A Systematic Literature Review of Non-Compliance with Low-Carbon Building Regulations

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Review

A Systematic Literature Review of Non-Compliance with Low-Carbon Building Regulations

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Abstract: Low-carbon building regulations are acknowledged as critical instruments to facilitate the building industry's decarbonization transition. However, recent studies have shown that non-compliance with low-carbon requirements is under-researched, leading to a significant divergence between policy intentions and actual performance. In light of this, the paper aims to provide a synthesis of existing research on non-compliance with low-carbon building regulations. It does this using a systematic literature review combined with bibliometric and text mining techniques. Through reviewing 26 scholarly works from the last decade, the paper demonstrates a peak production year around 2015, the year of the Paris Agreement, with the USA and Australia as key countries of concern. Subsequently, the study reveals three focused research areas: the development of building policy during the low-carbon transition; the role of building energy performance requirements in achieving low-carbon buildings; and building energy code compliance. Findings suggest widespread non-compliance with building energy codes and also indicate influencing factors and associated enhancement strategies. Finally, the paper identifies gaps in the investigation of new forms of building energy codes; an inconsistent conception of compliance; and a lack of understanding in building practitioners' compliance behavior. The study contributes to knowledge by providing future research areas in this under-researched topic and by successfully applying both bibliometric and text mining analysis in the construction management domain. This is found to have advantages in terms of time efficiency and objectivity. It also offers practical implications for industry by minimizing the gap between policy intentions and real compliance performance.

Keywords: building regulation; energy efficiency; low carbon; non-compliance; systematic literature review

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1. Introduction

The framework of the United Nations Climate Change Conference of the Parties (COP) [1] signifies international recognition of climate change and intensifies the urgency to limit global warming. In recent reports [2,3], the Intergovernmental Panel on Climate Change (IPCC) has highlighted the building industry's key role in achieving this goal. Governments around the world have issued a wide range of policies to drive the low-carbon transition in the building sector. For instance, the European Parliament and Council have established a legislative framework consisting of the Energy Performance of Buildings Directive (EPBD) 2010 (Directive 2010/31/EU) and the Energy Efficiency Directive 2012 (Directive 2012/27/EU). Furthermore, the European Union has amended the EPBD 2010 and introduced the current EPBD 2018 (Directive 2018/844/EU), which mandates that all new buildings must be nearly zero energy from 31 December 2018. In Canada, Natural Resources Canada has similarly established R-2000 standards [4], which promote energy-efficient building practices and technology solutions. It was additionally supported when the City of Vancouver rolled out a Zero Emissions Building Plan in 2016 to require all new buildings to achieve zero emissions by 2030 [5]. In the Pacific, New Zealand has also established a "Building for Climate Change Programme" in 2020 [6], which sets operational and embodied carbon reduction targets for buildings. These initiatives underline the significance of regulatory instruments within the building industry in spurring carbon emission reduction globally.

Notwithstanding the considerable efforts made via these regulatory measures, the difficulty in compliance with low-carbon building regulations has been a long-standing issue worldwide [7–11]. As per a recent study [12], compliance with low-carbon building regulations is not only under-achieved but also under-explored in existing literature, which has resulted in a divergence between low-carbon building regulations' intentions and actual performance [13].

Given this scarce academic attention, the examination and evaluation of existing compliance studies within the context of low-carbon building regulations is necessary to find prevailing research interests and prospective research areas. This will narrow the difference between policy intentions and real performance. Therefore, this study aims to analyze research on non-compliance with low-carbon building regulations by content-analyzing key research areas developed from a set of bibliometric and text mining analyses. By doing so, the authors intend to contribute to the ongoing debates about non-compliance and low-carbon building regulations and lend support to the mixed application of analytical methods to derive focused research areas. The study also seeks to provide building policymakers and wider industry communities with a list of contributing factors to the non-compliant status quo and potential strategies to improve the situation, which might help narrow the divergence due to non-compliance.

The paper firstly presents and analyzes a set of bibliographic information regarding publication distribution (yearly production, focused geographic regions, journal outlets, and co-authorship network). Secondly, focused research areas within the extant literature are derived through a combination of keyword co-occurrence and text mining analysis. Thirdly, the status quo of non-compliance, influencing factors for non-compliance, and proposed strategies to enhance compliance are synthesized. Finally, research gaps and future research directions are elicited.

2. Materials and Methods

The study used a systematic literature review (SLR) following the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) framework [14]. Review studies often demonstrate a dearth of shared guidelines, which may lead to less replicability in such literature [15]. According to Rethlefsen et al. [16], PRISMA is the most widely used guidance for systematic literature reviews to date. It has a methodological and analytical procedure that is clear and easy to understand. It also provides a transparent literature selection process and thus assures the reporting quality of the literature review [17]. As per Pawson et al. [18] and Denyer and Tranfield [19], a structured five-stage research design following the PRISMA protocol has been developed, as displayed in Figure 1.

For stage 1, a background study has been performed. Though policies promoting low-carbon buildings have been introduced in many countries and regions, knowledge of policies on low-carbon buildings is still limited [13]. Moreover, it has been noted that non-compliance has been an ubiquitous issue in the US [12], Australia [21–23], the UK [24], and many developing countries [25], which has greatly hindered the progression of low-carbon transition. It has also been argued that non-compliance with low-carbon building requirements is under-explored in the US [12]. Further, in a report that particularly investigated the Australian building regulation framework, Harrington and Toller [22] stressed that key elements of an optimal low-carbon policy setting for the built environment should constitute, among others, encouraging compliance and over-compliance with the regulation. Due to this increased interest and popularity for non-compliance with low-carbon building regulations, a comprehensive review of existing studies can provide benefits in terms of identifying areas where research work has been focused and where additional research avenues are required. Accordingly, the following research questions were framed to guide the current investigation:

