North America, each with five studies. Australia and Europe each contributed two studies, while South America contributed only one study. Asia accounts for about 72% (US$17.8 trillion) of the GF-in-GBs investment opportunities across all emerging markets [4]. Besides, Asian countries such as China and India are seen as key players in green financing, given their relatively high GHG emissions [12,44]. These could explain why Asia has so far contributed most of the GF-in-GBs studies. It is surprising that although the US dominates the green finance debate [12], its GF-in-GBs research has been limited. It could be that its green finance debate has yet to be extended to green buildings. However, there persists a huge US$250 billion annual investment gap in climate change mitigation solutions across the US [45]. Increasing the US-based GF-in-GBs research might therefore significantly impact investment and policymaking. Similarly, Africa, South America, and Europe have vast GF-in-GBs investment opportunities [4] that merit further research.

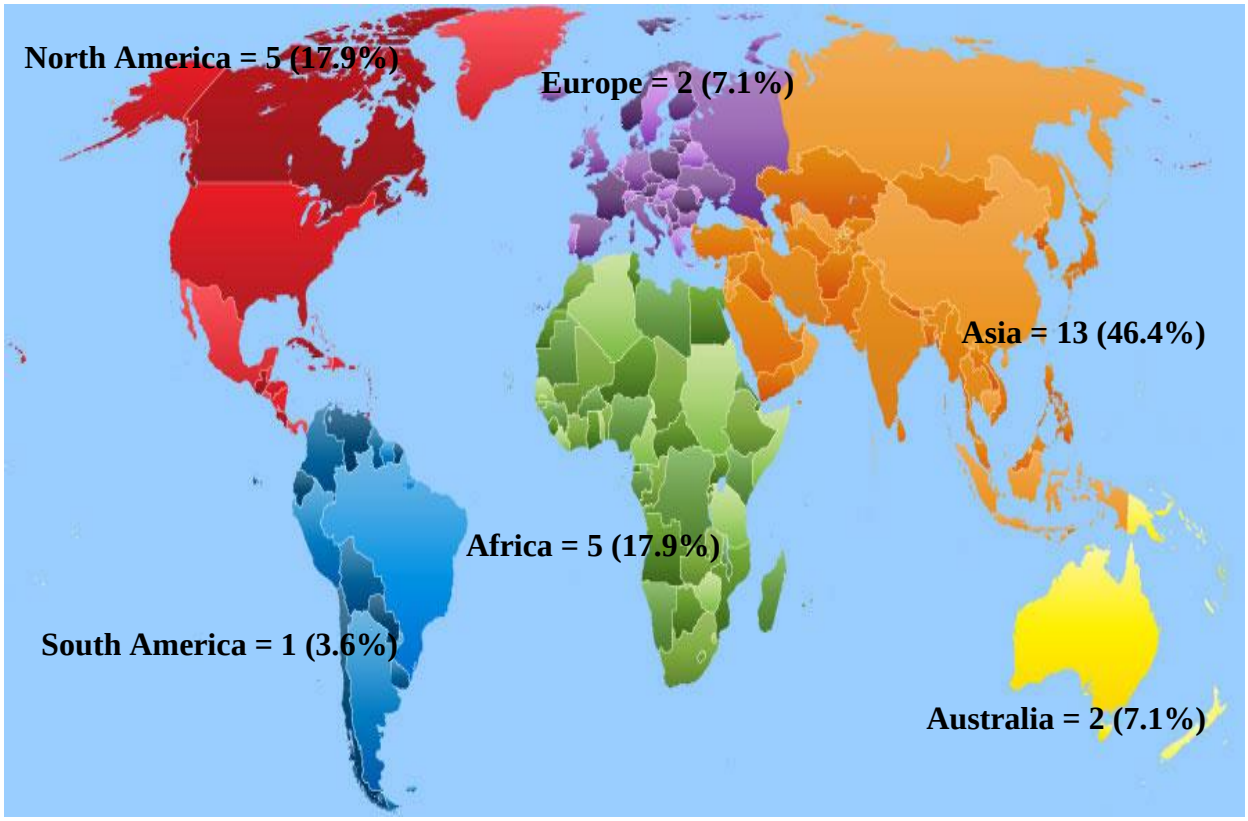

Fig. 3. Number and percentage of studies by continents. Round-off errors may occur in calculating percentages.

This figure plots the total number and percentage of studies originating from the various continents. The list of countries publishing in the research area in each continent include: China, Hong Kong, Japan, India, Singapore, Philippines, Republic of Korea (Asia); South Africa, Kenya, Nigeria, Ghana, Uganda, Rwanda, Burundi, Tanzania (Africa); Finland (Europe); US (North America); Australia. Note that some studies, such as the one of South America [46] focused not on a specific country but on the continent as a whole. Source of the map: https://www.map-menu.com/world-map.htm

Only few (nine, 32% of) studies reported research funding details [30,47–54], the rest reported no funding details. It may be that GF-in-GBs research lacks the needed funding. Funding agencies, investors, the government, and research institutions and universities should collaborate in funding and pursuing GF-in-GBs research.

Moreover, only 10 (36% of) studies were found in academic research journals, such as *Building and Environment*, *Real Estate Economics*, *Building Research & information*, *International Journal of Construction Management*, *Engineering*, and *Journal of Cleaner Production*. The rest of the studies were in conference proceedings (three studies, 11%), book chapters (two, 7%), and reports, industry guides, or working papers (13, 46%). There has been limited research from the academic research community. This finding agrees with that of [12] that green finance research has received limited attention from the academic research community. Academic researchers and

journal editors may align their future research focuses with GF-in-GBs to promote climate change mitigation.

GF-in-GBs studies have focused on three major areas: (1) new construction of green buildings, (2) green buildings energy efficiency and retrofits, and (3) green finance knowledge and housing loans, as shown in Fig. 4. Most (75%) of studies focused on applying green finance in constructing new green buildings, reflecting the high demand for new green buildings for low-carbon economic growth [4]. Moreover, constructing new green buildings offers the opportunity to integrate energy efficiency into the building design and avoid costly retrofits later, maximising the financial benefits of energy savings [55]. Green buildings energy efficiency and retrofits, and green finance knowledge and housing loans, however, remain understudied. As the International Energy Agency (IEA) [56] recommends the efficiency retrofits of public assets to promote green buildings, there is a need for studies on leveraging green finance in building energy efficiency and retrofits.

