

Systematic Review on the Barriers and Challenges of Organisations in Delivering New Net Zero Emissions Buildings

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Abstract: Achieving the net zero emissions target that was set in the Paris Agreement to mitigate the risks of climate change seems increasingly difficult as countries and sectors of the economy are falling behind the expected trajectory. The building and construction industry, as one of the main contributors to global emissions, has an essential role to play toward this aim. Net zero emissions target has been introduced to this sector as well; however, achieving it is a very challenging and complex task. Many studies have been undertaken on implementing different measures and strategies to reduce the industry's carbon footprint. These studies identified many challenges and barriers in transforming the industry. This paper aims to provide a systematic review of challenges that organisations face in delivering new net zero emissions buildings. The relevant journal articles published since the Paris Agreement were identified and analysed using mixed-method data analysis, including quantitative (science mapping) and qualitative (thematic) analysis. The result showed increased attention to the subject over this period, with China, the UK, and Australia being the top contexts for research. The most discussed groups of barriers were “economic”, “knowledge”, and “technical”, respectively, followed by “organisational”, “market”, “technological”, and “legal” barriers.

Keywords: carbon; net zero emissions; barriers; challenges; building; construction; stakeholders



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1. Introduction

Climate change has been a major global concern for a long time, and its influence is considered the top global risk in terms of severity over the next decade [1]. The leading cause of climate change is the increasing level of greenhouse gases, mainly CO₂, in our atmosphere, causing the greenhouse effect and trapping the heat in our atmosphere. Compared with the pre-industrial era, the level of CO₂ in our atmosphere has increased by about 50%, from about 280 ppm to 421 ppm [2]. There is no doubt that human beings, through various actions such as consuming fossil fuels, deforestation and farming livestock, have been largely contributing to that [3]. It has been estimated that humans generated about 1.5 trillion tons of CO₂ during this period [4].

The importance of the matter is recognised by most governments in the world. In the 21st Climate Change Conference (COP21) held in Paris in 2015, 196 parties signed a legally binding treaty, which is known as “The Paris Agreement,” to take necessary steps towards the mitigation of climate change. The main goal of this agreement was to maintain the average global temperature well below 2 degrees Celsius above the pre-industrial level and make necessary efforts to limit the temperature rise to 1.5 degrees [5]. To achieve this aim, the coalition agreed to cut carbon emissions by 45% by 2030 and reach net zero emissions by 2050 [6]. A target that seems beyond reach unless all sectors take immediate and profound actions to reduce emissions [7].

Many sectors of the economy contribute to GHG emissions; among them is the building and construction industry, which is considered one of the major ones. Data shows that

in 2019, the building sector emitted 12 gigatonne CO₂ equivalent, which represents 21% of global GHG emissions. More than 95% of emissions in the building sector are in the form of CO₂, and if we only count CO₂ emissions, the contribution of this sector is as high as 31% on the global scale. Of the total amount of emissions in buildings, 82% were the result of energy use, and the remaining 18% were embodied emissions from building materials, mainly steel and cement, that were used for the construction and renovation of buildings [7]. These numbers show that decarbonising the building sector is crucial in achieving the 2050 net zero emissions target. However, by the year 2021, the industry had only managed to reach about half of the decarbonisation goal, and the gap between expected and actual performance has been widening since 2018 [8].

The concept of net zero has been introduced to the building industry as well, which commonly refers to a very energy-efficient building that meets its energy demand through emission-free sources over an established period of time [9]. When the development of new buildings is concerned, some definitions, such as the one introduced by the World Green Building Council [10], include maximum reduction in embodied carbon as well. As this research is concerned with new building delivery, the latter definition has been adopted. Studies show that achieving net zero emissions is feasible by a combination of strategies, which include reducing energy demand through passive design measures, increasing efficiency by utilisation of energy-efficient building systems and technologies, and using renewable energy technologies to generate the energy demand needed for the building [11,12]. In the context of new buildings, embodied carbon must also be reduced to the maximum possible level. However, transitioning to carbon neutrality for the building and construction industry, which is among the most traditional and fragmented sectors, is not an easy task [13]. Numerous stakeholders are involved in the process, and a wide range of macro and micro factors, including economic, market, political and legislative, geographical, sociocultural, professional, technical, and technological factors, contribute to this transition. Studies conducted in different countries show barriers in each of these domains that are hindering the industry in its carbon neutrality journey [14]. Addressing them requires a deep understanding of their nature and root causes.

These challenges can be investigated and discussed in different stages of the building lifecycle and from the perspective of various stakeholders. Considering that about 60% of the global building stock that will exist in 2050 has not been built yet [15], it is vital to ensure that new buildings are developed according to net zero emissions targets. Meanwhile, decisions and actions of construction organisations during the predesign, design, and construction stages highly determine the building emissions across its lifecycle; therefore, it is crucial to investigate the challenges that these organisations face as they attempt to develop new net zero emissions buildings in order to address them.

While the building and construction industry continues to struggle to achieve the net zero emissions targets, our review of the literature found a very limited number of review articles on the challenges related to the carbon neutrality transition in the building and construction industry. Some review papers limited their scope to a particular geographical region, such as developing countries, the global south [16], and China [17]. Some others discussed only one aspect of net zero emissions building, such as energy efficiency [18], renewable energy generation [19], etc., or had a holistic view of the barriers without concentrating on any specific stage of the building lifecycle or stakeholder groups that experience them [16,20]. No recent review article was found to focus on the barriers and challenges that organisations face in the delivery of new net zero emissions buildings from initiation till the end of the construction stage. Therefore, this paper aims to fill this gap through a systematic review of the literature since the Paris Agreement to provide an up-to-date review of the challenges that organisations have faced or perceived across the globe in their attempt to move toward the delivery of new net zero emissions building.

2. Methods

In this paper, a systematic review of the literature was conducted following Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) to reduce bias in the review process and provide a transparent report of steps taken [21,22].

“Scopus” database was used to search and identify the publications using keywords: (“Building Industry” OR “Building Sector” OR “Built Environment”) AND (Emission* OR “Energy-efficient” OR “Low-carbon” OR “Nearly zero-carbon” OR “Net zero-carbon” OR “Zero-carbon” OR “Carbon-negative”) AND (Challenge* OR Barrier* OR Obstacle*). Initially, the search engine presented 1103 records, and by limiting the results to journal articles in the English language published between 2015 and 2023, 384 articles were identified. In the next step, the title, abstract, and date of publication were screened to evaluate their relevance to the scope of this study in terms of content and time period (from 12 December 2015, when the Paris Agreement was signed, to the end of 2023) which led to the exclusion of 242 records. Subsequently, the remaining 142 records were screened by reading the full text, and only 66 records were found relevant to the scope of this review.

In the next step, through a search of the abovementioned keywords on Google Scholar and the snowballing method, an attempt was made to identify further articles that were not identified through the Scopus database. Following the same screening process, 22 additional journal articles were found to be relevant to this research, which brought the total number of included records to 88 articles. Figure 1 elaborates on the steps that were taken in the process. In the inclusion criteria that were used during the screening process, this study did not limit itself to those articles that directly discussed net zero emissions, and it included every research that related to different aspects of delivering net zero emissions buildings such as embodied carbon, circular economy, energy efficiency, on-site renewable energy generation, etc.