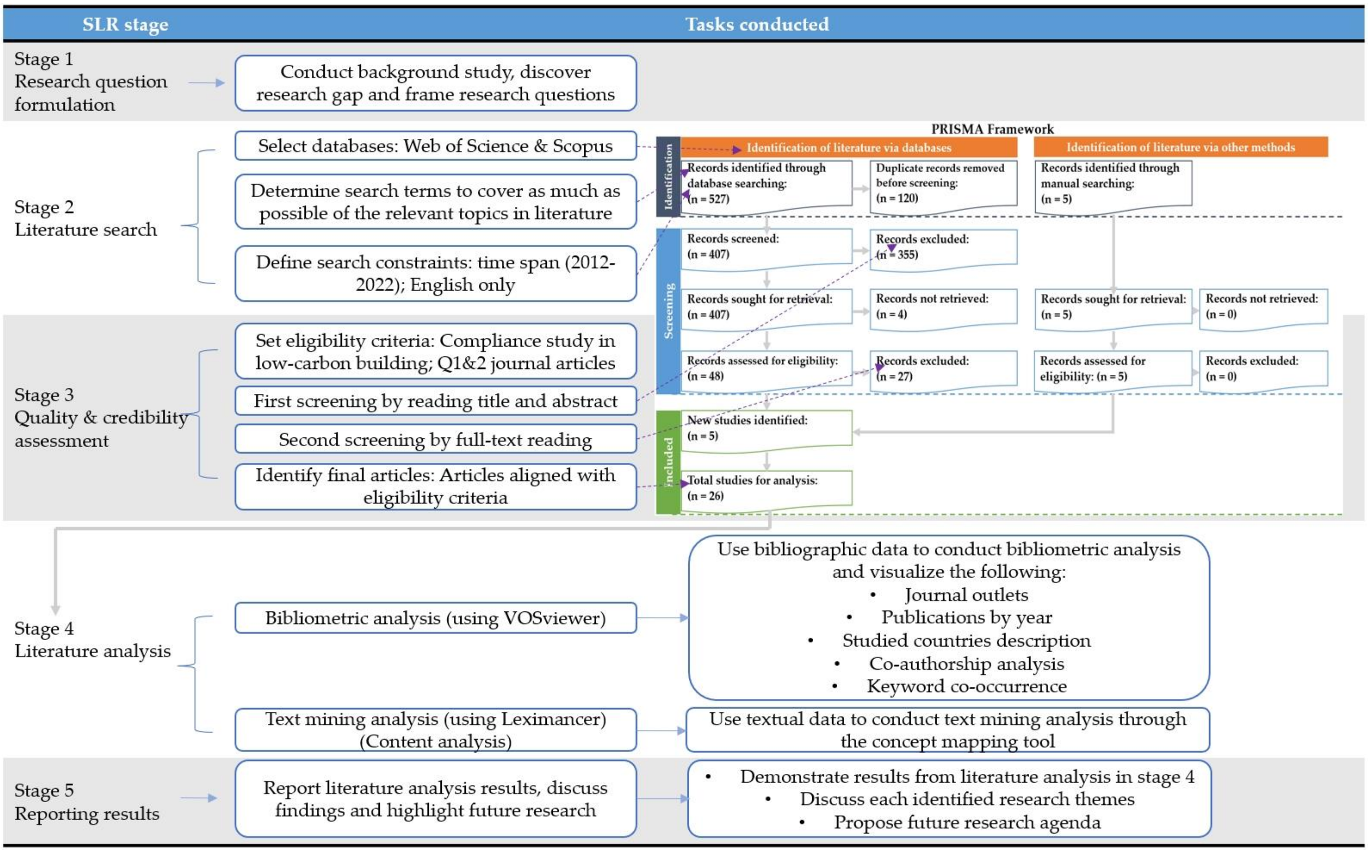

Figure 1. Five-stage SLR methodology following PRISMA framework, adapted from [18–20].

RQ1: What are the key areas of research concerning non-compliance with low-carbon building regulations?

RQ2: What are the limitations and gaps within the extant literature that direct future research in compliance studies?

For stage 2, a search of the relevant articles was performed in September 2022. Firstly, Web of Science and Scopus were chosen as search engines. These databases were chosen as they assemble a collection of the most relevant sources of academic research in the domain of social science [26], and they also represent the most extensive databases that have been used in most literature search and bibliometric analysis tasks [27]. Secondly, key search terms were considered. As suggested by Bilro and Loureiro [28], the authors determined different search terms from the existing literature to cover, as much as possible, all the relevant topics in this field of research. Following the definition of zero carbon and zero energy homes by Berry, et al. [29], keywords relating to low-carbon were determined as: low-carbon, zero carbon, energy efficiency, net zero, and zero energy. Furthermore, according to Siddiki et al. [30] and Chanin and Welsh [31], compliance is defined as a behavioral state in a particular time, situation, and place that is in conformance (completely or partially) with behavioral directives, such as those embedded in legislation. Hence, keywords concerning compliance were selected as: non-compliance, under-compliance, and compliance. Additionally, search terms related to building regulation were also chosen. A summary of search terms is illustrated below:

("non-compliance" OR "under-compliance" OR "compliance") AND ("low-carbon" OR "zero carbon" OR "energy efficiency" OR "net zero" OR "zero energy") AND ("building" OR "construction") AND ("regulation" OR "requirement" OR "provision" OR "policy" OR "code" OR "standard" OR "by law")

Next, two further constraints were implemented as part of the search. One restriction concerned the publication years of the articles. As it is apparently more valuable when investigating compliance with the latest standards, the paper narrowed down the year span to the past decade (2012–2022). The other constraint limited papers to works published in English.

Stage 3 examined the eligibility of the articles. Only studies relating to compliance in the domain of low-carbon building have been considered. The other inclusion criterion is related to article type, only literature from good-quality journals (Q1 and Q2-rated journals) has been considered to ensure the reliability of the selected articles.

A total of 527 results (136 from Web of Science and 391 from Scopus) were identified through the initial search. These results were then exported and converted to an MS Excel file for further processing, including extracting publication information, removing duplicates, and filtering publications based on the title, abstract, and keywords. In this step, 120 duplicated articles were removed. Then, a title and abstract screening process removed publications whose content was not relevant to the scope and objectives of the research and those without an abstract. Considering the scope of the current study, only publications relating to (non)compliance studies in the field of low-carbon building regulations were included. After the screening process, 355 records were excluded. Following this step, four pieces of literature were unable to be retrieved and were excluded. Next, the process of quality and credibility assessment was carried out by reading the full texts of the remaining 48 articles. 27 records were excluded as they did not explore the compliance topics in the building industry or they were not published in Q1 or Q2 journals. Consequently, 21 studies were considered eligible for analysis. Additionally, 5 research works were further identified through searching websites and citations. The final set of 26 pieces of literature was organized using the bibliographic management software Endnote.

Subsequently, in stage 4, a bibliometric analysis involving both performance analysis (number of publications per year, studied geographic area description, and journal outlets) and science-mapping analysis (co-authorship and keyword co-occurrence analysis) was carried out. Bibliometric analysis has been frequently adopted in literature reviews so that an enhanced review of research work can be achieved [32,33]. As stated by Donthu et al. [34], performance analysis is standard practice in bibliometric studies, which aims to reveal the contributions of research constituents to a certain field (e.g., yearly published articles, studied regions, and journals), whilst science-mapping examines the relationships between research constituents. Co-authorship analysis was chosen as a bibliometric indicator as it reflects social interactions among authors [35,36]. Despite the debate on its meaning and interpretation [37], co-authorship analysis has been widely used to reveal and assess collaboration patterns among authors or organizations [38]. Keyword co-occurrence was performed as keywords resemble the core content of research works [39], and their co-occurrence can further elaborate on the content of each thematic cluster [40]. Moreover, keyword co-occurrence analysis also contributes to the forecasting of future research agendas [34]. This study employed the software VOSviewer to visualize bibliographic results because of its ease of operation and effectiveness of bibliometric mapping, as well as its trending usage in recent scholarship on construction management [41–43]. Thus, it allows the authors to visually identify the areas that are highly investigated and the areas that lack exploration.

Aligning with the research method described by Chen and Lin [44] and Nguye et al. [45], the study also utilized the text mining analysis software Leximancer to supplement bibliometric analysis so that overlapping themes from the two analyses can be generated. More specifically, VOSviewer utilizes bibliometric information to generate co-words for keywords of each piece of literature, whereas Leximancer produces prevalent concepts from whole textual data [46]. Although they used different datasets, they shared certain common themes. Such a combination has been adopted in a handful of studies in the architecture, engineering, and construction sectors [45,47] and other research domains such as marketing [48], culture, and aesthetics [49]. As implied by Nguyen, London, and Zhang [45], the mixed application of both analytical tools is helpful in demonstrating research themes in the existing literature and indicating prospective research areas, thus being worth further application considering the research questions of the present study.