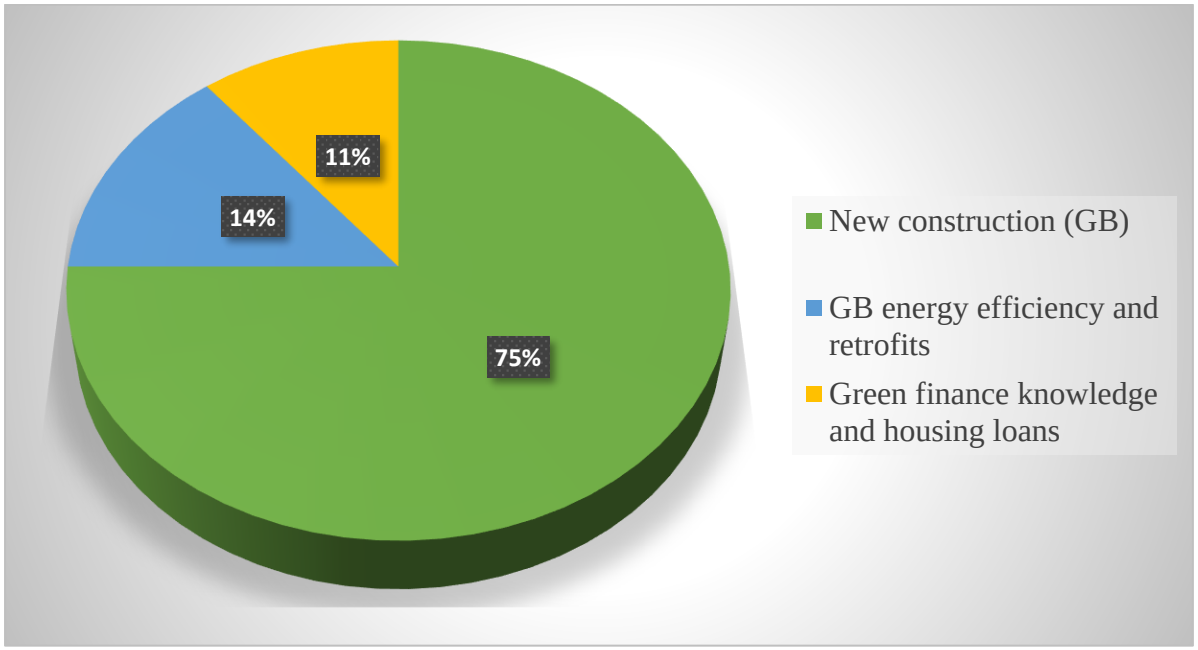

Fig. 4. Major areas of GF-in-GBs research.

In addition, this study further identified seven GF-in-GBs research themes which could be broadly classified under the three major areas (Fig. 4): (1) GF-in-GBs policy guide and performance, (2) obstacles and drivers of GF-in-GBs, (3) GF-in-GBs solutions and trends, (4) financing building energy efficiency and retrofits, (5) financing green affordable housing and real

estate, (6) GF-in-GBs knowledge sharing and counselling, and (7) case examples of GF-in-GBs; discussed in detail in Section 5.

4.2. Methodological characteristics of GF-in-GBs research

Table 4 and Fig. 5 show the methodological characteristics of reviewed studies, which vary in terms of their data collection and analysis methods. As shown in Table 4, previous studies gathered data using questionnaire surveys, interviews, qualitative documents or reports analyses, literature reviews, case examples, archival/statistical data, and mixed methods. Reports (including literature reviews, qualitative document analyses, and case examples) are found to be the most widely used methods, used in 68% of the studies. With the studies published in the academics databases, archival/statistical data, questionnaire surveys, and interviews were the preferred methods.

Table 4
Data collection and analysis methods in GF-in-GBs research.

Data collection methods	Number of studies	Percent
Reports (including literature reviews, qualitative document analyses and case examples)	19	67.86
Mixed methods[a]	3	10.71
Archival/statistical data	3	10.71
Questionnaire surveys	2	7.14
Interviews	1	3.57
Data analysis methods	**Number of studies**	**Percent**
Qualitative analysis (content or report analysis)	20	71.44
Statistical analysis	2	7.14
Econometric analysis	2	7.14
Computational analysis	2	7.14
Hybrid analysis	2	7.14

[a] The mixed methods include 'archival/statistical data + expert panel' [59], 'interviews + questionnaire surveys' [53], and 'report analysis + questionnaire surveys' [5].

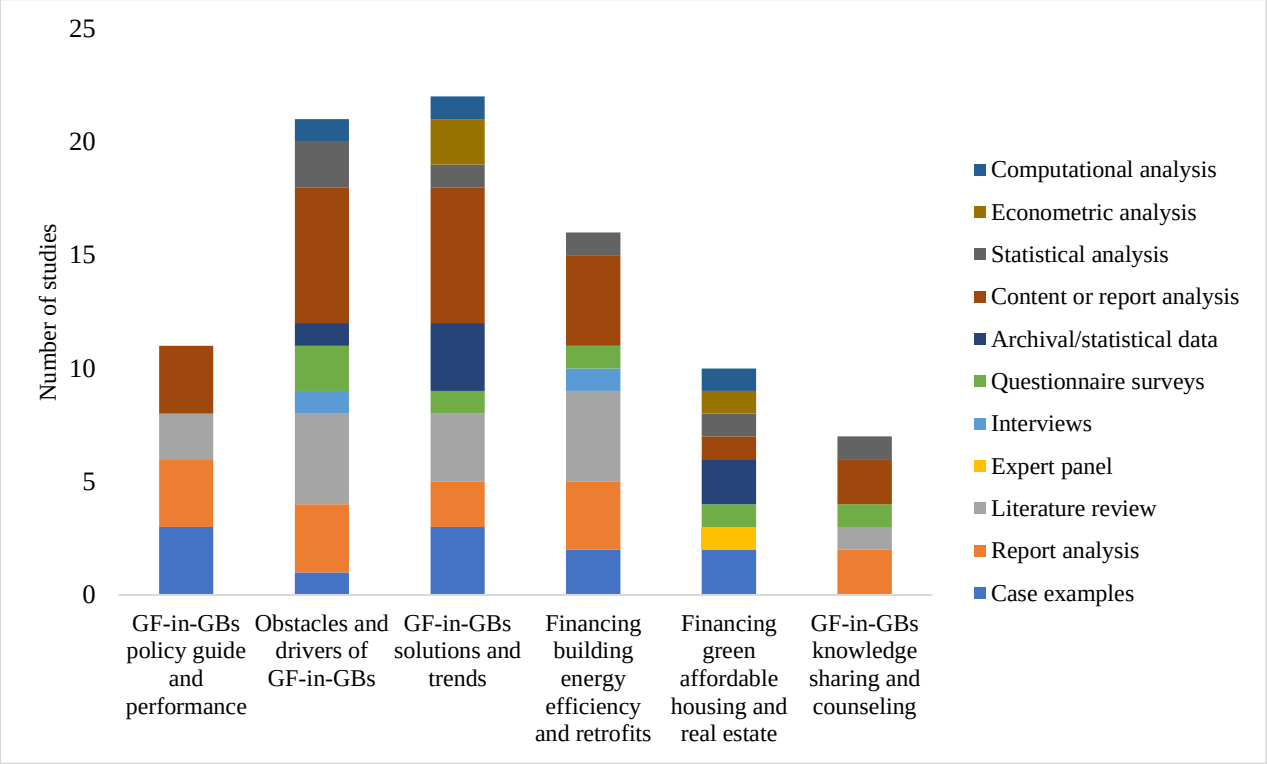

Fig. 5. Research designs of GF-in-GBs research.

Survey is one of the main data collection methods in academic research. It involves the gathering of data from respondents, generally through questionnaires or interviews, with the aim to generalize from a sample to a population [57]. All the studies that used questionnaire surveys, although few (only four studies), involved sample sizes ranging from 50 to above 200, as shown in Table 5. In future research such large sample sizes as above 200 is strongly encouraged to derive valid and reliable results and conclusions. Interviews are usually used in qualitative research to understand the opinions, experiences, and attitudes of respondents [59]. Three industry interviews were conducted with 10-50 experts in past studies. For interviews, five respondents are considered adequate provided they are *experts* in the field [60]. As indicated earlier in Table 4, three studies used mixed methods, 'archival/statistical data + expert panel' [61], 'interviews + questionnaire surveys' [53], and 'report analysis + questionnaire surveys' [5], as their primary data collection methods. Mixed method, also known as methodological triangulation [57], is useful to overcome the weaknesses and exploit the strengths of different methods when used separately. Such merit

should be widely leveraged to improve future GF-in-GBs research. In MacAskill et al. [61], the expert panel was used in the mixed methods framework to validate the study findings.