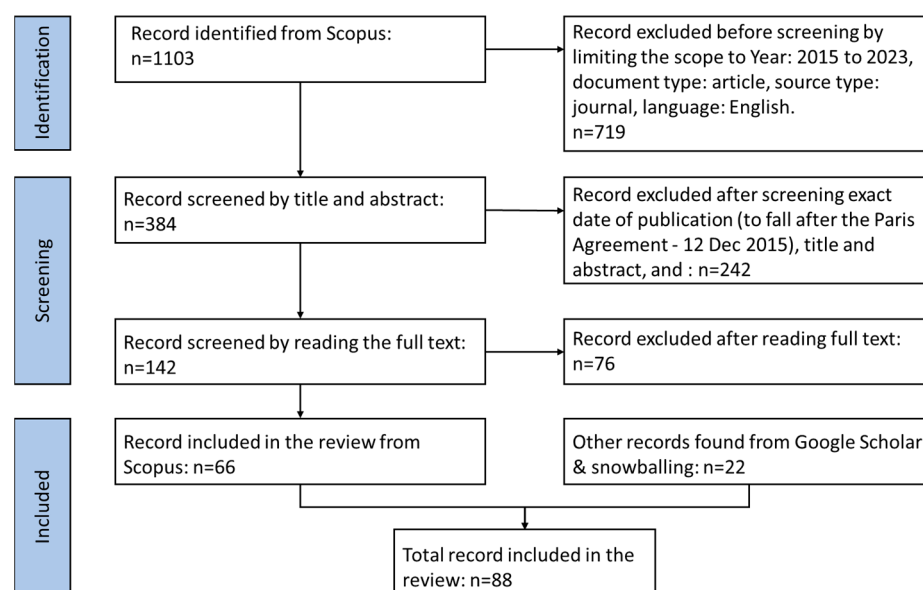


Figure 1. PRISMA diagram.

A combination of quantitative and qualitative methods was used in this paper to analyse the data. First, a bibliographic analysis was conducted, which allowed the examination of the publication date, geographical distribution of articles, and keywords co-occurrence with Microsoft Excel and VOSviewer 1.6.20 software. Furthermore, qualitative content analysis (QCA) was performed using NVivo 14 software. The QCA process involved reading the selected records thoroughly, identifying and coding the data relevant to the aim of this research, grouping them, finding themes, and categorising the data, and finally reporting the result [23].

3. Bibliometric Analysis

The annual distribution of our selected journal articles is illustrated in Figure 2. The bar charts show that the number of publications sharply increased from a minimum of 2 articles in 2016 to 12 in 2019. A sudden drop was observed in 2020, which may have been due to the COVID-19 pandemic that severely impacted global higher education and research cooperations [24]. However, the subject picked up significantly more attention in the following years, reaching a maximum number of 19 journal articles in 2022. Despite the slight fluctuation in numbers, overall, an upward trend and increased attention to the research related to net zero emissions buildings was observed.

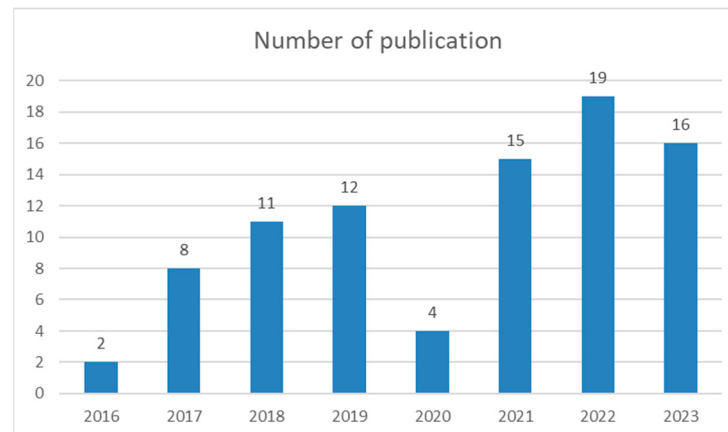


Figure 2. Annual publications.

Moreover, the geographical distribution of the articles was analysed to investigate research hotspots for the subject. For this purpose, instead of using bibliographic data from Scopus, the researchers identified the geographical context of papers by reading the full article text. The result of the analysis is presented in Table 1. China, with 13 publications, was at the top of the list, followed by the UK and Australia, with 11 and 7 publications, respectively. However, the research topic in most countries has not been sufficiently explored during this period.

Table 1. Geographical focus of articles.

Region	No. of Articles	Region	No. of Articles	Region	No. of Articles	Region	No. of Articles
China	13	Malaysia	3	MENA	1	Iraq	1
UK	11	New Zealand	3	Belgium	1	Morocco	1
Australia	7	Nigeria	3	Brazil	1	Norway	1
Not Specified	6	Singapore	3	Chile	1	Peru	1
Sweden	5	Denmark	2	Czech Republic	1	Philippines	1
Canada	4	Finland	2	Egypt	1	Qatar	1
Iran	4	Japan	2	Germany	1	Ireland	1
Saudi Arabia	4	Netherlands	2	Ghana	1	Syria	1
US	4	Turkey	2	India	1	UAE	1
Whole Europe	3	Vietnam	2	Indonesia	1	-	-

Furthermore, keyword occurrence analysis was conducted to understand the major themes discussed in the literature. For this purpose, both author keywords and index keywords, which were extracted from the Scopus database for the relevant articles, were analysed using VOSviewer 1.6.20 software. The same words in singular and plural form were combined to provide a more accurate result. By limiting the minimum number of occurrences to five times, 48 keywords met the criteria. The most frequently occurring keywords include “building” = 33 times, “energy efficiency” = 32 times, “construction industry” = 21 times, “sustainable development” = 20 times, and “carbon emission” = 17 times. The keyword occurrence map is presented in the figure below (Figure 3).

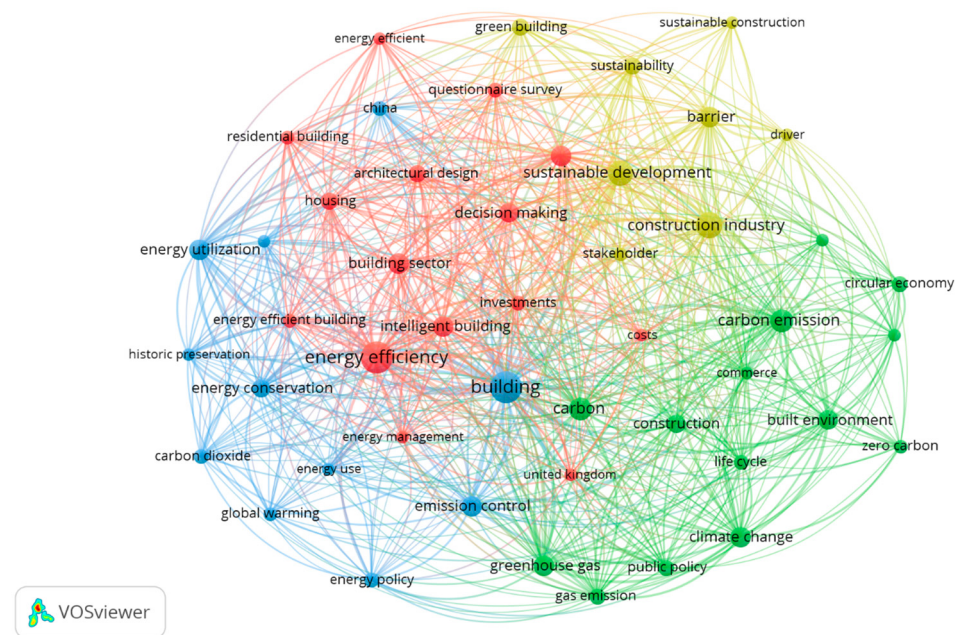


Figure 3. Keyword co-occurrence in selected publications.