In terms of performing content analysis, Leximancer has shown its advantage in examining data in a more objective and efficient manner [50]. It reduces a researcher's bias, which is often embedded in manual handling of text (e.g., using QSR NVivo and manual coding) [51]. Therefore, the usage of Leximancer has grown in popularity, especially in research work where large quantities of textual data are involved [52].

In stage 5, findings corresponding to each elicited research area were synthesized, and future research areas were proposed.

3. Results

The results from stage 4 and stage 5 in Figure 1 have been shown in this part. Firstly, the results of bibliometric analysis and text mining analysis (stage 4) have been discussed in Sections 3.1 and 3.2. Secondly, in Section 3.3, the findings and future research (stage 5) have been discussed.

3.1. Bibliometric Analysis

3.1.1. Publications Distribution

Firstly, yearly publications and their focused geographic regions have been analyzed. Figure 2 depicts the yearly distribution of the selected articles during the period of 2012–2022 and the regions of research interest.

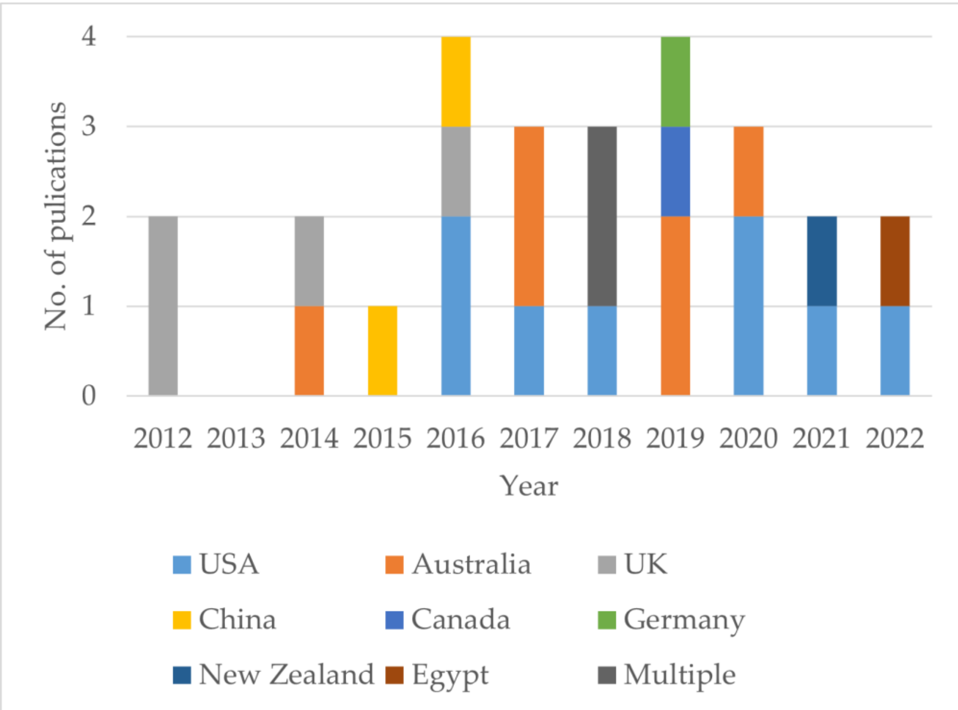

Figure 2. Paper distribution by year and focused geographic region.

It can be noticed that the overall trend exhibited an ascending tendency from 2012–2020. The maximum number of publications was found to be between 2016–2020, with an average of 3–4 publications annually. This could be partially attributed to the increased awareness of carbon emissions in the building industry since the introduction of the Paris Agreement in 2015. However, it is notable that since 2020, there have been fewer publications per annum. This phenomenon is not surprising, as the impact of COVID-19 has caused substantially less research to be published [53]. It should also be recognized that the literature search was performed in September 2022. Therefore, the number of publications in 2022 has not fully reflected the whole year's production at the time of this study.

It is also evident from Figure 2 that the United States has published the most research in this area. As per Seyrfar et al. [54], the US federal and municipal governments have implemented many national and local regulations to meet the carbon reduction goals of the wide economy. As a consequence, an increasing number of US cities have enacted low-carbon building regulations to facilitate the goal achievement in the building sector. Similarly, the study from Jacobsen [55] also suggested that, as a federal-system country, most U.S. states have enacted building energy codes and gradually increased code stringency [55]. Given this background, many scholars have conducted research in various states to evaluate building energy code compliance, e.g., [56], or proposed advanced compliance assessment methods, e.g., [55,57].

Ranked as the second-most frequently studied country, Australia has also paid great attention to non-compliance issues. Australia is one of the highest emitters per capita in the world [58]. The government's commitment to net-zero emissions by 2050 has been reaffirmed in "Australia's Long-term Emissions Reduction Plan" released ahead of the United Nations COP26 climate conference in 2021 [59]. For achieving this target, as stated in this whole-of-economy plan, Australia's building sector needs to nearly achieve decarbonization by 2050 [59]. In Australia, many regulatory measures targeted at low-carbon buildings have been developed, however, the current building policies and enforcement measures in Australia are unlikely to deliver the low-carbon industry as targeted [60,61]. A prevailing explanation is the difficulties in complying with low-carbon building requirements [7–11]. In fact, Australia has undertaken some government-led projects to promote the low-carbon building industry. For instance, since 2012, the National Energy Efficient Building Project (NEEBP) has been launched in Australia, which was co-funded by all Australian states and territories through the Council of Australian Governments (COAG) Energy Council. The NEEBP project aimed at facilitating the Australian government, building industry, and consumers to achieve better energy efficiency in new and existing buildings [62]. To date, NEEBP has published many reports outlining challenges in the compliance and enforcement of the energy efficiency requirements in the National Construction Code. Indeed, prior to the establishment of NEEBP, several initiatives had been proposed at the federal level. For example, in the April of 2009, specific measures to increase energy efficiency of buildings were set out in a COAG 2009 communiqué as proposing: (1) an increase in the stringency of energy efficiency for all classes of commercial buildings; (2) mandatory disclosure of energy efficiency for all classes of commercial buildings; (3) the phase-in of mandatory disclosure of residential building energy, greenhouse, and water performance at the time of sale or lease, commencing with energy efficiency by 2011; and (4) an increase in energy efficiency requirements for new residential buildings to six stars, or equivalent, nationally in the 2010 update of the Building Code of Australia with full implementation in all states by 2011 [63,64]. These initiatives could raise awareness in academia to more actively investigate the under-compliant phenomena.

In addition to the above analysis, the journal sources of the publications have been examined. Within the 26 articles, 18 journal sources were identified. It is noted that "Energy Policy" was the journal that published the highest number of works (5). Meanwhile, "Energy Efficiency" contributed the second largest source of articles (3). Both journals relate to policy implications in the domain of energy. It is also observed that the majority of journals (16) were in the field of energy, building sciences or general construction management, whereas only two journals ("Columbia Law Review" and "Journal of Legal Affairs and Dispute Resolution in Engineering and Construction") belonged to legal scholarship. Other journal sources included, among others, "Energies", "Energy and Buildings", "Environmental Politics".