Table 5

Sample sizes and response rates in GF-in-GBs research.

Studies involving questionnaire surveys (sample sizes)	Number of studies	References
50-99	1	[51]
100-200	1	[5]
Above 200	2	58,60
Studies involving interviews (number of interviews)	Number of studies	
10	1	[61]
Above 30	2	[53,54]
Response rates	Number of studies	
Below 60%	1	[5]
60-80%	1	[51]
80-100%	2	[53,58]
Not specified	1	[54]

After data collection, different methods were used for data analysis. Based on the data analysis methods, the studies were classified into (1) qualitative analysis (content or report analysis), (2) statistical analysis (or descriptive statistics), (3) econometric analysis, (4) computational analysis (including artificial intelligence (AI) algorithms), and (5) hybrid analysis) (Table 4). Most (71% of) studies used qualitative analysis (including content or report analysis). In the statistical analysis-based studies, methods including frequencies, mean scores, and percentages were used [5,53]. An and Pivo [48] implemented the econometric analysis in exploring both cross-sectional and time series variations in Energy Star and LEED status among commercial mortgage-backed securities buildings. Based on data provided by the US Green Building Council and Trepp loan data, a matched sample analysis, difference-in-difference, and a standard Cox proportional hazard model were employed. Similarly using the real options pricing theory and the binomial lattice model, Lee et al. [30] proposed a financing model to facilitate green building projects with governmental guarantee based on Certified Emissions Reduction.

Two recent studies [47,61] adopted computational analysis. MacAskill et al. [61] developed a novel system dynamics model to forecast a business as usual and green building scenario framed around the recently introduced Australian Affordable Housing Bond Aggregator policy framework. System dynamics is well suited to policy and complex systems analysis that aims to

gain a broader view of problems, build conceptual models, and avoid unintended consequences of decisions. Moreover, a neural networks-based weighted influence non-linear gauge system model was developed [47]. Based on green financial supportive factors, this model was then used to establish a multi-layer green building influencing factors index system. Using related statistical data of green buildings and green finance of China, the factors influencing green buildings development were analysed. Two other studies employed hybrid analysis combining descriptive statistics and advanced quantitative techniques. The studies used 'descriptive statistics +inferential statistics of *t*-test and analysis of variance' [58], and 'descriptive statistics + statistical cost analysis between conventional and green buildings' [51]. Fig. 5 presents the data collection and analysis methods (Table 4) applicable to the identified GF-in-GBs research themes. Most of the methods have been used in two of the research themes, obstacles and drivers of GF-in-GBs, and GF-in-GBs solutions and trends.

4.3. Stakeholders in GF-in-GBs research

Stakeholders refer to individuals or groups with interest in a particular issue [62]. It is necessary to identify the stakeholders involved in GF-in-GBs research, to understand what the stakeholders focused on most or least, providing insights on stakeholder-related directions for further research. GF-in-GBs studies were conducted from the perspectives of various stakeholders (Table 6).

Table 6
Stakeholders involved in GF-in-GBs research.

Stakeholders	Number of studies	Percent
Managers of financial institutions (e.g., banks, pension funds, and opportunity funds)	3	10.71
Construction professionals (e.g., building contractors, quantity surveyors, civil/building engineers, architects)	3	10.71
Local housing authorities/affordable housing experts	2	7.14
Real estate/project developers	2	7.14
Senior representatives of listed real companies/real estate investment trusts (REITs)	2	7.14
Senior representatives of real estate private equity funds	1	3.57
Investment managers	1	3.57
Officials of energy service companies	1	3.57
Independent investors/owners	1	3.57

Understandably, managers of financial institutions (e.g., banks, pension funds, and opportunity funds) and construction professionals (e.g., building contractors, quantity surveyors, civil/building

engineers, architects) were the major stakeholders. Others were local housing authorities/affordable housing experts, real estate/project developers, and senior representatives of listed real companies/REITs. This aligns with [63] who claimed that financial institutions are important stakeholders in green finance development, as they are considered the largest contributors to direct green finance. Further, [64] identified construction professionals such as architects as key stakeholders in green building development. Hence, it is not surprising that these stakeholders were also identified as the key stakeholders in GF-in-GBs studies. Other stakeholders were senior representatives of real estate private equity funds, investment managers, officials of energy service companies, and independent investors/owners. However, to our surprise, other stakeholders such as government authorities (except local housing authorities identified in a single study [53]), research institutions/academics/researchers, environmental economists, environmental scientists, financial economist, suppliers, law experts, etc., were missing in past GF-in-GBs studies. We therefore recommend that for a holistic understanding of this research area, future studies should incorporate these critical stakeholders.

5. Discussion

A summary of the reviewed studies is provided in Appendix A, while Fig. 6 gives a summary of findings of this study. The concept and types of green finance serve as the foundation for this scoping review, which explored the annual publication trend, distribution of studies by continents, and general and methodological characteristics of studies. Finally, research themes and recommendations for future studies were explored.

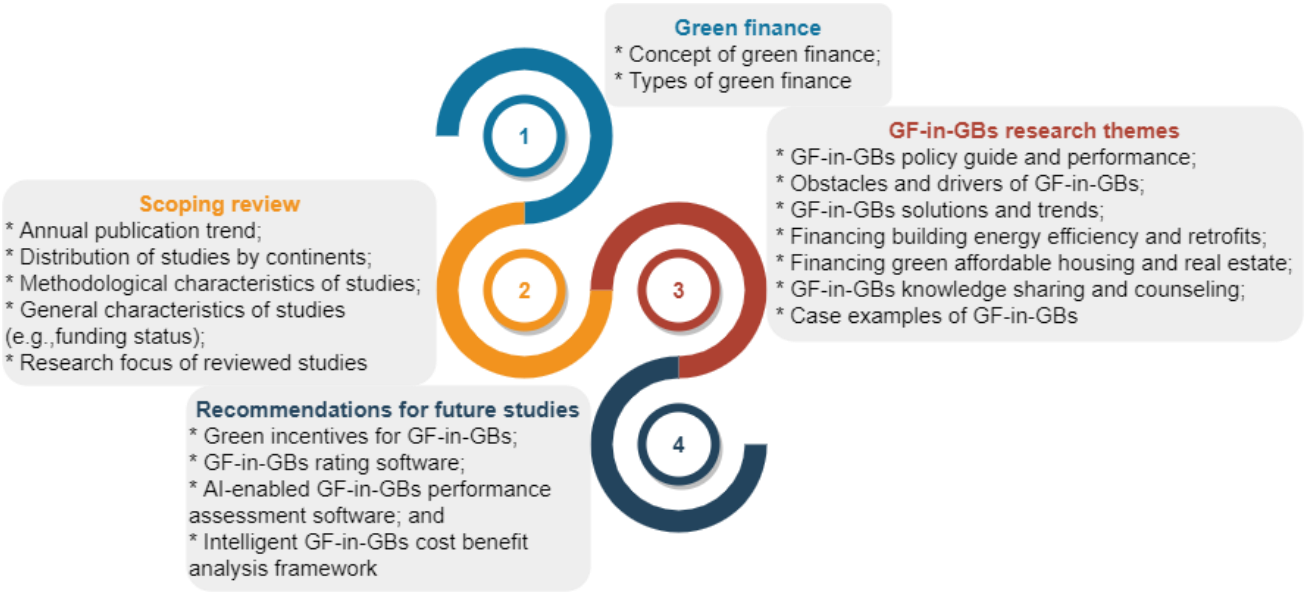

Fig. 6. Summary of findings.