4. Qualitative Analysis of the Barriers and Challenges of Organisations in Delivering New Net Zero Emissions Buildings

The selected publications were thoroughly reviewed to investigate the challenges and barriers that have been observed or perceived by organisations in different countries in their journey toward the design and construction of new net zero emissions buildings. Numerous barriers were identified and categorised into various groups, including economic barriers, market barriers, knowledge barriers, technical barriers, organisational barriers, technological barriers, and legal barriers. Table 2 provides a complete list of identified barriers, their references, and number of occurrences. They are further elaborated on in the following sections.

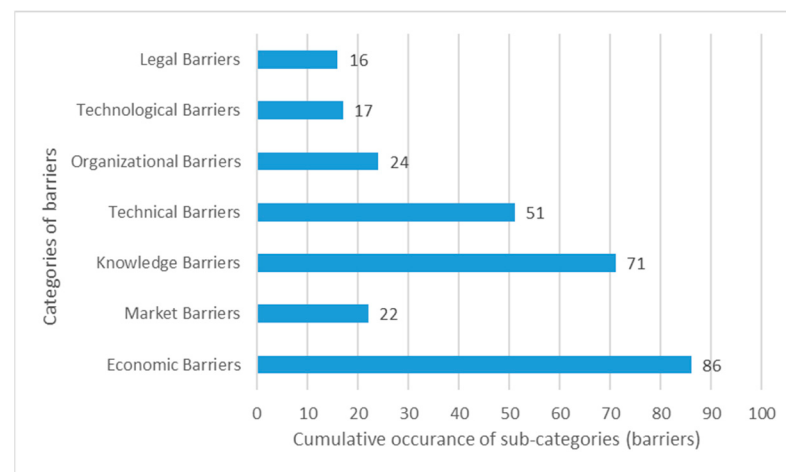
The barriers are defined in this review as follows:

- **Economic:** these barriers are due to the insufficient economic feasibility of implementing measures to achieve net zero emissions buildings and financial restrictions regarding such implementation.
- **Market:** these include the factors that restrict the obtainment of materials and resources for the project.
- **Knowledge:** these include barriers related to the availability of required skills and knowledge necessary for transitioning to a carbon-neutral industry.
- **Technical:** these include barriers related to processes, procedures, practices, and software tools.
- **Organisational:** these include barriers existing within construction companies and firms that hinder the delivery of net zero emissions buildings.
- **Technological:** these encompass the barriers to the availability and use of appropriate hardware tools and systems in the industry.
- **Legal:** these include legal and contractual factors associated with net zero emissions buildings' delivery that pose significant limitations in the industry.

The cumulative occurrence of barriers under each category, as illustrated in Figure 4, indicates that “economic”, “knowledge”, and “technical” barriers are, respectively, the most discussed categories within the scope of our research in selected articles.

Table 2. List and categorisation of challenges and barriers to delivering new net zero emissions buildings.

Theme	Barriers	Occurrence	Reference
Economic barriers	Higher initial investment cost compared to conventional buildings	47	[14,25–70]
	Lack or insufficient financial incentives	26	[13,14,26,29,31,34,35,38,40,41,44,47,50,53,54,59–61,64,67,70–75]
	Difficulty of accessing to finance	9	[14,35,37,40,44,57–60]
	Lack of standard and viable value appraisal for sustainable building	4	[40,65,76,77]
Market barriers	Limited availability of sustainable materials and technologies	12	[37,48,49,51,52,54,56,57,78–81]
	Limited availability of local suppliers	7	[25,26,39,48,51,57,62]
	Lack of effective collaboration between project teams and suppliers	3	[13,32,73]
Knowledge barriers	Inconsistent and unclear definitions and language	7	[14,31,45,61,64,82,83]
	Lack of awareness among stakeholders	24	[13,26,40,42,45,50,52,54,56,57,59–62,69,72,73,75,84–89]
	Lack of skills and expertise	40	[13,26,27,31–33,35,38–45,48,50–54,57,59–62,73,76–79,82–85,87,90–93]
Technical barriers	Issues with data availability	20	[13,14,31–33,35,38,41,49,51,53,57,59,69,74,78,81,86,94,95]
	Lack of benchmark and sample projects	7	[26,33,35,52,57,59,92]
	Inconsistency in methodologies, software and databases for embodied carbon calculation and building performance simulation	5	[64,82,96–98]
	The negative impact of green materials on building durability and performance	5	[27,51,65,91,99]
	Increased complication in design and construction due to material reuse	7	[13,49,56,78,81,99,100]
	Time constraints	7	[13,38,52,54,69,101,102]
Organisational barriers	Insufficient capacity and capability of construction enterprises	5	[29,70,82,102,103]
	Failure to integrate carbon neutrality requirements into the organisation's business model and operation	4	[32,38,53,57]
	Lack of involvement, integration, and collaboration of stakeholders	11	[13,14,31,35,47,59,60,82,93,104,105]
	Lack of R&D support from external institutions	4	[52,57,75,92]
Technological barriers	Underdeveloped infrastructures	5	[56,62,80,99,106]
	Poor quality and performance of sustainable technologies	6	[35,39,48,52,69,74]
	Complexity of using sustainable technologies	6	[14,37,52,53,67,90]
Legal barriers	Lack of standards and guidelines	6	[27,49,52,56,65,81]
	Restrictive and outdated rules and regulations	5	[51,65,99,107,108]
	Lack of feed-in tariff for on-site renewable energy generation	1	[109]
	Procurement methods with imbalanced risk allocation	4	[48,52,78,100]

**Figure 4.** Cumulative occurrence of barriers under each category.

4.1. Economic Barriers

4.1.1. Higher Initial Cost

The most cited barrier/challenge found in the literature for delivering net zero emissions building is the higher initial cost of net zero emissions building compared to a conventional building. This higher cost is associated with different aspects of a project. First, the design of net zero emissions buildings requires more time and utilisation of more design tools, which leads to more costs, and the designers who are capable of such design may charge additional premiums as such skills are not widely available in the market [67]. Additionally, sustainable materials required for reducing embodied carbon (e.g., timber,

low-carbon concrete, etc.) and improving the energy efficiency of buildings still have higher market prices [27,41,51]. Furthermore, energy-efficient building equipment, as well as technologies for the generation of on-site clean and renewable energy, incur additional costs to the project [41]. Moreover, labour cost was another aspect highlighted in the literature. Godin et al. [40] discussed that new skills and techniques are required for the construction of net zero emissions buildings, and if the construction team do not have prior experience or training, more hours of work would be needed for trial and error to perform the task correctly, which results in higher labour costs. Furthermore, if the project is seeking sustainability-related certification, the relevant registration and assessment fee add extra cost [59,65,67]. Very often, clients do not have enough capital to handle the additional cost required for net zero emissions building, which causes a significant challenge [53]. While the higher initial cost is vastly discussed in the literature, there is an argument that the higher cost, at some level, is just perceived. For instance, Di Turi et al. [12], who conducted an economic assessment of delivering a new net zero energy office building, concluded that achieving this aim is possible at a cost comparable to the average value of new conventional buildings in the market.