Next, a co-authorship was analyzed, where the threshold of minimum documents was not applied due to the intention to obtain a complete analysis of all the authors. Ultimately, a total list of 65 authors were found. A fractional counting approach was chosen over the full counting method as “the most reasonable idea seems to be to treat each reference cited in a publication as being equally representative, and this is what is done by fractional counting” [65]. Overall, the whole author network is fragmented into 22 isolated clusters, implying that the authors tend to cooperate in small groups. Notably, the largest sub-network consists of Dr Robert A. Enker and Prof. Gregory M. Morrison from Australia (three articles on the topic of building codes and the low-carbon building sector), followed by the group taking Dr Stephen Berry from Australia (two articles on the topic of Australian building energy efficiency), and the group of Helen Garmston and Prof. Wei Pan from the UK and Hong Kong SAR (Special Administrative Region), respectively (two articles on the topic of compliance situation in the UK building energy code). The results suggest that the majority of the influential studies have been domestic collaborations. The remaining author clusters are generally small and fragmented, exposing international disinterest and isolation.

3.1.2. Keyword Co-Occurrence Analysis

In a similar approach, as suggested by [65], keyword co-occurrence was performed following a fractional counting method. To obtain a holistic image of research keywords, the minimum number of occurrences was set to one. Meanwhile, the current study followed the default association strength method to conduct the normalization process, as recommended by the VOSviewer Manual [66]. A thesaurus file was prepared by the authors to merge similar keywords (e.g., “building energy standard” is merged to “building energy codes”). After processing all the 111 keywords in VOSviewer, 11 clusters of 58 items have been revealed, as displayed in Figure 3.

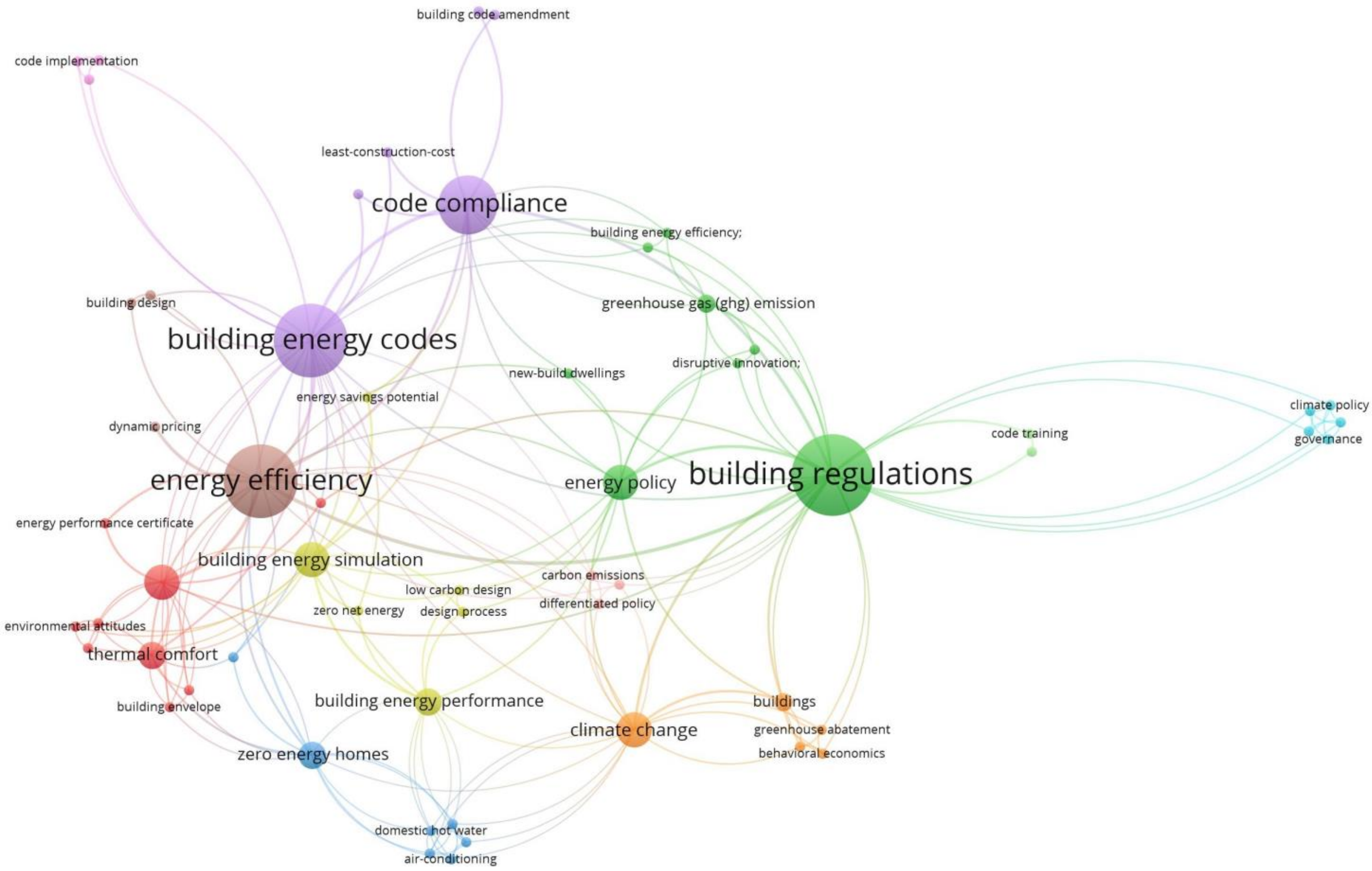

Figure 3. Keyword co-occurrence map (lines indicate relationships among keywords (i.e., co-occurrence), and nodes' sizes represent frequency of keyword-occurrence).

As shown by the dispersed colors in Figure 3, keywords were categorized into several clusters. Interestingly, from these nodes, it appears that “low-carbon” is not a frequently mentioned term. Rather, “energy efficiency” becomes a more relevant concern in the selected studies, which formed one core cluster colored in brown. The following paragraphs elaborate on the main clustering results (large-sized nodes) and associated issues of inquiry.

Cluster 1 (green)—Building regulations against greenhouse gas emissions. Research in this cluster mainly concerns the development of building regulations and energy policy against the backdrop of greenhouse gas emissions.

Cluster 2 (brown)—Energy efficiency in buildings. This big cluster encompasses the core topic of energy efficiency in buildings, covering the sub-topic (shown closely connected to the red cluster in Figure 3) relating to building thermal performance and energy performance certificates.

Cluster 3 (purple)—Compliance of building energy codes. This cluster generally covers issues in building energy code compliance, especially during code enforcement.

Overall, clusters 1, 2, and 3 are closely interrelated, as reflected by the thick lines linking among them. Such interconnectedness reveals the hot exploration of the implementation of building codes, especially building energy codes due to the importance of energy efficiency in the building sector. It further indicates an emerging investigation into the significance of the topic of building energy code compliance during its enforcement process.

Conclusively, three interlinked key clusters were discovered through the bibliometric analysis based on keywords in each selected paper. Nevertheless, as indicated in Section 2, keyword co-occurrence produced by VOSviewer merely relies on authors’ subjective choice of their keywords. Text mining, meanwhile, crawls through what researchers actually wrote and recognizes derived patterns [45]. In the next section, results from text mining analysis of the whole textual content of the reviewed works are provided.