This section overviews reviewed studies and discusses the major research themes identified. Based on identified gaps, recommendations for future research and practice are developed. Finally, the strengths and limitations of this study are also discussed.

5.1. Overview of reviewed studies and research gaps

The study results confirm that GF-in-GBs has been under-researched, in line with Zhang et al. [12]'s finding that the green finance topic in general itself has also been under-researched. As shown in Fig. 2, this research area has experienced an inconsistent and stunted growth. This could be due to inadequate funding, as few studies reported associated research funding. Moreover, most studies originated from Asia followed by Africa and the US, reflecting the plentiful GF-in-GBs investment opportunities in these regions [1]. Yet, the overall number of studies is still very limited, necessitating more future research.

The reviewed studies adopted multi-method designs comprising reports, literature reviews, case examples, questionnaire surveys, interviews, and archival/statistical data, and mixed methods. The analyses adopted in the various studies included qualitative analysis (content or report analysis), statistical analysis (descriptive statistics), econometric analysis, computational analysis (including AI algorithms), and hybrid analysis. Most studies based on content analysis of reports, while

empirical studies remain rather limited. Furthermore, only few studies were published in academic journals and conferences. The grey literature dominates with reports from international organizations such as the UNEP and IFC. The results suggest that there has been limited attention to GF-in-GBs from both academia and industry.

This study identified seven distinct GF-in-GBs research themes, namely GF-in-GBs policy guide and performance, obstacles and drivers of GF-in-GBs, GF-in-GBs solutions and trends, financing building energy efficiency and retrofits, financing green affordable housing and real estate, GF-in-GBs knowledge sharing and counselling, and case examples of GF-in-GBs; discussed below.

1. GF-in-GBs policy guide and performance

A section of the reviewed studies focused on development of GF-in-GBs policy guides. With the government as a key promoter of green buildings, policy incentives play a critical role [12] in GF-in-GBs. In a sustainable building finance report, UNEP [52] presented a practical guide to project financing in East Africa, which includes green construction finance product structure, assessment and assurance practices, and market development and evaluation. The report further identifies property and energy master planning, finance and delivery strategy, investment models and market tests as best practices and knowledge resources for GF-in-GBs products and market development. Other studies assessed the performance of GF-in-GBs. Lee et al. [65] assessed the GF-in-GBs performance along with the roles of sustainability engineers in Hong Kong. It was revealed that sustainability engineers play key roles in improving the comparability and transparency of green impacts for green finance initiatives. From above discussion, it is clear that the role of policy in stimulating GF-in-GBs is key. Although governments have stressed the need to build green through the Nationally Determined Contributions [4], there is also a need to create an enabling environment for developers to build that green. Such environment should create a house of bankable green building projects for green investors. However, the critical question is how these policies can drive building green through the now-available green building rating tools [66].

Furthermore, extant studies provide limited evidence of how policy can drive green buildings investments through incentives. Besides, the available green building rating tools focus on achieving the green requirements. The issue of costs and benefits to the investors has been largely neglected. This gap could be addressed by the next generation of GF-in-GBs studies, to inform investors of the costs and benefits of holding green buildings investments portfolio.

2. Obstacles and drivers of GF-in-GBs

GF-in-GBs development has seen some level of growth due to several drivers. Wang et al. [47] indicated that green financial support is a main influencing factor in green buildings development. Other drivers of GF-in-GBs include high return on investment [5,47,54,67], reduction of financial cost in investing in green buildings [47,67], green certification, potential to perform green retrofits, reduced negative environmental impacts (e.g., carbon emissions, energy consumption, and waste management), and with specific targets for their reduction [5,67], corporate social responsibility or responsible investment guidelines, increased asset liquidity, high resilience against earthquakes and climate change, and futureproofed for building code regulatory changes and compliance [5], market competition, strategic asset management activities to improve the efficiency of operations and overall sustainability performance, value creation opportunities, and local regulatory minimum requirements [54].

Despite the drivers, several barriers and challenges inhibit the widespread adoption of GF-in-GBs. They comprise: lack of green insurance products [47], split incentives, lack of incentives, capital expenditure, capital expenditure, lack of credible information dataset, and lack of knowledge about green building benefits, new technology [58,67–69], changing government policies and low government capacity [58,68], financing risks [50,58]. Financing risks include: market risks, credit risks, liquidity risks, sector risks, policy risks, financial risks, environmental risks, risks due to contract forms [50,69], and high lending risk due to low collateral asset value and high performance risks of energy efficiency projects [70]. Other barriers are local market conditions [52], no standardized technical assessment system to benchmark GF-in-GBs [5],

mismatch between the longevity of buildings and the relatively short holding periods for real estate assets in investment portfolios [67]. Suerkemper et al. [70] also identified additional key barriers of GF-in-GBs including lack of transparency of the energy service companies (ESCOs) and a general lack of in the energy service business; a long project lifetime, lack of technical knowledge (which makes it difficult to assess risks and future cash flows of energy service projects); lack of tools to assess ESCOs credit default risks; lack of generally accepted monitoring & valuation (M&V) standards for ESCOs; high transaction costs (due to small scale of projects). A combination of these barriers has resulted in the underinvestment in green buildings.

Although these studies included surveys, interviews, literature reviews, and archival data analysis, there is a need for more empirical studies that include drivers and barriers of GF-in-GBs to confirm the reported findings or otherwise. Additionally, due to the consistent growth of the GF-in-GBs market, further studies could identify new drivers and barriers. These could be a useful addition to both future researchers and other GF-in-GBs stakeholders. To further improve the market development, it is critical to investigate the interrelationship between the identified drivers and barriers to reveal the underlying connections which is currently lacking in extant studies. Knowledge of the GF-in-GBs drivers and barriers weights and relationships will aid policymakers in identifying which drivers and barriers need urgent attention.

3. GF-in-GBs solutions and trends

Several studies have proposed solutions and approaches for GF-in-GBs towards a low carbon economy. For example, Nenonen et al. [71] described how property developers can use green bonds for sustainable life cycle management and continuous development of properties. Other studies have also identified green bonds, green funds, green loans [47,67,72], green banking, and green housing loans [73] as suitable investment vehicles for green buildings. Green mortgages have been proposed as a mechanism to encourage the design and construction of sustainable homes, and procurement of energy and resource efficient appliances [52,73]. Other GF-in-GBs models are green bilateral loans, green syndicated or club loans, and sustainability-linked loans

[74]. Mo [50] indicated fiscal financing, bond financing, equity financing, finance leasing, and carbon market financing as some approaches to GF-in-GBs. Besides, "green sukuk", an Islamic form of green bonds is preferred in Asian countries such as Indonesia and Malaysia. In recent times, governments have explored several avenues including carbon pricing, cost at source to the negative impacts associated with GHG emissions, [75] as effective contributions to the Paris Agreement. Finally, [30] proposed a financing model to solve financial barriers for implementing green building projects. Based on Certified Emission Reductions for the increased cost, it was discovered that both private and government guarantees is feasible with the model.

From the review, the literature has focused on the types of GF-in-GBs. However, this information largely does not profit investors as they seek more tangible benefits associated with GF-in-GBs. In Lee et al. [30]'s work, a payback period for the worst scenario in GF-in-GBs in the Republic of Korea of 7.55 years was revealed. Also, [48] argue that green buildings carry 34% less default risk on green loans. Such studies [30,48] make investors well informed of the potentials in GF-in-GBs. As such, future studies could focus on investigating the risks, costs, and benefits that accrue to green buildings investors through both primary and secondary data analysis.

