CONSTRAINTS FOR REDUCING CARBON EMISSIONS AND ENERGY CONSUMPTION IN BUILDINGS - A SYSTEMATIC REVIEW

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Abstract. Even though a significant emphasis is placed on carbon emission reduction in buildings, several constraints continue to hinder its practical implementation in buildings. Over the past 25 years, much research has been conducted to explore the constraints of delivering low-energy/ carbon buildings in different sectors. However, those constraints have not been organized properly, requiring a detailed and comprehensive approach to identifying and listing the constraints to deliver low-energy/carbon buildings. Furthermore, a systematic review has still not been conducted to explore these studies, which have identified and discussed constraints. Therefore, this paper aims to systematically explore the previous literature to identify and list the constraints to delivering low-energy/carbon buildings. The presented outcomes are based on a review of published journal papers from 2001 to 2024. According to the findings of the literature review, 92 constraints were identified under 9 categories. It was revealed that the adaptation of low-energy/ carbon buildings in developed countries has gradually increased over time, while there is no significant movement in developing countries.

Keywords. Energy, Carbon Reduction, Low Energy/Carbon Buildings, Constraints For Low Energy/Carbon Buildings, Sustainability

1. Introduction

Climate change and resource scarcity have increased the awareness of sustainable practices worldwide during the past two decades (Pérez-Navarro et al., 2023). With the rapid development of industrialization and urbanization, the world has been shifting towards low-energy/carbon buildings over the last few years (Hafez et al., 2023). Since one-third of global greenhouse gas (GHG) emissions and one-third of energy consumption are accounted for by buildings, the building sector is one of the main targeted industries to reduce greenhouse gas emissions and energy consumption (Dino & Meral Akgül, 2019). The buildings cause negative impacts on the environment during different stages in their life cycle, such as the processing of raw materials, transportation of raw materials, construction, operation and maintenance, and demolition (Zou & Couani, 2012). In addition to that, global GHG emissions and energy consumption are increasing continuously due to higher population growth rates, changes in lifestyles and increasing building stocks (Urge-Vorsatz et al., 2013). This continued increase in energy consumption has affected the global temperature increase, leading to severe climate changes in future (McCarthy et al., 2010). In addition to that, international organizations related to energy/ carbon such as the International Energy Agency [IEA], Regulatory Indicators for Sustainable Energy [RISE], and the findings of much research have emphasized the impact of the rapid increase of energy demand and carbon emissions from building construction industry and existing building stocks.

Many scholars have emphasized that low-energy/carbon buildings are the more significant and highly supportive strategy for achieving environmental sustainability goals in the building industry (Isiadinso et al., 2011; Li et al., 2023; Sartori & Hestnes, 2007). Low-energy carbon buildings can be interpreted as buildings which have low GHG emissions and less energy consumption using energy efficiency improvement measures throughout their lifecycle (Li et al., 2023). Low-energy/ carbon buildings aim to reduce carbon emission and energy consumption in different stages of the building life cycle, such as planning, designing, construction, operation, demolition and recycling (Sartori & Hestnes, 2007). Currently, building floor area is rapidly increasing globally due to the higher growth rate of the population. However, most countries are trying to reduce the carbon emissions and energy consumption of new constructions and existing

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building stock through various macro-level and micro-level carbon reduction and energy-saving initiatives (Pan & Ning, 2015). Further, accepting the adverse impact of rapid urbanization, the entire world is taking action to shift urban areas towards low-carbon cities (Ng et al., 2013).