4.1.2. Lack or Insufficient Financial Incentives

Incentivisation is a practice that many governments have used to mitigate the higher initial cost of net zero emissions buildings and encourage industry to adopt sustainable practices. However, numerous studies conducted in different countries suggest that such incentives are lacking or insufficient [31,53,60]. Even in places where incentives have been introduced, the industry often believes that the size of incentives is not enough to make a significant difference [44,61,72]. Huang et al. [72] also pointed out the long procedure time required to obtain the dedicated financial incentives as a challenge.

4.1.3. Difficulty in Accessing Project Finance

Financing is a common practice that projects can use to gain access to the initial capital required for building projects. This is particularly important for net zero emissions buildings, which are known to require higher initial investment. However, studies show that there are often no explicit financial mechanisms that could support and encourage the adoption of such projects [57,59], and financing options are, in most cases, nonexistent or limited [44,60]. One of the reasons, pointed out by Franco et al. [37], is financial institutions' lack of confidence in the success of sustainable building projects, which makes them reluctant to support them.

4.1.4. Lack of Standard Value Appraisal for Sustainable Buildings

Another challenge is related to determining the value of net zero emissions building. The sustainability features in such buildings add value and provide energy savings to tenants in the operation phase. However, when it comes to assessing this added value in the market, no standard methods exist, which poses a risk to developers [76]. This is a challenge for obtaining finance as well since the appraisal method used by financial institutions often does not consider energy-efficiency features in their assessment, leading to the calculation of a value that is less than the construction cost [40]. As a result, buyers cannot obtain the mortgage amount that they need, and sellers cannot recover their initial investment at the time of the property sale [77]. This problem exists in the rental market as well, which prevents property owners from increasing their rent compared to conventional properties and, therefore, causes a challenge for their return on investment [76].

4.2. Market Barrier

4.2.1. Limited Availability of Sustainable Materials and Technologies

Construction of net zero emissions buildings involves using materials with low embodied carbon, energy-efficient building service equipment, and on-site renewable energy generation technologies. As the construction of such buildings is still relatively new, the

materials and technologies required are not widely available in the market, and the existing product range is not sufficient [54,78]. Environmental certification of materials is also essential in providing the buyer with the necessary information and giving them confidence about their environmental performance. However, as Ismaeel [79] pointed out, the materials with such certifications are not widely available. Limited availability is also a concern when reclaimed materials are intended to be used, and projects often struggle to find sufficient quantity and quality of reclaimed materials [49,80].

4.2.2. Limited Availability of Local Suppliers

The shortage of local suppliers is another market-related challenge discussed in the literature. The availability of local suppliers is essential for the ease of obtaining information in the planning stage, installation of systems in the execution stage, and providing maintenance support in the operation stage. Geissler et al. [39] discussed these barriers related to the supply of materials and technologies for sustainable building design and construction in Nigeria. In the absence of local suppliers, the project procurement team has to import project requirements from foreign sources, which leads to additional time, cost, and risk [51,57]. Some countries may even have additional challenges in importing the materials and technologies that they need for reasons such as sanctions, which Khaddour [48] discussed in the context of Syria.

4.2.3. Lack of Effective Collaboration between Project Team and Suppliers

Effective collaboration between the project team and suppliers is essential in obtaining the necessary information, materials, and products required for net zero emissions building projects. Makvandia and Safiuddin [73] reported the difficulty of working with suppliers to procure project requirements as one of the common barriers to delivering net zero emissions buildings. Additionally, Carlander and Thollander [32] pointed out the inability of technology suppliers to provide relevant information in a way that is useful and understandable. They also highlighted the project team's lack of trust in the information offered by technology providers, which is one of the critical factors influencing collaboration [110]. Cruz Rios et al. [13] stated the same issue in relation to secondary materials suppliers as one of the main barriers to circular building design.

4.3. Knowledge Barriers

4.3.1. Inconsistent and Unclear Definition and Language

When discussing the subject of climate change and reducing emissions in the building and construction industry, several definitions and terminologies (low-carbon, nearly zero, net zero, zero carbon, etc.) have been used that cause confusion about the concept and scope of the subject matter. This inconsistency of language and definition acts as a barrier to understanding and adopting the concept [45]. Although the general goal of the net zero emissions concept is clear, industry practitioners understand these concepts differently [31], and the scope of the concept is not clear [14]. Pan and Pan [61] also pointed out that there is no unified definition, which caused it to be a concept rather than a practical approach. Skillington et al. [64] referred to this problem in relation to embodied carbon and different scopes defined in policy mechanisms and international standards.

4.3.2. Lack of Awareness among Stakeholders

A large number of studies discussed the lack of awareness about net zero emissions building and its different aspects as an important barrier to its development. This lack of awareness exists among different stakeholders, including the public, developers, contractors [61,69,89], government officials [56], etc. Lack of awareness related to several subjects was discussed in the literature, including the importance of climate-neutral buildings [62,75], lifecycle cost and benefits [13,50,54], circular built environment [56], government's economic and fiscal instruments, such as incentives [72], and technologies such as building integrated photovoltaic [52].

Studies suggest that the public and end-users have a very limited understanding of the importance of climate-neutral buildings [62,75], what exactly it is (Graham & Warren-Myers, 2019), and what benefits they have [40]. Clients also sometimes do not understand the effect that their decision about their home design has on its energy consumption [88], and industry practitioners are not well aware of existing materials, technologies, and approaches for net zero emissions [60].

4.3.3. Lack of Skills and Expertise

Design and construction of net zero emissions buildings require skills and expertise that people involved in conventional projects do not necessarily possess. This includes the application of new building codes, tools, technologies, materials, methods, and approaches [31]. Studies show that companies have difficulties finding the right people across different disciplines to successfully carry out such projects [73], and this skill shortage seems to exist across different levels, from architects and engineers to labourers and trades on construction sites [60]. This lack or insufficiency of stakeholders' expertise is a major barrier to the diffusion of net zero emissions buildings [35,73]. In the design of net zero emissions buildings, several tools are used for the creation of integrated design, modelling, simulation, and analysis of energy consumption, calculation of embodied and lifecycle emissions, etc. Application of these tools and software, which had not been necessary for conventional building projects, is a complex process that requires new expertise to be obtained [111]. The inability to use these software and tools was identified as a barrier [83,84]. Moreover, a few studies discussed this barrier in introducing wooden construction to countries where wood-based materials like timber have not been considered a common construction material. In such countries, replacing concrete and steel with timber is a challenging task as professionals involved in the industry do not possess technical skills for designing and constructing with wooden materials [38,44,51].

Insufficiency of technical knowledge and expertise was discussed with respect to other areas as well, such as building code [84], energy efficiency and sustainable technologies [26,32,53,87], building integrated photovoltaics [52], life cycle assessment (LCA) [33], carbon accounting methodologies [91], assessing operation and maintenance cost [91], circular economy strategies [13], energy flexibility strategies such as short-term thermal energy storage in built environment [90], and insufficient recognition of product brands and their competitive advantage [59].