4. Financing building energy efficiency and retrofits

According to the IFC, the buildings sector consumes more than half of global electricity for heating, cooling, and lighting accounting for 28% of energy-related GHG emissions. Resource inefficient buildings run the risk of losing economic value due to progressively severe regulations, pressure from financial regulators to manage and disclose climate risks, and changing consumer preferences, as well as shareholder demands [4]. This has increased investments in building energy efficiency and retrofits globally especially in 2019 (US$152 billion) [1]. Mo [50] reported an estimated US$250 billion investment opportunities for greening and retrofitting buildings in China According to the UNEP [1], this increase in energy efficiency investments is driven by both the increase in construction industry investment activities across the globe and continued efforts in policies from Europe and China to direct greater investments in building energy performance.

Kennedy et al. [49] also noted that China has implemented many successful policies in the building sector in recent years, but there is still considerable scope for improvement in the energy efficiency of Chinese buildings. In a more recent study, Zhang et al. [53] surveyed western China to uncover green financing investment opportunities for building energy retrofits. [70] also identified some barriers to building energy renovations in China.

We infer that there is a growing global demand for building energy efficiency and retrofit leading to increased investment opportunities. This can be attributed to the available non-green buildings. 2-5% of the existing building stock would need to be renovated annually until 2050 [4]. With attractive returns even in the short-term, due to direct cost saving and value appreciation, the building energy efficiency and retrofits market is expected to grow at an annual compound rate of 8% from 2018-2023 [4]. It thus obvious that building energy efficiency and retrofits represent vast green finance opportunities. For both industry players and researchers, this is an area that demands greater investment and attention if we seek to achieve the goals of the Paris Agreement. However, China has been the focus of past studies due to the high GHG emissions. This also indicates a lack of studies in other parts of the world which is a disturbing trend due to the stock of nongreen buildings. We therefore urge researchers to redirect efforts in country-specific building energy efficiency and retrofits investment needs to inform stakeholders.

5. Financing green affordable housing and real estate

To promote green financing in green affordable housing and real estate development, recent studies have identified how data can be used to drive such investments. GBC Australia [76] described how green building rating tools such as the Green Star, GRESB and NABERS can be used to attract sustainable finance for real estate. To provide a better understanding of green finance in green real estate, Tan [5] used the case of China to investigate such relationship and its impact on the investment market. The outcomes of the study revealed that GF-in-GBs is driven by favourable policy environment and huge capital demand. Real estate market players are encouraged to take advantage of this rising green opportunities, technology, and innovation to deal

with climate change and other environmental issues. To solve the issue of split incentives, a GF-in-GBs barrier, MacAskill et al. [61] explored how bond-based funding mechanisms offer opportunities to integrate green building practices into the Australian affordable housing bond aggregator policy framework. Further, [48] showed that, *ceteris paribus*, green buildings carry 34% less default risk. The findings presented in this review suggest that green finance is critical to solving the crippling affordable housing situation globally. We argue that, financing green affordable housing and real estate results in both social and environmental sustainability [77]. Hence, extensive research is needed to assess the potentials in this area to meet the rising need for green affordable housing.

6. GF-in-GBs knowledge sharing and counselling

Past studies have investigated how GF-in-GBs knowledge sharing facilitate its adoption and development. Martin [42] demonstrated how counselling for green residential finance products can be effective in confronting the lack of homebuyer knowledge regarding potential energy costs, conservation, and efficiency to aid decision making. Despite the importance of increasing awareness of the now-available GF-in-GBs investment opportunities [72], Li and Tsoi [46] revealed a lack of studies in this area, especially in Latin America. From this review, we also observe that GF-in-GBs have received little attention in the literature. Future research could align their focus to take advantage of this embryonic research area to reveal the hidden benefits in GF-in-GBs and to promote sustainable development.

7. Case examples of GF-in-GBs

GF-in-GBs has seen substantial growth globally in recent years. This section of the study discusses various case examples in the reviewed studies. For example, Nenonen et al. [71] assessed the commitment of a Finnish property owner company in GF-in-GBs. It was revealed that, at the end of 2018, the company had about US$100 million allocated proceeds from green bonds issued rededicated to financing green building projects. Lee et al. [65] reported that the New World Development Group in Hong Kong have invested over US$776.1 million of green bonds and green

loans in green buildings. Bancolombia and Davidienda, two commercial banks in Colombia, offered competitive rates for both green construction finance and green mortgages [1]. In 2008, Mexico's Vinte became the first housing developer in Latin America to issue a sustainability bond [1]. Kenya's Acorn Holdings and the International housing solutions in South Africa have also made significant progress in raising green bonds for financing green affordable homes [1] in Africa. The reviewed studies illustrate several case examples of GF-in-GBs in recent years. We recommend that stakeholders involved in GF-in-GBs will publish their implementation successes and challenges to encourage new investors in this area.

5.2. Recommendations for future studies: research and practice

This study has conducted a scoping review of both academic databases and the grey literature on GF-in-GBs. Despite the huge investment opportunities, this research area has received less attention from both the academic research community and industry. Discussed next are the identified gaps, and suggested directions for future research and practice.

First, the findings of the study show that China, US, and Africa are the major contributors of studies related to GF-in-GBs. It is surprising that although the US dominates the green finance debate [12,78], its GF-in-GBs research has been limited. It is thus recommended that US will take the lead in funding research focused on promoting GF-in-GBs to motivate research from other countries. Governments and international organizations are therefore encouraged to collaborate with the academic community to increase future research. Besides, as an emerging research area that promises to be benefited from the contributions made by all countries, there is significant room for improving the number of publications from most countries to significantly advance the global knowledge and practice. Albeit, academic researchers and journal editors may align their future research focuses with GF-in-GBs to promote climate change mitigation.

Furthermore, the reviewed studies adopted multi-method designs comprising reports, literature reviews, case examples, questionnaire surveys, interviews, and archival/statistical data, and mixed methods. The analyses adopted in the various studies included qualitative analysis (content or

report analysis), statistical analysis (descriptive statistics), econometric analysis, computational analysis (including AI algorithms), and hybrid analysis. Most studies based on content analysis of reports, while empirical studies remain rather limited. Furthermore, only few studies were published in academic journals and conferences. There exists considerable scope to increase empirical studies to advance the state of current knowledge in GF-in-GBs. Future studies could explore the application of AI technologies or algorithms such as internet of things, big data analytics, data and text mining, machine learning and deep learning algorithms to improve the performance of GF-in-GBs and to predict the market value in real time. However, with the available studies, there is no sufficient data to conduct a systematic review, bibliometric analysis, or meta-analysis.

Discussed next are the recommended areas for future research in GF-in-GBs.

1. Green incentives for GF-in-GBs

Green incentives through tax subsidies are critical to the GF-in-GBs market. To ensure the rapid development of green buildings, a green building certification system that provides basic guarantees for financial support and tax subsidies is recommended [47]. Tax subsidies to green finance products, such as green development funds, green credits, green insurance, can support green buildings development. National governments could therefore introduce green incentives such as tax subsidies to incentivise GF-in-GBs. Studies focused on the cost-benefit analysis and implications of tax subsidies on GF-in-GBs could be useful in policymaking. Other green incentives such as income tax credits or holidays, non-tax incentives, direct government grants and guarantees, rebates, discounted development application fees could be applicable to GF-in-GBs. For instance, income tax credits or holidays have been successful in promoting solar projects and electric vehicles [79,80]. On the other hand, non-financial incentives such as floor-to-area density, green building finance technical assistance, expedited permitting, regulatory relief, green management teams in building and planning department [81] could be improved and implemented

for adoption by green buildings financiers. These government incentives, both financial and non-financial, must be geared towards upscaling GF-in-GBs.