Nevertheless, a significant reduction in carbon emissions and energy consumption cannot be seen despite several efforts taken. It is also important to note that delivery and development of low energy/ carbon buildings require advanced technologies in construction and building operation, sustainable building materials, reliable simulation analysis, complex architectural designs, strong policy support, consumer acceptance, higher capital, proper supply chain, skilled labour, proper awareness, education and training, etc…Therefore, delivering low energy/ carbon buildings have become challenging than that of conventional buildings (Olanipekun et al., 2017). This emphasises that there may be multiple constraints which hinder the development and delivery of low-energy/ carbon buildings. There may be several factors, obstacles and conditions that reduce the effectiveness of the delivery of low-energy/ carbon building projects and adaptation strategies (Huang et al., 2018). Several studies reveal that the approach of moving towards low-carbon buildings has been retarded due to several socio-technical factors, rather than solely social Barriers or solely technical barriers. According to Osmani & O'Reilly (2009), challenges to the delivery of low-carbon buildings can mainly be identified under legislative, cultural, financial and technological factors.

However, Zou et al. (2018) identified the availability of previous pilot projects, demand in the construction market for low-carbon buildings, construction technologies, support from the government, awareness, knowledge and training regarding sustainable practices as the factors which hinder the development and the delivery of low-carbon buildings. From a financial perspective, Baek & Park (2012) discussed that higher capital costs for low energy/ carbon buildings and prolonged payback periods for the initial investment adversely affect investment decisions in the low energy/carbon buildings. When considering the financial risk associated with low-carbon/energy buildings, the cost of projects is highly uncertain and therefore, it is unpredictable in the long-term and medium-term. Chan & Grace (2006) identified that the lack of financial incentives for low-energy/ carbon projects is another main constraint. Lack of public awareness and knowledge regarding carbon emission and energy consumption, and high-energy-consuming lifestyles have been identified as social barriers by Afshari et al. (2016). Liu et al. (2010) identified four major problems in low-carbon building projects, such as a lack of social participation, a lack of regulatory support and mechanisms, and a lack of low-carbon techniques and funding sources. In addition to that, the behaviours of the occupants, cultural backgrounds, and consumer choices directly affect the effectiveness of low-carbon building projects. Zhang & Wang (2013) emphasise that different types of legal, administrative, financial, non-governmental and social factors restrict the implementation and promotion of low-carbon buildings in the construction industry. Moreover, lack of information, lack of required skills and geographical barriers are some of the issues identified to reduce the effectiveness of law carbon building projects (Du et al., 2014; Rock et al., 2019).

Even though several studies have been conducted to outline barriers to the implementation of low energy/ carbon buildings, there is no proper systematic review to explore all the barriers in different dimensions. Since there is a growing trend towards low-energy/ carbon buildings, it is important to ensure that these projects are delivered more efficiently and effectively. Therefore, identification of constraints is essential for academics and professional practitioners to set strategies to overcome these constraints in planning and implementing low-energy/carbon building projects. To contribute to fulfilling this requirement, this study aimed to identify and categorize the constraints to delivering low energy/ carbon buildings through a systematic literature review of published journal papers from 2001 to 2024. This paper presents the list of the constraints and categorization of the constraints to delivering low-carbon buildings.

2. Review methods

Peer-reviewed journal papers were reviewed to conduct the systematic review to explore the previous publications to identify the constraints affecting the delivery of low energy/ carbon buildings. According to Pickering & Byrne (2014), a systematic review differs from a traditional literature review which involves a small and often incomplete number of publications because a systematic review involves a stand-alone piece of research that explores the existing knowledge in the field and provides insights into quite specific areas.

The steps which were outlined by Hu et al., (2013) and Moher et al., (2009) Were used to present this study and to conduct the intended review. Related papers were identified through one of the most popular and comprehensive databases which is called the 'Web of Science' electronic publications repository. "(Barriers OR Constraints OR Challenges) AND (Energy OR Carbon) AND (Buildings OR Building)" are the keywords used for the database search. The articles were searched by its title and the journal articles which were published from 2001 to 2024 were considered for the study. Only the published articles in journals were considered to ensure the quality. Book reviews, editorials, and papers for conference proceedings were excluded from the review. After applying the above search strategy, 220 publications were found in the database. After the manual screening, 115 publications were utilized to explore the constraints of delivering low energy. The data retrieval process from the selected journal articles was conducted using a manual data extraction approach by carefully reviewing each article and manually recording relevant data in an Excel spreadsheet. Finally, collected data were manually analyzed to identify identical constraints and to categorize them accordingly.