Furthermore, a lot of technical know-how is obtained and consolidated through prior experience. Such experience gives industry professionals the confidence to make decisions and reduce project risks and errors. Attia et al. [82] suggested that the construction industry in southern Europe is not prepared with experience for the design of nearly zero buildings, which poses a challenge to its development. A similar barrier was reported by other scholars for the development of green building [92], the use of nontraditional materials [57], and multicomponent system reuse [78].

Very frequently, extensive training is required to enable industry transition to carbon neutrality. Universities have done a very poor job of equipping the young workforce with the necessary skills required, and their curriculum is often inadequate [13,35,43,45] and disconnected from real-world practice [42]. Although academic institutions have come to the realisation that change in their curriculum is necessary, the pace of this change seems to be very slow [73]. Furthermore, for those professionals who are already past their academic stage and are working in the industry, professional vocational training is required to obtain the skills they need. Such education seems to be missing as well [59,62]. Time and resources required for specialised training are another challenge for obtaining the required skills [27]. Some studies suggest that owners and developers expressed a lack of time to learn about new technologies, which affects their ability to make informed decisions [76]. This insufficient training is not just limited to construction professionals. Shapiro [77] found this issue among officials who are responsible for the evaluation of code compliance and highlighted that they are not well trained in the new codes.

4.4. Technical Barriers

4.4.1. Issues with Data Availability

With regard to data, a few issues were identified in the literature, including lack or insufficiency of data, concern about the accuracy and reliability of data, lack of database and data system, and user-unfriendliness of data. Multiple publications discussed that the lack or insufficiency of data in multiple areas is hindering stakeholders from making informed decisions. Ohene et al. [14] highlighted the difficulty of accessing cost and financing information, and Nguyen et al. [59] suggested that there are not enough data on cost benefits from multidisciplinary research. Carlander and Thollander [32] mentioned the concern of their research participant about finding information about newly introduced technology, as well as the reliability of the information source, and Franzini et al. [38], who explored the barriers to using wood as a sustainable material for multistorey construction in Finland, identified that almost all respondents had difficulty finding relevant information. Additionally, Low et al. [51] found the unavailability of technical information about mass-engineered timber as a barrier to its adoption in Singapore. Attia et al. [82] and Li and Wang [112] emphasised the importance of monitoring and comparing calculated and actual performance of buildings and stated that very few case studies are available that provide this important data for designers to benefit from.

Lack or insufficiency of data for the public was discussed in other contexts as well, including renewable energy technology installation [74], the performance of building energy efficiency technologies [35], low carbon materials and their performance [33], the recycled content of materials [78], availability, quality and quantity of reclaimed building components [13], the performance of reclaimed materials [81], and the rules for planning and executing reuse projects [49]. Furthermore, studies also found data gaps in existing tools used for the calculation of embodied carbon and energy simulations [53]. In this regard, Bui et al. [31] mentioned insufficient country-specific data on the embodied carbon of building materials and the embodied carbon of building services such as HVAC.

Moreover, some studies emphasised the importance of well-known and reliable databases for public access to information and considered the lack of such a challenge for the industry [59]. The lack of a comprehensive database for sustainable technologies [57], materials choices [41], and country-specific embodied carbon of materials [95] was identified in our review. In addition, Karavai et al. [94] discussed the lack of a data system required to document actions and practices that were found to be beneficial for emission reduction. Finally, Martek et al. [86] brought attention to the user-unfriendliness of data and argued that available data are not presented in a way that an ordinary user could fully understand.

4.4.2. Lack of Benchmark and Sample Projects

The concept of net zero emissions in the building and construction industry is relatively new, and most organisations have no experience in the delivery of such projects. Real-life examples of such buildings need to be built, demonstrating what and how materials and technologies can be utilised to meet the expected targets and prove that they are technically and economically viable. They also need to be accessible to relevant stakeholders so they can visit, study, and learn from them. Several studies showed the lack or insufficiency of such example projects [26,33,35,52]. Additionally, Qin [92] argued that even when sample projects exist, their performance is not satisfactory and, therefore, cannot provide real solutions that organisations need to solve their technical problems.

4.4.3. Inconsistency in Methodologies, Software and Databases for Embodied Carbon Calculation, and Building Performance Simulation (BPS)

Another challenge is the variation in the result of carbon and energy performance assessments. There are multiple methodologies and tools for life cycle assessment with different inventory databases, which generate different assessment outcomes for the same building [64,96]. Pomponi et al. [97], in their research, conducted an experiment where the same case study information was given to different independent assessors for the

calculation of embodied carbon. Their analysis showed significant differences in the outcomes. Although international standards have been developed to guide the industry in this regard, there are still inconsistencies in the methodologies that are being used, as well as the value of embodied carbon in the lifecycle inventory database. Furthermore, the subjective choice of the assessor can have a significant influence on the assessment outcome. If sufficient specification of materials is not provided, the assessor could have a range of options to choose from when calculating embodied carbon, which could generate significant variation from the actual value [64]. Attia et al. [82] also mentioned that there is a disparity in the use of performance indicators, which results in inconsistent assessment outcomes. Moreover, a similar issue was reported in relation to building performance simulation tools that use a wide range of data to accurately predict the future energy consumption of buildings. One of the key inputs is the building occupancy rate, which cannot be precisely predicted when new buildings are designed; therefore, the design team mostly has to rely on the existing relevant databases and archetypes. Research shows that there are inaccuracies in those databases, which leads to a performance gap that questions the reliability of these methods and software tools. For instance, in the case of UK residential buildings, Buttitta et al. [98] found that failure of existing archetypes to properly consider occupancy profile can lead to a difference between calculated and actual head demand as high as 30%.

4.4.4. Negative Impact of Green Materials on Building Durability and Performance

Studies pointed out that, generally, environmentally sustainable buildings have shorter lifespans [65]. One of its reasons is the replacement of more durable materials like reinforced concrete and steel with wood-based materials like timber. Replacing conventional concrete with other materials for certain building components can compromise its durability and increase its vulnerability to deterioration over time [27]. Wood-based materials are less durable and are prone to degradation due to mould and termite attacks [51]. Keena et al. [99] pointed to this issue and mentioned that currently, the service life of most laminated timbers used as structural components is only 60 years, while based on circular economy logic, they should last for at least a hundred years. Another drawback of wood-based materials is their lower fire safety [51], which consequently have stricter fire safety regulations and measures [91], resulting in increased costs. Moreover, mass-engineered timber limits building height, as it is not safe to build high-rise buildings with this material [51].

4.4.5. Increased Complications in Design and Construction Due to Material Reuse

Using reclaimed materials is a great way to reduce the carbon footprint of the building industry. However, several factors hinder its widespread use. First, material reuse limits design freedom [78] and complicates the design and construction process [81]. There are uncertainties and concerns associated with the performance of reclaimed materials [78], and there is no guarantee of their quality and strength [56]. Even when their specification is reasonably clear, very often, it is difficult to match the specification of reclaimed materials with the requirements of new projects in terms of size, strength, quantity, etc. This is particularly difficult for structural components as they are often custom-designed and optimised to exactly match the requirements of a specific project [13,49,100]. Keena et al. [99] also acknowledged this difficulty and pointed out that this is even more challenging in earthquake-prone regions where reinforced concrete is commonly used. Matching the seismic resistance of such reclaimed components with project requirements is a difficult task.