3.2. Text mining Analysis

All selected articles were introduced to the Leximancer. Before generating a concept map, three precautions were taken to purify the results. Initially, in “Text Processing settings”, the “file tag” was applied to allow the analysis to treat each article as a case and make the comparisons more straightforward. Subsequently, in the “Concept Seeds”, the researchers removed certain auto-identified seed words and terms from the analysis as they did not directly concern the research domain (e.g., table, figure, during). Thirdly, to avoid confusing outputs, semantically similar concept seeds were combined (e.g., “houses”, “housing”, and “residential” were all combined to “dwellings” and singular and plural terms such as code/codes were merged). Resultantly, Leximancer has generated a list of 57 word-like concepts in order of their frequency of occurrence in the text, which are shown as grey labels on the map. Figure 4 presents an overview (i.e., the concept map) of the result, indicating the main themes in the research work and interrelated concepts.

Similar to the keyword co-occurrence analysis result, it has been noted from Figure 4 that “low-carbon” is not a central concept extracted by text mining analysis. Instead, “energy efficiency” takes a more dominant role in the selected articles. Next, the emerging core themes contributing to the research domain as per the heated map relevancies in Figure 4 have been disclosed as follows: “energy” (red), “code” (yellow), “policy” (light green), “design” (green), “dwellings” (blue), and “control” (purple). The warmer the color, the more relevant the related themes. An interpretation of three key themes and their connectedness is provided below.

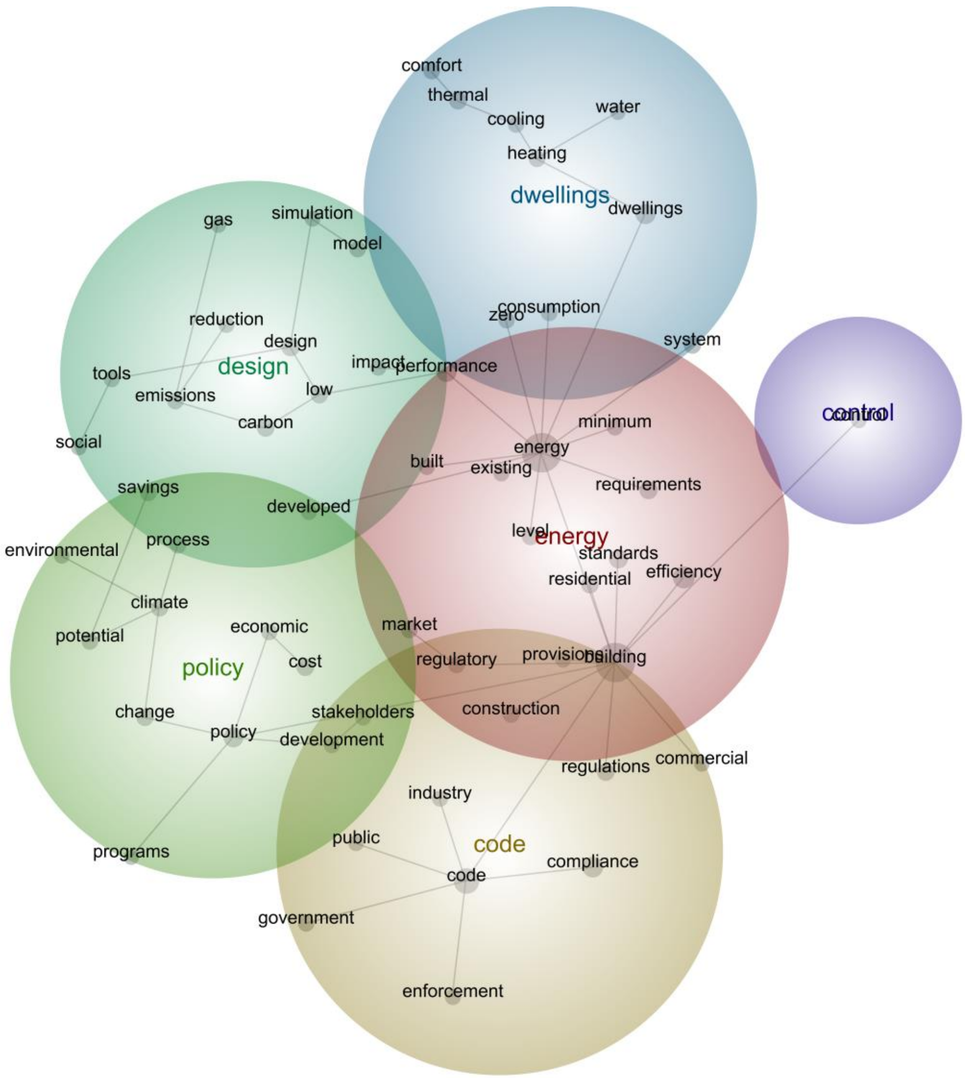

Figure 4. Themes and concept map from text mining analysis generated by Leximancer.

Theme 1 (red)—Energy. Other than the self-explanatory concept "energy", the biggest identified concepts in this theme are "building", "efficiency", "performance", "requirements", which indicates the wide-discussed topic of building energy efficiency and performance requirements.

Theme 2 (yellow)—Code. Within the theme of "code", the most significant concepts are "code", "building", and "compliance", and "enforcement". Taking into consideration the overlapping with the theme "Energy", it unveils the utmost issue of building energy code compliance during the enforcement process.

Theme 3 (light green)—Policy. The theme "policy" entails a wide range of key concepts such as "policy", "climate" and "change". Since the core concept "policy" is strongly connected with the concept "building", it suggests the hot research topic of building policy development under climate change.

Obviously, themes 1, 2, and 3 are also closely related to each other, as the three bubbles partially overlap with each other in Figure 4. Especially, links between core concepts "building" and "policy" as well as among core concepts "energy", "building" and "code" are manifested. It strongly reflects the relevant topic of building policy and more narrowly focused building energy codes. Furthermore, "code", "building", "energy", "compliance" and "enforcement" are also linked, indicating the topic of code compliance during enforcement. According to Nguyen, London, and Zhang [45], these dual analyses lend support for yielding focused research areas in the reviewed literature. Overall, in the current study, the text mining outputs generated by Leximancer are generally in agreement with those obtained by the keyword co-occurrence produced by VOSviewer in the preceding section, as shown in Figure 5.