2. GF-in-GBs rating software

There is the need to integrate green finance into existing green buildings rating systems to quantify the impact and benchmark the sustainable performance of green buildings. The GBC Australia [76] demonstrated how green building rating systems data can drive green investments. Tan [5] agrees that having green certification is fundamental to attracting capital and interest in green buildings investments. This is critical to securitizing green assets to attract more capital for GF-in-GBs. Existing green buildings software such as the IFC's EDGE (Excellence in Design for Greater Efficiencies) software allows users to apply different systems, solutions, designs, and techniques to discover the most cost-effective way to design and build green [4]. Similarly, EcoTool [4], AutoDesk Green Building Studio and Greengrade LEED Management software [82] etc., provide comparable solutions for green buildings improvement with the highest cost-benefit ratio. However, integrating green finance into existing green buildings rating software is yet to be achieved. Recent studies show that green buildings ratings systems like the Hong Kong Beam Plus possess such limitations [65]. Nonetheless, such integration would provide a platform for the assessment of potential building energy efficiency retrofits based on big data analytics and smart algorithms to prioritize capital utilization that will increase the performance and value of green buildings. With such information on energy efficiency gains easily available, a cheaper source of debt financing can be provided by pro-environmental investors. This platform can also help green buildings investors to identify available investments they prefer. Based on a similar web-based application using big data, ING Real Estate Finance provided discounts on sustainable loans for Dutch green buildings investors [83]. For easy access of information to facilitate GF-in-GBs, we recommend the integration of such green finance platforms into green building rating systems. This would serve as a benchmark for measuring sustainability performance of GF-in-GBs and to

facilitate access to discounted green finance. Future studies could therefore investigate and develop such an integrative software/platform.

3. AI-enabled GF-in-GBs performance assessment software

Artificial intelligence (AI) has been widely used in the architectural, engineering, and construction industry to address its complex and difficult problems such as construction automation [84]. Leveraging such technologies to GF-in-GBs will be valuable to both investors and developers. For instance, big data analytics [84] could be useful in analysing green buildings database. The knowledge gained could be useful to improve the performance of green buildings and thereby green finance. As pointed out by Agyekum et al. [58], lack of credible information dataset on green buildings impedes green finance. To solve this problem, Tan [5] proposed green buildings big data analytics for an improved valuation model for GF-in-GBs. AI technologies that integrate key financial variables such as rental growth, terminal value, discount rate, and collects green buildings performance data (e.g., energy consumption) would be a significant valuation tool to reflect the real-time market value of green buildings through actual revenue and expenditure forecast [5]. An AI software that could provide real-time data on the performance of green buildings and its resultant value in green finance would be very useful to investors. Future studies could explore how to integrate AI technologies to analyse real-time green buildings data. 4D printing technologies could then be used to optimise the performance of green buildings [85] to enhance the monetary value and returns to green finance investors. Moreover, natural language processing (NLP) can be used to analyse unstructured green buildings data to extract relevant metrics for GF-in-GBs decisions. Besides, digitizing green certification and verification processes could be achieved via blockchain and embedding IoT (internet of things) chips in green buildings. Finally, to overcome the barriers of access to data and information asymmetries, big data and machine learning could be adopted to reduce the costs and time of gathering and analysing large amounts of complex green buildings data. AI technologies can be employed to reduce search costs for environmental performance data which can promote the access to discounted green loans [83].

Since the literature has not taken advantage of the benefits that come with adopting AI technologies in GF-in-GBs, further research in this area could provide more insights to stakeholders.

4. Intelligent GF-in-GBs cost-benefit analysis framework

Cost-benefit analysis refer to the process of comparing the financial costs and benefits of particular actions [86]. This assesses the costs and benefits of alternative options to aid decision making. According to Dodgson et al. [86], cost-benefit analysis monetizes the value of expected outcomes of an option based on the theory of willingness-to-pay. To evaluate the economic value of green buildings to foster development, several studies have adopted the cost-benefit analysis approach [87,88]. However, much attention has not been paid to cost-benefit analysis of GF-in-GBs. Besides, with the capital-intensive nature of green buildings, and the initial years of the project life-cycle likely to experience negative cash flows, bond financing should be investigated from the perspective of financing cost [67]. To close this gap, we propose an improved intelligent cost-benefit analysis framework for GF-in-GBs. This would be a useful tool for potential green buildings investors to forecast their potential investment gains. For robustness, the intelligent model could adapt a multi-criteria decision-making analysis tools [86] in its development. In conformity, the UNEP [52] proposed the development of costs/benefits and value capture models for financing sustainable building projects. According to Oguntuase and Windapo [72], a more comprehensive and robust evidence about the cost-benefit analysis of GF-in-GBs will provide a holistic knowledge about the economic returns to attract socially responsible investments. The intelligent framework is proposed to include AI technologies to interact between GF-in-GBs actors (such as issuers, investors, government agencies, rating agencies, and project developers) remotely. The proposed framework could incorporate: (1) embedding IoT chips and blockchains in green buildings to collect data for verification and certification processes; or a web-enabled big data-based application to collect green buildings data from developers or borrowers, (2) integrating green buildings data into existing green building rating software and using NLP to

655 analyse the unstructured data to retrieve relevant metrics for certification and ratings; government
656 agencies may use the available data to develop promotive GF-in-GBs incentives, (3) employing
657 big data analytics and machine learning to analyse green buildings database when structuring
658 green bonds to inform investors of environmental performance of green buildings; and analysing
659 data using big data analytics to forecast revenue and expenditure of GF-in-GBs. Future research
660 could investigate the possibility of developing this cost-benefit analysis framework.

661 *5.3. Strengths and limitations of this review*

662 The strengths of this study include the use of rigorous and transparent methods throughout the
663 entire process. Additionally, it was guided by published protocols regarding scoping reviews. To
664 ensure a representative and wider coverage of the literature, the search was pre-tested in various
665 databases so that the most relevant databases and the grey literature were chosen for the review.
666 Relevant studies were independently screened by two reviewers (the authors) who met repeatedly
667 to resolve conflicts. The identified and eligible studies were retrieved and extracted for full test
668 analysis by another author. Two authors finally scrutinized the data extracted to enhance the data
669 quality. The Zotero reference manager was used to ensure that citations and documents were
670 properly accounted for during the process.

671 Still, this study has some limitations. These limitations should be considered when interpreting
672 the findings of this study. First, we acknowledge that a Google search for grey literature is limited,
673 hence, we cannot confirm that all relevant grey literature has been included. We also admit the
674 limitations of a Google search, as this is not easily reproducible by others [38]; however, we
675 provide as much details possible. Secondly, like most scoping reviews [34], the quality of the
676 included studies were not assessed. That being the case, gaps in literature related to the quality of
677 the study cannot be identified based on this scoping review. Furthermore, no scoping review expert
678 was contacted. The reviewed studies were based on the agreed discussion of the three authors
679 based on the pre-defined criteria for this study. This means that some excluded studies might be
680 considered relevant to the topic at hand, and future reviews should consider including other experts

in the selection of studies for scoping reviews or possible systematic reviews. Last, the literature search was based on certain keywords, which might not reflect the full picture of the research area. Future studies may include more keywords.