3. Results and Analysis

This section presents the overview of the review of the 220 reviewed articles through the keyword search as mentioned in the methodology. Even though 220 articles were received by the keyword search, 34 publications were removed from that list after the abstract screening. Further, 8 articles were removed from the list after assessing the full text for eligibility. In addition to that, 11 articles were removed due to issues in retrieving full-text articles. Finally, 167 publications were reviewed for this study. Among them only 115 papers were used to identify the constraints that hinder the delivery of low energy/ carbon buildings. The primary target of this section is to present the trend of the publications and highlight the identified constraints that hinder the delivery of low energy/ carbon buildings and time series analysis of the identified constraints. Figure 1 shows the article retrieving process.

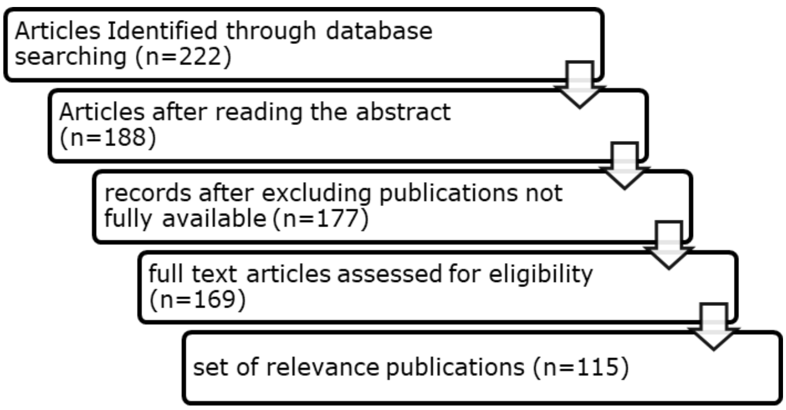

Figure 1: Article retrieving process

3.1 TRENDS OF PUBLICATIONS

Throughout the past 25 years, a notable increase can be seen in published studies on low-energy/ carbon buildings. The evolution was started in 2012 and gradually increased thereafter. A little attention has been given by scholars to studies related to low energy/ carbon buildings during the years 2001-2011. Accepting the rapid urbanization, increasing building stocks and associated climate changes, more countries have started to focus on decarbonization in the built environment over the past two decades. The amount of research on exploring the constraints hasincreased in line with the escalation of global commitments to delivering low-energy/carbon buildings. Figure 2 shows the number of publications related to low-energy/carbon buildings over the last 25 years.

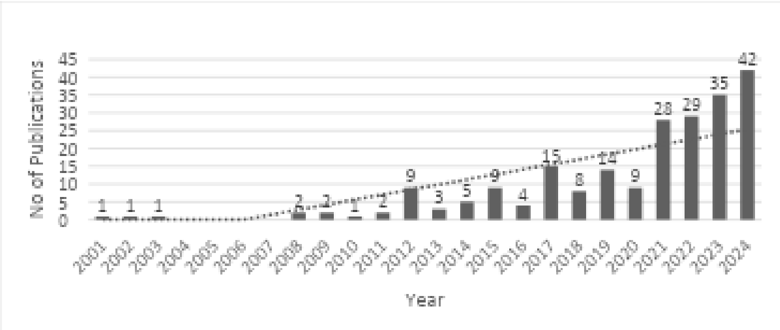

Figure 2: Number of publications from 2021 to 2024

When considering the geographical distribution of the papers, publications have been spread all over the world. Figure 03 shows the geographical distribution of articles.