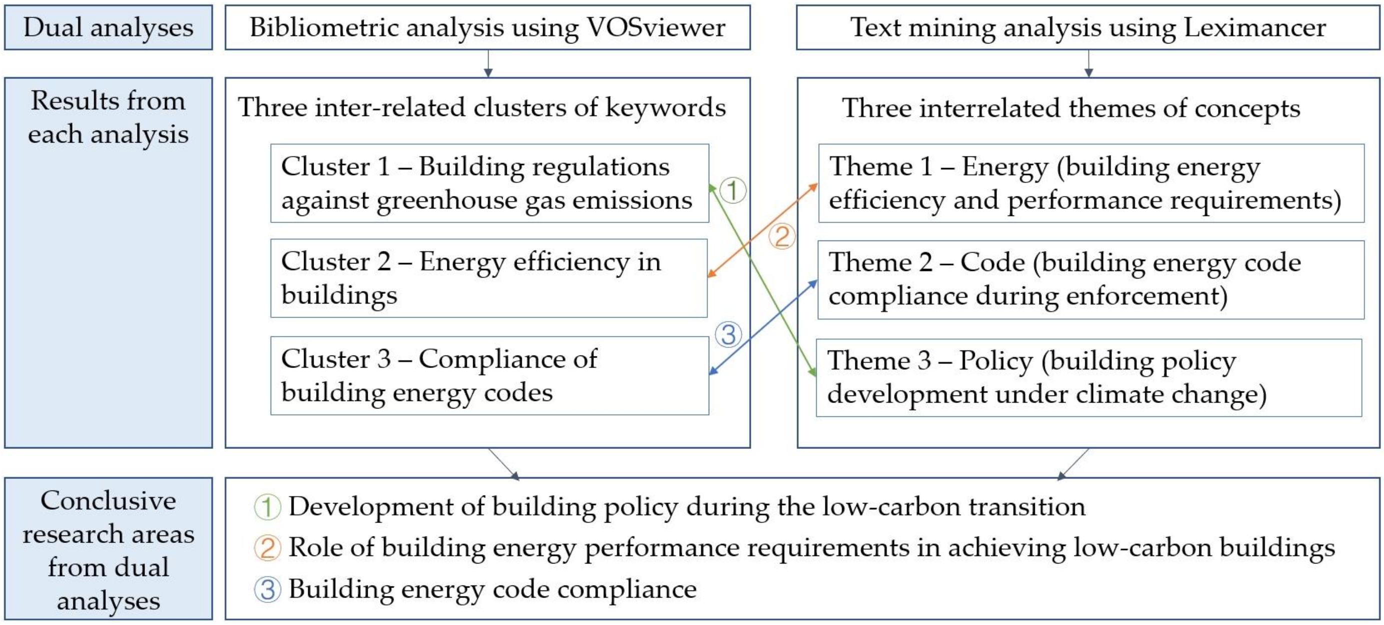

Figure 5. Derived research areas in the reviewed paper-set based on combined analyses.

Then, following the approach described by Wright et al. [67], a directed content analysis [68] was performed on the three focal areas. The following section presents the discussion of each research area in detail.

3.3. Qualitative Analysis

According to Figure 5, the first focused area is the development of building policy during the low-carbon transition. The second area is the role of building energy performance requirements in achieving low-carbon buildings. The third focal area is building energy code compliance, which includes two sub-topics: (1) the status quo of building energy code non-compliance; (2) influencing factors to non-compliance and strategies to enhance compliance. The remainder of this section discusses prominent findings.

3.3.1. Development of Building Policy during the Low-Carbon Transition

The Paris Agreement denotes international acknowledgment of climate change and exacerbates the desperate necessity to reduce carbon emissions. A significant body of research posits that the building industry provides an incomparable opportunity for greenhouse gas abatement. Against this background, a large portion of the reviewed literature has indicated building policies' role in facilitating the building industry's shift toward low carbon.

For instance, in their work, the authors Enker and Morrison [69] drew evidence from international climate-related organizations' reports [70–72] and the trajectory of Australian climate policy milestones and advocated that building regulations have been generally postulated as having a transitional role in the emergence of a low-carbon building industry. The same conclusion has been drawn in several other studies [8,73,74], in which building policies have been well recognized as playing a key role in achieving the goal of carbon emission reduction. In addition, many studies reviewed in this paper [7,8,12,54,69,75–77] have introduced the developments of building policies in various countries and regions. As per the summary in [8], key building policy types include, among others, building energy codes, appliance standards, building energy certification programs (or performance benchmarking laws), and voluntary or mandatory agreements. A recent study [78] has implied similar findings regarding building policies targeting the Australian residential building industry. As per these authors, in Australia, a combination of the aforementioned types of building policies have been implemented by the federal, state, and municipal governments with the aim of alleviating the low-carbon movements in its housing sector. It is also noted that the best practice policy framework towards a low-carbon building industry should set short, medium, and longer-term emissions targets within the nation's carbon budget at all times [22].

Notably, with a few exceptions, most of the regulations analyzed in these studies have focused on residential dwellings. This finding is consistent with the conclusions made by Burke et al. [79] that low-carbon residential housing has been commonly proposed by academia and policymakers worldwide as a solution to reduce greenhouse gas emissions. Summarized from part of the selected articles [24,80,81], the reasons for heavy reliance on residential properties involve their significant contribution to carbon emissions and energy consumption, their large building stock, and their high level of construction activity. Nevertheless, the lack of research on comparing the global context of low-carbon non-residential sectors is apparent. More attention should be devoted to the appraisal of low-carbon regulations in industrial, commercial, and public buildings, and identification of best practices for reaching optimal effectiveness, as argued by the article [69].

It can be concluded that, following the ratification of the Paris Agreement, greenhouse gas abatement in the building industry has become an international policy priority. Such commitment has encouraged governments to accelerate the deployment of regulatory measures targeting the low-carbon building sector and also highlighted the importance of building regulatory tools in driving greenhouse gas abatement globally. The current review also highlights an urgency to undertake more studies benchmarking contemporary low-carbon-related building policies in the non-residential sectors.

3.3.2. Role of Building Energy Performance Requirements in Achieving Low-Carbon Buildings

After in-depth review, the dominance of building energy efficiency and its performance requirements has been highlighted, as shown in many reviewed studies [7,8,12,54,73,74,77,80,82]. This finding is not surprising, as the top keyword identified from both analyses is notably "energy efficiency", not "low-carbon".

The significance of building energy efficiency is a popular topic. As pointed out in [80], the focus on building energy efficiency is due to governments' concerns about energy security and energy productivity, which drives countries to improve energy efficiency in buildings. Another study [76] analyzes from the contrasting perspective of building consumers, implying future increases in energy prices will result in higher utility costs for building end-users. Therefore, building energy efficiency will gain more importance. Further, Seyrfar, Ataei, and Osman [54] stated that building energy efficiency had the highest potential for cost-effective and massive carbon emission abatement. This argument is paralleled with the statement made by Nobel Prize winner and former US Secretary of Energy Steven Chu: "the quickest and easiest way to reduce our carbon footprint is through energy efficiency. Energy efficiency is not just low-hanging fruit; it is fruit that is lying on the ground" [83].

Improving energy efficiency through building energy codes is another well-discussed subject. Building energy codes are defined as rules and requirements for the design and construction of energy-efficient buildings [84], as well as a set of mandatory minimum energy performance requirements to regulate energy use in buildings [85]. Based on the literature, the reasons for such a focus on building energy codes are multifaceted. Firstly, building energy codes can offer one of the best prospects for greenhouse gas abatement [8,74]. More specifically, as demonstrated in [74], building energy codes provide governments with a superior policy instrument for greenhouse gas abatement because they reduce carbon emissions from a key industry whilst simultaneously producing unrivalled combined benefits to the economy, the environment, and society. Secondly, building energy codes can have a substantial impact on the traditional behavior and building industry practices at play [8].