Moreover, from a visual and aesthetic point of view, stakeholders think that using reclaimed materials in façade and other exposed parts of buildings would make it more difficult to have a uniform quality and achieve architectural intent [78]. In addition, the transportability of reclaimed building components is another challenge that can cause project developers to miss the opportunity for reuse, as sometimes components come in sizes that cannot be transported through standard trucks or containers [13].

4.4.6. Time Constraints

The design and construction of net zero emissions building requires more time than conventional projects as more measures need to be considered in the process. The concern about extension in project schedules acts as a barrier to incorporating sustainability measures [54,69]. Industry practitioners expressed that they do not have enough time for such consideration [101,102]. Designers are also often under much pressure and have a very tight schedule for the completion of project design, which has a negative influence on their ability to incorporate sustainability measures such as circular design [13]. Furthermore, stakeholders also need to dedicate time to professional training to obtain the necessary skills for the delivery of net zero emissions building. Lack of personal time for such training was expressed as another barrier by Franzini et al. [38].

4.5. Organizational Barriers

4.5.1. Insufficient Capacity and Capability of Construction Enterprises

In transitioning to a net zero emissions industry, construction companies are required to change the way they operate. This necessitates a certain amount of in-house skills and expertise, which needs to be obtained either through hiring new employees or retraining existing ones, which is resource-consuming and, therefore, discourages companies from moving toward that path [29]. Utilisation of new technologies is also required, which many companies do not possess [70]. Small enterprises particularly have more challenges in this regard [102], and one reason is their financial limitation. Attia et al. [82] pointed to the inability of contractors to follow best practices and perform their tasks with high technical accuracy as another challenge. Additionally, Franco et al. [37] highlighted that immature construction methods prevent proper implementation of what has been designed and contribute to the performance gap. Attempting to deliver net zero emissions buildings without addressing these issues can lead to ineffective design and construction of buildings that are unable to meet desired energy and carbon performance and failing to observe the benefits that were assumed as a basis for the economic viability of projects [103].

4.5.2. Failure to Integrate Carbon Neutrality Requirements into the Organisation's Business Model and Operation

Our review found that there are some aspects related to construction organisations that act as a barrier to the development of net zero emissions building. Very often, low carbon and energy efficiency are not integrated into the companies' business models [53], and such measures are not considered important by top-level managers [57]. Furthermore, organisations that are welcoming of new ideas for sustainability often fail to implement them successfully as they do not assign any specific person to act as an agent for pushing the idea forward and leading the organisation in its new agenda [32]. Another key consideration is the development of human resources. Organisations need to incentivise and motivate their human resource to continuously educate themselves and learn the necessary skills required for the utilisation of new materials, methods, tools, and technologies. The lack of such incentivisation was found to be a barrier by Franzini et al. [38].

4.5.3. Lack of Involvement, Integration, and Collaboration of Stakeholders

Emission consideration adds another level of complexity to the already complicated process of building development. This complexity cannot be addressed by the traditional design and construction approach, where different disciplines work in isolation and hand over the job to the next one. Such an approach prevents an integrated design that considers the whole project lifecycle and, therefore, is a barrier to sustainable building development [59]. It is well established that the delivery of carbon-neutral buildings requires the participation and collaboration of all project stakeholders, especially the core project team. However, studies highlighted that the lack of such integration and collaboration continues to hinder net zero emissions building development. Bui et al. [31] pointed to this barrier and mentioned that lack or ineffective involvement of contractors at an early stage

prevents their consideration from being integrated into building design, and insufficient communication between architects and engineers results in inefficient design. Additionally, Thompson et al. [93] highlighted the importance of communication between the design team, client, facility manager and operation team in accurately predicting the future use of buildings and emphasised that insufficient communication can cause the designer to make wrong assumptions in their building performance modelling, and consequently, the actual energy demand can be significantly different from their calculations. Cruz Rios et al. [13] also elaborated that a lack of collaboration between the design team and contractor prevents architects from having the necessary data required for design for disassembly (DfD) and, therefore, hinders circular economic design. Moreover, an effective communication network contributes to forging the required collaboration among stakeholders. Nguyen et al. [59] found that in the context of Vietnam, such a communication network is lacking. In addition, Graham and Warren-Myers [42] mentioned the difficulty consumers have in communicating their desire for energy-efficient homes to builders.

Meanwhile, bringing multiple actors together to collaborate toward the same goal increases the complexity [82]. Among the causes of this complexity are counterproductive or split incentives of different stakeholders [90]. Carlander and Thollander [32] elaborated on the different incentives that customers, suppliers, and contractors have in integrating energy-efficient technologies in building projects and how they cause issues.

4.5.4. Lack of R&D Support from External Institutions

Construction organisations require continuous support from institutions that work in research and development (R&D). Literature suggests that such support is lacking. Mohamed et al. [57] stated that there is no local R&D institution for green building technologies in Saudi Arabia. Lu et al. [52] also pointed out the absence of R&D support that covers the whole industry chain of building integrated photovoltaics, which is a barrier to the wide adoption of such technology in Singapore. In China, Xue et al. [75] found that the R&D institutions that work in the green building industry are immature. It was highlighted that they are unable to provide sufficient support to the industry through improving and upgrading green building products while the industry is in demand of it. The construction industry faces numerous challenges in transitioning to environmentally sustainable building, and in overcoming them, specific solutions to each of those challenges are needed, which are hardly proposed in reports generated by counselling institutions [92].

4.6. Technological Barriers

4.6.1. Underdeveloped Infrastructures

Some studies pointed to a lack of infrastructure as a barrier to delivering net zero emissions buildings. Keena et al. [99] stated that while technologies and methods for decarbonising mineral-based materials (e.g., steel and cement) and producing biobased materials are known, supporting infrastructure is still lacking. Piderit et al. [62] also highlighted the lack of industrial manufacturing infrastructure for large-scale production of building materials and equipment for net zero emissions buildings. Mhatre et al. [56] and Nußholz et al. [80] discussed this lack of infrastructure in the context of the circular economy and mentioned that required technologies, tools and methods for the separation, collection, and recovery of building materials are missing. Additionally, Unuigbo et al. [106] pointed to poor and unreliable electricity infrastructure in Nigeria, which has been unable to match the demand and forced the built environment to rely on fossil fuel-based generators at the building level as a solution.

4.6.2. Poor Quality and Performance of Sustainable Technologies

The low quality and performance of available technologies were another matter of concern discussed in the literature [48]. Cristino et al. [35] mentioned the poor quality of imported building energy efficiency technologies and their unsuitability for the region. Wu et al. [69] suggested that available green technologies are immature and do not perform

as they should. Moreover, Geissler et al. [39] stated that there is a serious quality issue in renewable energy technologies, and Lu et al. [52] pointed to the low energy conversion rate of building integrated photovoltaic systems as a barrier to its implementation. Additionally, Song et al. [74] highlighted that the use of renewable energy for heating and cooling is not as reliable as conventional energy sources due to intermittency, which causes more vulnerability of households to hot and cold weather.