6. Conclusions

For the first time, this study reviewed the existing research on GF-in-GBs to identify research trends along with knowledge gaps that can be addressed in future research. Theoretically, this scoping review has charted academic databases and the grey literature on GF-in-GBs. The findings of the study show that this research field is both under-researched and under-invested. A good section of the relevant literature have been produced within the grey literature through international organisations such as the UNEP and IFC. Also, due to available limited studies, systematic reviews might not be the best way forward at the moment. Future studies should thus focus more on empirical studies to increase GF-in-GBs research. The application of AI in GF-in-GBs will be a useful addition to stakeholders.

Practically, this study serves as a state-of-the-art reference point for GF-in-GBs. This study identified some investment opportunities and gaps in this research area. The findings thus serve as a guideline for policymakers and practitioners to assess their level of preparedness towards the adoption of GF-in-GBs.

We hope the findings of our review can contribute to filling research gaps and gaining an in-depth understanding of how to best approach GF-in-GBs.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Appendix A. Content analysis of reviewed studies.

SN	Author(s)	Country/ region	Title	Study scope/keywords	Study highlights	Results/outcomes	Recommendations/solutions
1	Wang et al. [47]	China	The influencing factors of China's green building development: An analysis using RBF-WINGS method	Green buildings; Green finance; influencing factors	To identify the influencing factors of green building development; to calculate the weights of each influencing factor by integrating RBF neural network with WINGS methods; to investigate the effects of each factor on green building development by finding core variable, and provides references to the decision-making of government departments	Science and technology are the main fundamental influencer of green building development; Industrial size and green financial support are the main influencing factors	Development of a green building certification system that provides basic guarantees for financial support; tax subsidies to support GF-in-GBs products, such as green development funds, green credits, green insurance
2	MacAskill et al. [61]	Australia	Examining green affordable housing policy outcomes in Australia: A systems approach	Affordable-housing policy; green building; green bonds; systematic dynamics; sustainable development	To explore how a recent shift towards bond-based funding mechanisms offer an opportunity to integrate green building practices, and influence regional social, environmental and economic outcomes	A novel system dynamics model is developed to forecast a business as usual and green-building scenario framed around the recently introduced Australian affordable housing bond	A sensitivity analysis to reveal policy refinement recommendations that would yield the benefits of green affordable housing without sacrificing the small reduction in housing stock delivered by the proposed program; policy enhancement opportunities such as developer grant
3	Oguntuase and Windapo [72]	Nigeria	Green bonds and green buildings: new options for achieving sustainable development in Nigeria	Clean energy; green bonds; green buildings, investment vehicles	To examine the concept of green buildings and green bonds as an investment vehicle for achieving the SDGs including affordable and sustainable energy for human settlements in Nigeria	Green bonds as a viable investment vehicle to provide sustainable and affordable housing; green residential building concept should be the first step towards achieving green building bonds since houses are a primary human need	Making green building bonds a priority in the public policy around urbanisation and achievement of the SDGs in Nigeria; government should provide incentives such as subsidies, tax reduction, rebate systems and other concessions to attract green bonds for housing
4	UNEP [1]	Kenya	2020 global status report for buildings and construction	Buildings and construction; zero-emission buildings; green building	Towards a zero-emissions, efficient and resilient buildings and construction sector	Investment in energy efficiency in buildings is growing but lags behinds overall building construction investment; the key ingredient to unlocking investment flows is green building certification, which helps serve as a verification instrument for facilitating the issuance of green bonds and other forms of sustainable finance	Standardized metrics and reporting requirements are essential for financiers to catalyse investment at the scale required to green the construction market
5	Agyekum et al. [58]	Ghana	Obstacles to green building project	Construction professionals; green building projects;	To examine the perception of professionals in the Ghanaian	Five key obstacles identified: split incentives, risk related barriers,	Future studies should be conducted to seek the views of governments,

			financing: an empirical study in Ghana.	project financing; obstacles; construction industry	construction industry regarding the obstacles to green building project financing	capital expenditure, lack of incentives, and initial capital cost	financial institutions, and green building consumers; strategies to alleviate the obstacles
6	Kapoor et al. [67]	Japan	The viability of green bonds as a financing mechanism for green buildings in ASEAN	Green buildings; green bonds; energy efficiency; ASEAN; green sukuk; ICMA green bond principles; ASEAN green bond standards; sustainable finance	To examine green bonds as a mechanism through which investment in green buildings in ASEAN can be increased	Green bonds market in ASEAN is currently small, there is large potential for growth; green bonds can complement traditional modes of financing for green buildings such as bank loans; green bonds are a suitable mechanism for financing green buildings	Enabling the demand for green bonds through information provision; promoting local currency bond financing through domestic institutional investors
7	Lee et al. [65]	Hong Kong	Green finance performance and role of sustainability engineers in the Greater Bay Area	Challenge and opportunity in green financing	To discuss the role of sustainability engineer in green finance project throughout the four components of green finance project by providing technical support to quantify and assess the environmental impacts and benefits	Technical and financial assessment together encourage the development of green finance market in Hong Kong	Sustainability engineers could play a critical role in assessing the comparability and transparency of green impacts for green finance initiatives
8	Zhang et al. [53]	China	Unlocking green financing for building energy retrofit: A survey in the western China	Building energy retrofitting; green finance; ESCOs; barriers	To identify and analyse the key barriers in terms of access to green finance encountered by ESCOs and financial institutions	The main barriers at policy level are short or uncertain lifetime of public funding schemes, relatively lower energy price and split incentives	Integrated capacity building is crucial and urgently needed for unlocking green financing for ESCOs; building up dialogue and cooperation alliance among stakeholders is utmost important for unlocking the green financing market; funding mechanisms and models that emerge from the local level should be disseminated in China
9	Tan [5]	China	Green Finance and Real estate in China	Green finance and green real estate; quantify green efforts for a measurable return; green building certification and property management	Factors affecting investment decisions in green assets; drivers of investment in green assets; expected returns on green investment in green assets	Having green certification is fundamental to attracting capital and interests in green building investments; financial returns is the key driving force for green investment	Strengthening the impact of green building certification and property management; adopting an intelligent building management platform; integrating big data and building analytics for an improved valuation model; strengthening the standards for green building certification
10	GBC Australia [76]	Australia	Maximising your investment: Using rating tools to attract	Green building rating systems; using data to drive investment; benefits of ratings and benchmarking	To provide information about sustainable finance in the built environment in Australia	The right data and information are critical when issuing or investing in a green bond to reduce the risk of "greenwashing" or poor	Largely untapped opportunities for companies that have energy inefficient and high carbon portfolios to transition to a low