In the reviewed studies, many have discussed the international context and developments of contemporary building energy codes. According to two articles [73,82], there are generally two approaches that have been adopted in building energy codes worldwide: the prescriptive approach and the performance-based approach, with a global shift toward the latter one. A prescriptive approach prescribes an acceptable solution, while a performance-based approach describes the minimum performance. Importantly, the adoption of two approaches can lead to a variety of options for demonstrating compliance [73]. For instance, based on the reviewed paper [80], in the Australian building energy code, demonstration of compliance for Class 1 detached houses can be achieved through (1) conforming to deemed to satisfy elemental provisions in the National Construction Code; and (2) using accredited energy rating software as determined under the NatHERS scheme. However, as embodied carbon has gradually become the dominant source of carbon impacts in the building sector [86], there have emerged new forms of building energy codes, such as life-cycle building energy codes [87]. Further investigation is required on new types of energy codes, as indicated by the reviewed article [73] and a more recent study [88].

To sum up, building energy efficiency is an important feature valued by both the government and building consumers. For government bodies, energy efficiency means energy security and productivity and is a key and probably easier path toward a low-carbon society. For consumers, concerns around high energy prices and utility bills are the main drivers of their attention. As a result, many governments have implemented and enforced building energy performance requirements (i.e., building energy codes) to reinforce energy efficiency in the building sector. Existing discussions illustrated different approaches throughout the evolution of building energy codes and identified the need to investigate new emerging forms of building energy codes.

3.3.3. Building Energy Code Compliance

Within the overarching research area of compliance with building energy codes, two sub-topics have been identified and elaborated on in the paragraphs below.

- Status quo of building energy code non-compliance

As indicated in [89], there has been a well-documented record of non-compliance with building energy codes in both the residential and commercial sectors. However, the severity of building energy code non-compliance varied. For example, a study conducted in the USA [89] has indicated that the compliance rate of the building energy code in residential buildings ranged from 0% in New York to 100% in Oregon between 1990–2012. The information greatly supports the argument of scattered compliance levels in various USA states, as stated in [12]. In the Australian residential building industry, the compliance situation during the design stage was better than in the construction stage. From the paper [80], it was found that 81.7% of housing during 2016–2018 was designed only to meet the minimum energy code requirement, with 98.5% actually falling below the economic and environmental optimum. When moving to the construction stage, as per the article [90], under-compliant behavior such as substandard construction and the use of substandard equipment and materials have been frequently discovered. In another study [75], which investigated the situation in the UK, the status appeared to be worse. The authors identified that only one-third of the 404 residential dwellings completed between 2006–2009 were compliant with Building Regulations Part L (i.e., energy efficiency requirements for the built environment in the UK). Then, one study in the context of China [77] has demonstrated a different picture, where compliance with Chinese civil building energy efficiency codes (including residential and public buildings) has increased from less than 10% in 2000 to nearly 100% in 2012.

It is found that most studies have investigated the compliance status in the residential sector, leaving greater room for further exploration in non-residential buildings. Furthermore, it has been identified that many of the above status quo descriptions differed in terms of the concept of compliance. For instance, in the paper [73], the researchers categorized compliance into several degrees, including non-compliance, grey non-compliance, grey compliance, and compliance. In another article [80], the author considered a bias toward minimum performance as suboptimal. As indicated by Yeung [91], the diverse conception of compliance may lead to inconsistencies in understanding compliance among the scant literature. Therefore, it is argued that a comprehensive understanding of compliance in the context of building energy codes should be further researched to illuminate consistent analysis in future studies. Additionally, as indicated by Garmston and Pan [7], a clear quantitative description of the extent of non-compliance is missing. Hence, further quantification of compliance extent is needed, especially in terms of the gap between the as-designed and as-built energy and carbon performances of buildings.

- Influencing factors for non-compliance and strategies to enhance compliance

Knowing the status quo allows the identification of common influencing factors on non-compliance. Through reviewing a set of studies, several contributing factors affecting compliance have been identified, which have been sorted based on their association with stakeholder groups: regulators, regulatees, and building consumers. Such stakeholder-based classification is consistent with prior studies [13,78]. In the current study, regulators refer to policymakers and building control officers, which include, e.g., policymakers, building surveyors, and energy assessors. Regulatees refer to regulated building practitioners such as architects, designers, builders, engineers, etc. Building consumers refer to the occupiers and end-users of the buildings. Furthermore, potential strategies are also proposed in several pieces of literature. Table 1 provides a summary of the influencing factors and strategies.

Table 1. Influencing factors for non-compliance and corresponding strategies to enhance.

Category	Influencing Factors	Strategies
1 Lack of knowledge	Lack of knowledge among building control officers on building energy code and its compliance requirements * [24,73,89,92]	Provide training to code officers, and invite energy code specialists to provide technical support to code officials [12,81,89,93]
	Misuse of energy rating software by poorly trained or incompetent energy assessors ° [74]	Provide training to energy assessors [74] and establish an accreditation scheme [8]
	Lack of knowledge among industry practitioners on building energy code and its compliance requirements, and energy-efficient design techniques ° [7,73,74,93]	Provide handbooks or guidance to building designers; provide a training program for building practitioners [8,81,90,93,94]
2 Lack of training (linked with 1)	Lack of training provided by building control bodies to building practitioners and control officers * [7,12,73,74]	Provide training to building practitioners and control officers [81,90,93,94]
3 Weak enforcement	Lack of enforcement mechanism (e.g., problems with tracking and monitoring; devolved enforcement structure; inadequate funding for sufficient enforcement of building energy codes; no penalties implementation in reality; lack of national coordination) * [8,12,74,81,89,92]	Adopt measures as recommended in [21,95], as referred to in [74]
		Penalize any non-compliance by any responsible party with the legal requirements or hold them responsible for any oversights [76,89,92]
	Inaccurate building energy rating software * [56,74,96]	Invest in software tool development [92]
	Flawed compliance assessment procedure * [24,73,74,92]	Introduce life-cycle approach to compliance assessment [87]
		Develop a checklist as a tool to assist in the evaluation of compliance of a building design [8,87]
		Include comfort criteria in the energy performance assessment methodology [96]
		Allow trade-offs between the efficiency levels of various building elements to achieve the prescribed whole-building energy performance [97]
		More outcome-based compliance verification [74]

Table 1. *Cont.*

Category	Influencing Factors	Strategies
4 Content and amendment of building energy code	Building energy codes are too complex, with multiple standards and programs * [92]	Simplify specification and compliance approval for buildings using advanced building materials [69]
		Articulate a visionary objective for the building energy code (similar to UK's zero carbon building objective or "near zero energy housing" [69]
		Lock in periodic reviews of energy code provisions to address a development hiatus [69]
		Allow the opinions of the building code users to count in the building code amendment process [82,94,98]
	Building energy codes fail to provide incentives for going beyond minimum requirements * [12,55,92]	Introduce voluntary design benchmarks (e.g., German PassivHaus, Swiss Minergie) or building performance certificate schemes (e.g., Green Star, LEED) for energy efficiency well beyond minimum regulatory compliance levels [69,73]
	Short familiarization and transitional periods during code amendments * [7,73,82]	Provide clear guidance during new code updates [81]
5 Behavioral factors	Building practitioners and consumers are influenced by behavioral factors °† [8,93,94]	Use theories from behavioral science combined with the domain of public policy [8,74,98]
	Designers and architects tend to set energy performance levels at a regulatory minimum, failing to explore alternatives (i.e., heuristics of anchoring) ° [8,69,94]	
	Social norms and pressures perceived by industry practitioners from comparison with peers° [8]	
	Social pressure obtained from consumers ° [74,93,94]	
	Buyers focus on up-front costs rather than lifetime operating costs (i.e., heuristics of temporal discounting) † [8,93,94]	
	Poor attitude among control officers toward building energy, compared to health and safety * [74,89]	
	Prevailing attitude of industry stakeholders toward building energy codes is apathetic and ignorant ° [8,93]	
6 High compliance costs	High costs associated with increasing the stringency of building energy codes * [93,97]	Encourage insurance institutions to develop mechanisms to consider savings from energy efficiency [97]
7 Lack of awareness	Consumers' awareness toward energy efficiency is low † [74,93,94]	Develop a guideline that conveys to end-users the effect of energy savings and thermal comfort levels [74,81,89]
		Develop awareness campaigns and provide economic incentives to building owners or tenants [76]
		Draw on lessons from behavioral science to raise consumer awareness of energy efficiency benefits [8]
	Absence of awareness concerning issues of energy efficiency by the construction practitioners ° [81]	Establish environmental education to develop pro-environmental behavior and awareness [76]

Note: *: influencing factors attributed to regulators; °: attributed to regulatees; †: attributed to consumers.