4.6.3. Complexity of Using Sustainable Technologies

The complexity of using sustainable technologies is something that is tightly linked with education and training. The fact that the construction of environmentally sustainable buildings requires greater technologies is already a barrier to its development [67], and the perception (or reality) of their complexity adds another level to it [37]. Madhusanka et al. [53] found that stakeholders consider the complexity of technologies used in planning, design, construction, and management of net zero emissions, building a barrier to its adoption. Ohene et al. [14] discussed this difficulty, more specifically related to the use of renewable energy technologies in the building sector, as several factors determine its ease or difficulty of integration. In addition, Lu et al. [52] mentioned the problem with integrating on-site renewable energy systems into the grid. Finally, Johansen and Johra [90], who discussed the use of indoor build environments for short-term storage of thermal energy as a strategy for demand-side energy management, pointed to the difficulty of balancing local district heating equipment as a challenge.

4.7. Legislative Barriers

4.7.1. Lack of Standards and Guidelines

Standards are agreed specifications for products, processes, services, and performance [113]. They can be voluntary or mandatory and are important in guiding the industry toward sustainable design and construction. Literature suggests that such standards for some contributors to the delivery of net zero emissions buildings are lacking. Althoey et al. [27] pointed to the lack of standard criteria for the use of low-carbon concrete, and Souaid et al. [65] mentioned a lack of clear guidelines and standards for using low-carbon materials, which is a challenge for the designers. Similarly, Lu et al. [52] found that there is no specific design standard and code for building integrated photovoltaics, which is hindering its adoption. Furthermore, concerning material reuse, the same problem was discussed by Kanyilmaz et al. [49] and Pronk et al. [81]. In this regard, Mhatre et al. [56] argued that due to differences in the quality of reclaimed materials, regulatory bodies might be reluctant to introduce a standard for them.

4.7.2. Restrictive and Outdated Rules and Regulations

Literature suggests that when it comes to building regulations, there are some rules that are outdated, constraining and unaligned with the net zero agenda. One of these rules that was discussed by Souaid et al. [65] is the mandatory design requirement that does not allow for small-scale living space. Scaling down the living space is an effective method that has been proposed and used not only to reduce embodied carbon and energy demand [108] but also to address the affordability issue. However, some authorities, by setting the minimum living space too high, restrict the utilisation of such methods. The same applies to land subdivision policies, which in some places do not allow for the construction of more than one dwelling in a relatively large plot of land. It was also found that being too prescriptive in design rules is a barrier to integrative innovative solutions required for net zero emissions building [65]. Another issue that was pointed out by Himes and Busby [107] is the necessity of updating building codes to allow and encourage the use of sustainable materials. For instance, Low et al. [51] found that industry professionals are concerned about using mass-engineered timber as it might not be compatible with the current building code. Similarly, Keena et al. [99]

found that current legislation limits the reuse of recovered assemblies and materials and highlighted the importance of regulation updates.

4.7.3. Lack of Feed-In Tariff for On-Site Renewable Energy

Feed-in tariff is an important part of the on-site renewable energy systems, which are used in net zero emissions buildings. The surplus of electricity generated through on-site clean technologies (mostly through PV panels during the day) is commonly fed into the electricity grid network and, in return, provides economic benefits for the property owner. The lack of tariffs on this small-scale energy production was found to be a challenge by Uspenskaia et al. [109] in the Czech Republic.

4.7.4. Procurement Methods with Imbalanced Risk Allocation

The procurement method is another aspect that can hinder the development of net zero emissions buildings. Traditional hard bid tender, which awards projects to the lowest price even if it is way below the estimated price, risks the quality of construction and environmental objectives of the project [48,52]. Another issue with the traditional form of contract is risk allocation and the increased risks for the contractor when using secondary materials. Using reclaimed materials is a good way to reduce embodied carbon in building projects; however, due to uncertainties associated with the quality and expected lifespan of those materials, the risk of system failure increases. Under conventional contracts, the contractor has to bear the brunt of this risk due to their liability during the warranty period. This makes contractors reluctant to utilise reclaimed materials [78,100]. Furthermore, the literature also suggests that disjointed and inconsistent procurement approaches and rushed the process of commissioning and handover contribute to the performance gap [93].

4.8. Prioritisation and Interrelationship of Barriers

Several studies attempted to rank and prioritise the barriers. While most research considered the economic aspect to be the most critical barrier to the carbon neutrality transition [58,60,61], Ohene et al. [14], who sought the opinion of experts in developed countries, found that the legal/legislative barriers to be the most important category. However, this is not sufficient to generalise the result for all developed countries, as Gounder et al. [41] found that in Australia, the top barriers to the adoption of sustainable materials are still economic. This indicates that depending on the context of different countries and regions, the importance and priority of barriers can differ and, therefore, should be investigated.

Very few studies have been found on the interrelationships of barriers. Madhusanka et al. [53] investigated interrelationships and interdependencies of barriers in the context of high-rise, high-density cities and concluded that addressing the political/legislative and technological barriers is influential in mitigating organisational, market, and knowledge barriers. However, their study only elaborated on the binary-type relationship and did not consider the strength and significance of the relationship. Rodriguez et al. [76] also pointed out the interconnectedness of barriers to energy-efficient practices that go beyond individual categories. Furthermore, Mhatre et al. [56] investigated the cause-and-effect relationship of barriers to the circular economy in the Indian building and construction industry. Their analysis showed that some of the barriers to the application of secondary materials in the design and construction of new buildings are mainly caused by barriers in the deconstruction stage of the building lifecycle. Some of these main causal barriers include the lack of a safe and environmentally friendly process for recovering materials, lack of technology and infrastructure, lack of investment and funding, high cost of operation, and lack of a suitable business model for the circular economy.

5. Discussion

The review revealed an overall upward trend in the number of publications relevant to the barriers that organisations face in delivering new net zero emissions buildings. China,

the UK, and Australia were the top contexts of research, respectively. However, most countries have received very limited attention. Content analysis of papers revealed that organisations have experienced or perceived numerous challenges and barriers that hinder the design and construction of new net zero emissions buildings. These barriers are categorised into seven groups, namely economic, market, knowledge, technical, organisational, technological, and legal. Figure 5 presents the map of these barriers.