			sustainable finance for real estate	in green bond issuances; guidance for using rating systems in issuances		performing buildings being included in issuances by mistake	carbon future; green bonds are an important instrument to incentivise and finance the transition to low carbon and future sustainability
11	Nenonem et al. [71]	Finland	Towards low carbon economy - green bond and asset development	Green bonds; property development	To describe how property developer can use green bond as one instrument in sustainable life cycle management and continuous development properties	Focus on environmental sustainability, energy efficiency, economic sustainability (with green bonds) and social sustainability.	To identify the potential of social bonds and provide new perspective to responsible property owner and regenerative actions
12	Likhacheva Sokolowski et al. [4]	US	Green buildings: A finance and policy blueprint for emerging markets	Green buildings market; financing green buildings	Understanding the market and business case for green buildings	Investment opportunities by property and region; green buildings come with US$24.7 trillion investment opportunity over the next decade across emerging market cities	Need for green building definitions and metrics to catalyse investments at large scale; building awareness and capacity among key market players in terms of policy and finance
13	Ojo-Fafore et al. [51]	South Africa	Green finance for sustainable global growth: Costs and benefits of green buildings compared with conventional buildings	Benefits of green buildings; barriers to green building; drivers of green buildings; cost difference between conventional and green buildings	To compare green building and conventional building using the cost differences and economy impact to ascertain the benefits of green buildings over conventional buildings	Green buildings are more expensive than conventional buildings; however, the benefits accrue from green building makes green buildings cheaper in the long run	Encourage investors on financing green buildings and governments to encourage green buildings movements
14	Pradmod Chakravarthi and Aravindan [69]	India	A study on financing for sustainable construction projects	Financing; incentives; policies; project and sustainability	To propose a possible model for financing of sustainable construction projects	Financial vehicles that can be widely used for sustainable construction projects include: banks loans, green bonds, private capital, international assistance program, government funds and tax refunds (floor area ratio & height bonuses, tax abatements; fee waivers, award and marketing assistance)	Government should support sustainable construction project to reduce the problem of lack of financing
15	United Overseas Bank Limited [74]	Singapore	Green building trends and financing solutions	Real estate sector; sustainable financing; green building	Sustainable financing in the real estate sector	Green building will continue to evolve and grow, underpinned by a supportive regulatory framework and government incentives	Established financial institutions to provide industry support via green building financing and sustainability linked loans
16	Carbon Pricing Leadership Coalition & IFC [75]	US	Greening construction: The role of carbon pricing	Construction industry; carbon pricing	Applying carbon pricing mechanisms to the construction value chain	Financing structures influence carbon reduction	Policy drivers must be rolled out alongside carbon pricing mechanisms to promote sustainability in the construction industry, such as green building

							regulations and green procurement directives
17	UNEP [52]	East Africa	Sustainable building finance: A practical guide to project financing in East Africa	Green property finance	Property and finance market; value of green buildings - barriers, benefits and finance instruments; green property finance models	Best practices and knowledge resources for green financing in green building product and market development as a practical guide to project financing in East Africa	Developing green concessional construction finance; localised energy asset development and finance; focused effort is needed in creating locally relevant data sets, and costs/benefits and value capture models
18	Brodie and Hong [78]	China	Green financing: Greenlighting green investment into green real estate	Green financing; green real estate	Green financing in the global market and mainland China; Green real estate globally and mainland China	Governments (including China) are now looking to increasingly promote green financing in their domestic marketplaces; more funds are expected to be injected into green projects globally and in China with the expansion and maturation of green financial products and market supervision mechanism	More green real estate projects are expected to take advantage of green financing instruments in future; REIT development to encourage investment in green buildings (especially China)
19	European Bank for Reconstruction and Development [68]	Europe	Green building investments	Green building; green investments	Green building in transition economies: challenges and opportunities	Green building renovations vital to meeting Paris Agreement targets	Policy tools for green building investments; financing green building investments through local financial institutions; making retail more sustainable; raising standards through sustainable property funds; promoting green economy and capital market growth through green-labelled property bonds; targeting green building aggregates with structured finance products
20	Kennedy et al. [49]	China	Infrastructure for China's ecologically balanced civilization	Sustainable engineering; green growth; industrial ecology; low-carbon development; green finance	To describe the context of China's green investment needs and to broadly lay out the infrastructure requirements to achieve China's ecologically balanced civilization, including socio-economic considerations	China has implemented many successful policies in the building sector in recent years, but there is still considerable scope for improvement in the energy efficiency of Chinese buildings	Chinese engineers and building scientists need to further the development of net-zero green buildings; China need to develop its capacity in order to ensure that the private sector can play a role in delivering its green transformation

21	Gutierrez [73]	Philippines	Green banking: A proposed model for green housing loan	Green banking; green loans; climate change; energy efficiency	To propose a green housing loan model for banks	More green housing loans from banks will widen the scope of their client-base; green housing loans will give savings to borrowers on cost of borrowings and energy efficiency.	Government should intensify its own initiatives to encourage banks to offer more green products and services through offering some incentives such as regulatory points to banks that will intensify green banking; a massive awareness promotional campaign must be adapted by the banks to highlight the benefits of going green
22	Mo [50]	China	Financing energy efficiency buildings in Chinese cities	Financing demand for building energy efficiency projects	Financing demand for scaling building energy efficiency; existing financing modules for urban building efficiency projects; comprehensive financing solutions for urban building efficiency projects	Funding availability is key; market development should be valued; lack of criteria for measurement, reporting and verification of energy savings; technical capacity is crucial	Encourage concessional loans to high-star green buildings; establish insurance guarantee standard for green buildings; mandate insurance policy for building retrofits; establish green building development fund; issue municipal bonds for urban-scale building retrofits; encourage international cooperation and international green loans and funds.
23	Li and Tsoi [46]	Latin America	Latin America sustainable building finance knowledge sharing.	Sustainable building; sustainable finance	To review the current knowledge shared in the world wide web and academic journal database	Sustainable building finance academic publications from Latin American countries is limited in Latin American; other publications come from both local governments and international funding source such as the UN	More research should be conducted on sustainable building finance knowledge sharing.
24	Martin [42]	US	Home Purchase Counselling: The untapped green financing tool.	Green residential financing products	To introduce home purchase counselling as a supplement to or substitute for current green residential finance products by proposing an experimental demonstration	Counselling leads to consumer financial decision-making that accounts for energy efficiency; counselling applies empirically sound strategies for incentivising consumers through behavioural change; and counselling has demonstrated record of satisfying residential finance institutions while accomplishing positive outcomes for the consumer	The need to develop market-based financial strategies for residential energy-efficiency in this post-recession era still exists; exploring why housing market reform conflicts the expansion of energy-efficient housing finance products
25	Christensen [54]	US	Institutional investor motivation, processes, and expectations for sustainable building investment.	Sustainability; corporate strategies; office tenants; LEED; Energy Star	To examine the strategic motivations, processes, and expectations for institutional real estate owners around sustainable	Key decision drivers (market competition, strategic asset management activities to improve the efficiency of operations and overall sustainability	To take proactive steps to gather benchmark and manage assets with sustainability in mind to help property investors and managers to be able to distinguish their

					improvements and eco-labelling in office buildings	performance, and available incentives [cost-benefit-analysis or return on investment]), value creation opportunities, and local regulatory minimum requirements	buildings within their markets and reap the benefits
26	An and Pivo [48]	US	Green buildings in commercial mortgage-backed securities (CMBS): The effects of LEED and energy star certification on default risk and loan terms	Green buildings, green loans	To study the impact of green building loans in the CMBS market	A standard Cox proportional hazard model shows green building carry 34% less default risk. A matched-sample analysis gives similar results of 29% and 27% lower hazard rates for Energy Star and Energy Star of LEED respectively	Future studies should investigate the exact mechanism through which green status affects mortgage default
27	Suerkemper et al. [70]	China	Scaling up finance for building energy renovations in China: European and global experience	Green finance, building energy efficiency	To address barriers faced by ESCOs and financial institutions	Key barriers of financial institutions to finance building energy efficiency	Green credits, green securities, and other supportive mechanisms for financial institutions, which could be beneficial to seize the opportunity to scale up sustainable building development and refurbishment in the future.
28	Lee et al. [30]	Republic of Korea	A financing model to solve financial barriers for implementing green building projects	Green financing, green building projects	To suggest a financing model for facilitating green building projects with governmental guarantee based on Certified Emission Reduction (CER) which is an emerging trend in environmental finance	By testing the suggested financing model using the combination of degree of energy saving and CER price scenarios, the payback period for the worst scenario was about 7.55 years	The suggested model assumed governmental guarantees for the increased cost, but private guarantees seem to be feasible as well. To do this, certification of Clean Development Mechanisms for green buildings must be obtained

710

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