From Table 1, several prominent influencing factors have emerged. Firstly, a low knowledge level toward compliance with building energy codes has been observed for both regulators and regulatees. It was linked with a lack of training provided to them [74]. For building control officers, they have insufficient skills to assess energy compliance and little knowledge of building energy code and its compliance requirements [24,73,89,92]. Their lack of knowledge was linked to the fact that they do not prioritize building energy efficiency during assessment (compared to structural feature), but because they do not have sufficient training. For design and building practitioners, insufficient knowledge on compliance pathways and energy efficiency design and construction has been identified. Apparently, providing training and guided handbooks to those stakeholders was a reasonable solution to the issue.

Secondly, factors related to weak enforcement have been identified as a paramount problem. The foremost issue appeared to be a lack of enforcement mechanisms in place. The problem of devolved structure between government and enforcement entities has been especially prominent. As explained in [74], many jurisdictions have an enforcement structure where the government is responsible for building energy code administration and a private surveyor is in charge of enforcement. This devolved and separate responsibility structure has caused systemic vulnerabilities, especially in terms of conflict of interests, as private surveyors are usually contracted by clients or builders. It is indicated in a report [21] that some building surveyors may risk losing income if they build up a reputation for being difficult. Additionally, there has been a prevailing sign-off culture among building surveyors, as most of them have simply relied on sign-offs by other building professionals without auditing the documentation or physically inspecting energy efficiency features on-site. Meanwhile, no penalties for non-compliance in practice has also been identified as a relevant influencing factor in the studies [8,92], although penalty provisions are included in the codes. It is strongly suggested that a series of strategies in [21,95] should be adopted to reinforce enforcement regimes. These strategies include, inter alia, providing building surveyors with increased supervisory power and mandatory reporting obligations, establishing a mandatory inspection system with articulated inspection stages. Furthermore, compliance assessment procedures are a relevant concern. For instance, it is proposed that a life-cycle assessment methodology should be adopted [87]. Though this methodology echoes the significant role of embodied carbon and energy generated from the building sector, it has also encountered barriers such as a lack of product-specific data [86]. Other relevant factors relate to the design and implementation of energy rating software. Investment in energy tool development was identified as a corresponding strategy.

Thirdly, there have been several issues concerning the development and design of the building energy codes. A short familiarization period during code amendment [7,73,82], no provisions regarding incentives to go beyond code minima [12,55,92], complex content of codes [92] were discussed as influencing factors. Accordingly, simplification of codes and allowing code users to express opinions during code consultation were considered suitable strategies.

Fourthly, behavioral factors were also demonstrated as key challenges. Studies have shown the industry attitude toward building energy codes [8,93], perceived social pressure, and norms from customers [74,93,94] and industry peers [8], heuristics of anchoring (sticking to code minima and reluctant to go beyond) [8,69,94] and temporal discounting [8,93,94] were all relevant manifestations. Drawing lessons from the behavioral sciences and combining them with the domain of public policy were advocated as enhancement strategies by several literature [8,74,98].

Remaining influencing factors included high compliance costs and a lack of awareness of the building energy efficiency advantages, with potential strategies to overcome them provided, respectively.

It can be seen that the majority (ten factors) of the identified influencing factors can be attributed to the regulator's side, followed by regulatees (eight factors) and building consumers (three factors). The most significant issues concerned knowledge level, enforcement regimes, code quality, and behavioral factors. A large number of strategies have been proposed for responding to the challenges identified. Notably, as it is argued in one of the articles [8], building and design practitioners' behavior when they respond to building energy codes has not been sufficiently explored. Similar conclusions have been found in other studies. For instance, as implied by van der Heijden [10] and Pan and Ning [13], in the low-carbon building regulation debates, the majority of the literature has poorly addressed human behavior. This has caused a mismatch between actual compliance behavior from the RBPs and low-carbon requirements' intentions [13]. As per Meacham [99], the effectiveness of low-carbon requirements greatly depends on the compliance behaviors performed by practitioners. Therefore, the authors argue that a comprehensive understanding of regulated practitioners' compliance behavior with building energy codes warrants further investigation.

4. Conclusions

This research has performed a five-stage systematic literature review on 26 quality articles between 2012–2022, with the aim to elicit hotly debated research areas in existing studies relating to non-compliance with low-carbon building regulations and to further provide prospective research directions. Referring to RQ1, using a relatively novel analysis method combining bibliometric analysis and text mining techniques, three notable research areas have been derived. The first focal area relates to the development of building policies during the low-carbon transition. The study finds that under the global trend of building decarbonization, a wide range of building policies, including building energy codes, appliance standards, building energy certification programs (or performance benchmarking laws), voluntary or mandatory agreements, carbon budgets, have been implemented worldwide. However, most reviewed articles investigate the residential sector. Exploring more building policy developments in the non-residential building industry and identifying best practices by providing international comparisons should be given more attention. The second focal area concerns the dominant role of building energy performance requirements due to governments' general focus on energy security and energy productivity. It also implies that building energy efficiency is a core and easy pathway toward a low-carbon economy. However, new forms of building energy performance requirements have emerged, such as life cycle building energy codes. More studies are needed to investigate new forms of codes as the importance of embodied energy and carbon emissions has grown. The third focal area is related to building energy code compliance. Firstly, an overview of non-compliance status in key nations is presented. It implies a generally suboptimal compliance situation around the globe. However, a consistent conception of compliance in examining non-compliant situations regarding building energy codes is needed to provide more comparable results. Secondly, the influencing factors for non-compliance are investigated. The study shows that the influencing factors are a compound of policy, social, and behavioral aspects, and can be attributed to each stakeholder group, including regulators, regulatees, and building consumers. It also identifies the dearth of research to a comprehensive understanding of regulated practitioners' compliance behavior with building energy codes.

The contributions of this research are demonstrated to both knowledge and industry. Firstly, on the under-explored research topic of compliance with low-carbon building regulations, the study evaluates and synthesizes 26 high-quality scholarly works within the decade. The authors provide an overall landscape of the key research areas and key terms and concepts of concern. The implications for each identified research area are interpreted in detail, and potential areas for further research as per RQ2 are provided. Secondly, for the building industry, the identified influencing factors and associated strategies can serve as a starting point for policymakers or industry stakeholders to improve the non-compliance status and further reduce the divergence between low-carbon policy intentions and actual industry performance.

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