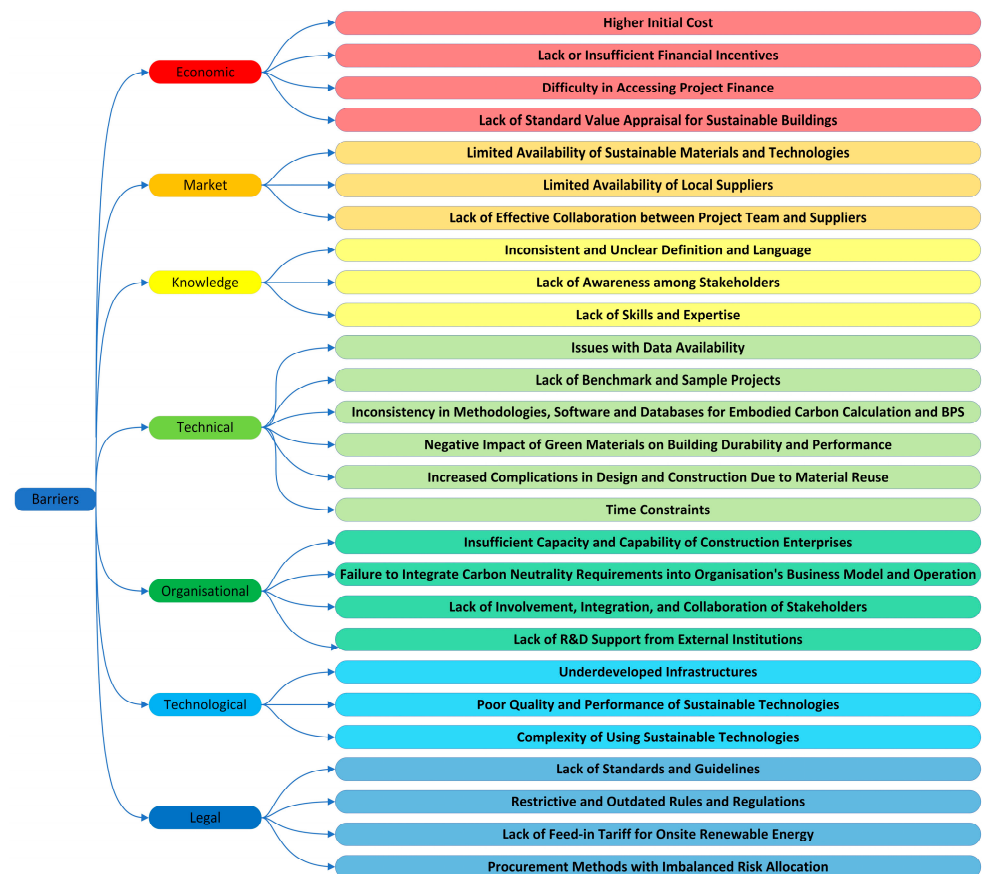


Figure 5. Barriers faced by organisations in delivering new net zero emissions buildings.

Regarding economic barriers, the high initial cost of net zero emissions building is a major challenge that stakeholders have been facing. The insufficiency of financial support instruments, such as incentives and difficulties in accessing finance for projects, made it more difficult to address this problem. Moreover, due to a lack of a standard and viable method for assessing the value of net zero emissions buildings, they are often undervalued, posing a high risk to the client's return on initial investment and negatively affecting their ability to obtain external finance. Knowledge-related barriers are the second most discussed group. Inconsistency and lack of clarity in the definition and scope of net zero emissions buildings, lack of necessary awareness, and inadequate skills, expertise, and experience continue to be a problem among the stakeholders.

Furthermore, numerous technical challenges have been reported. First, the data required for transitioning to carbon neutrality are not sufficiently and easily available, and a well-known and reliable database that stakeholders could refer to is also missing. User-friendliness issues of existing data have also been reported. Additionally, benchmark/sample projects that practitioners could refer to and learn from are not readily available. Meanwhile, inconsistency in methodologies, software, and databases that are used for carbon calculation and building performance simulation causes confusion and doubt about the accuracy of assessment tools. In addition, many low-carbon materials, especially wood-based, have a lower durability compared to conventional materials like concrete, which is a big concern. Material reuse, which is another way of reducing embod-

ied carbon in buildings, is also not challenge-free, as it often complicates the design and construction process. Lastly, project time constraints can act as a barrier. Projects often have very tight schedules, which may not allow the design and construction teams to properly integrate environmental considerations into their tasks and, on a personal level, to learn new skills and knowledge.

From an organisational point of view, integrating carbon neutrality requirements into organisations' business models and operations is essential, and failing to do so prevents this concept from actualising. Many construction enterprises, especially SMEs, do not have the capacity and capability in terms of financial resources, in-house expertise, and technologies to transition to carbon neutrality. External R&D institutions play an important role in providing necessary knowledge-based support to organisations. However, such support seems to be lacking. In addition, inadequate involvement, integration, and collaboration of actors and stakeholders within and outside organisations threaten the environmental objectives of projects.

A few technological barriers were also found, which include underdeveloped infrastructures related to manufacturing, circular economy and clean electricity generation, poor quality and performance of sustainable technologies, and the complexity of using them. With regard to market barriers, it was found that sustainable materials and technologies still have limited availability, and relevant suppliers are not widely available in local markets. Meanwhile, a lack of effective collaboration between the project team and suppliers challenges the attainment of necessary products and their relevant information. Finally, under the legal category, the lack of standards and guidelines, restrictive and outdated rules and regulations, and the lack of feed-in tariffs for on-site renewable energy were discussed. Procurement methods also influence the success of project environmental objectives. Methods like hard bids and traditional contracts focus too much on cost, limit collaboration, and place a high risk on contractors, which discourages environmentally sustainable practices in projects.

Regarding the priority and importance of barriers, while they can vary in different countries and regions, in most contexts, economic barriers are still considered the most important. Additionally, in attempts to address the barriers, it is important to evaluate the relationships among them. Targeting those that are considered the root cause has mitigating effects on subsequent barriers.

Certain gaps were identified in the literature as well. First, while most studies discussed the higher initial cost as one of the main barriers to delivering new net zero emissions buildings, some research argued that this barrier is, to some extent, perceived. It was suggested that such buildings, in some contexts, can be delivered at a cost that is comparable to the average value of new conventional buildings. There are insufficient studies to quantify the cost of net zero emissions buildings and compare them with conventional buildings in different contexts. Furthermore, when it comes to the priority of barriers, no study was found to compare the priorities between developing and developed countries or track the change in priorities over time in different countries as they progress toward net zero emissions goals. Meanwhile, the studies on the relationship between barriers are very limited and have not examined the strength of the relationship among barriers. Finally, the role and responsibilities of stakeholders in addressing each barrier have not been well investigated.

6. Conclusions

This study provided a review of the research conducted since the Paris Agreement to investigate the challenges that organisations in different countries have faced or perceived in developing new net zero emissions buildings. Twenty-seven barriers were found, elaborated, and categorised under seven groups. The outcome of this research provides a comprehensive reference of barriers that assist industry practitioners in understanding the potential challenges that they face as they aim to deliver new net zero emissions buildings,

helps regulatory bodies to understand the areas where the policies need to target, and aid researchers in recognising the aspects that research is required to find solutions.

Based on the identified gaps in the literature, this study provides some recommendations for future research. First, more research needs to be conducted to quantify the initial cost of optimal net zero emissions buildings in different contexts and compare it with conventional building value to provide evidence on the extent to which the higher cost is actual in different places. Second, future studies may compare the priority of challenges in developed and developing countries, as well as how they change as progress is made toward the net zero emissions goal. Additionally, a deeper evaluation of the causal relationship among the barriers and the strength of their links is essential. The investigation of barriers and challenges is the first step in paving the way toward a carbon-neutral industry. In this journey, stakeholders are not just powerless victims of these barriers, but they also have the ability to influence them. Future research may also focus on the strength of influence that stakeholders have on each barrier and the contribution that each can make to address them.

This paper had some limitations as well. The data were only obtained through Scopus and Google Scholar databases and only focused on journal articles in the English language that were available online since the Paris Agreement (12 December 2015) till the end of 2023. Furthermore, the challenges and barriers that were analysed and discussed were only limited to those that organisations face from the project initiation phase until the end of the construction stage. Further research needs to be conducted to understand the barriers faced by stakeholders in other stages of the building lifecycle, as well as other aspects, such as sociocultural and political, that contribute to the widespread adoption of net zero emissions buildings.

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