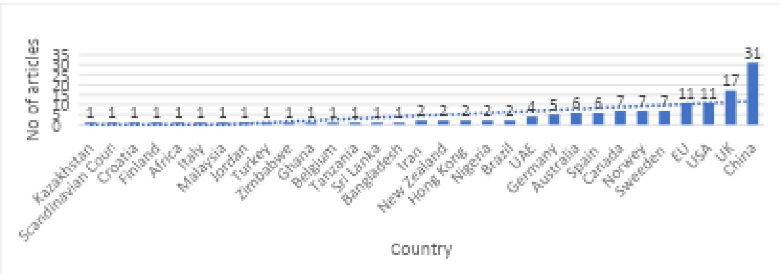

Figure 3: No of papers published in different countries

Accordingly, China and the UK had 31 and 17 articles respectively. The USA and European region had 8 publications each, Canada, Sweeden and Norway had 7 publications each, Australia and Spain had 6 publications each, Germany had 5 publications, UAE had 4 publications, Iran, New Zealand, Hong Kong, Nigeria, and Brazil had 2 publications, and remaining countries had 1 publication focusing on specifically exploring the constraints to delivering low carbon and low energy buildings. This highlights that the attention towards delivering low-carbon buildings has gradually increased over time in economically developed countries. Most of the developed countries have proactively planned to include carbon emission reduction and energy-saving initiatives in their future action plans to reduce the adverse impact on the environment. Hence there could be more concern about researching potential constraints to implement the planned initiatives aiming to achieve the intended sustainability development goals in those countries by overcoming the prevailing issues. However, there were few publications from developing countries highlighting their backward approach to delivering low-energy/ carbon buildings. Most of the developing countries focus on economic prosperity and enhancing sociological aspects, thereby most of the time environmental aspects are deprioritized neglecting the opportunities to pursue sustainability and overcome the climate change issue (Khosla et al., 2017). However, numerous socio-technical constraints can be identified in developing countries which restrict the effective uptake of delivering low-energy/ carbon buildings due to regulatory barriers, unstable economic conditions, and low levels of technical adaptation (F. Liu et al., 2010). Therefore, constraints in delivering low/carbon energy buildings in developing countries would be beneficial for rapid uptake of implementing suitability initiatives while achieving economic prosperity to overcome climate change issues.

In addition to the aforementioned trends, a brief emphasis on the productive journals in this specific area will be beneficial for future researchers to focus and explore more on the related publications. A total of 115 journals have contributed to this particular research area of identifying the constraints to delivering low-energy/carbon buildings. Among these journals, 'Energy and Buildings', 'Buildings', 'Energies', and 'Sustainability' had 13, 12, 11 and 8 publications respectively. 'Building and environment', and 'Energy policy' had 7 publications each while 'Journal of Cleaner Production' and 'Energy' had 6 publications each. 'Sustainable cities and society accounted for 5 publications each while 'Building research and information' had 3 publications under this specific topic. These journals can be identified as the most productive journals in this area. All the other journals had 2 or 1 publications under their names.

4. Discussion

According to the geographical distribution of the identified 115 papers, China has published the highest number of papers accounting for 31 publications followed by the UK had 17 publications. European countries had 25 publications while Scandinavian countries had 23 publications including, Norway, Sweden and Canada. In addition to that, the USA had 11 publications. It is noteworthy that 85.40% of the publications originated from developed countries with stable economies. It highlights that higher consideration for sustainability practices by delivering low-energy/carbon buildings can be seen in developed countries. A few numbers of publications have been published in developing countries highlighting their backward uptake of delivering low-energy/ carbon buildings. Only 20 papers among the identified papers originated from developing countries (India, Malaysia, West Indies, Sri Lanka, Bangladesh, Tanzania, Iran, Nigeria, Zimbabwe, Kazakhstan and Thailand). This implies the slow uptake in delivering low-energy/ carbon buildings in developing countries.

The total floor area of buildings in developing countries is rapidly growing in developing countries. More than 3 billion m^2, the majority being from the developing countries were built in 2018 with neither governing /oversight policies, nor mandatory energy and carbon performance requirements (IEA, 2019). This critical situation is a sign of very slow energy and carbon policy progress, demonstrating that the evolution of building energy usage and carbon emission reduction initiatives in particular is not keeping up with the rapid growth in developing countries (Madhusanka et al., 2020). Nevertheless, sufficient attention from scholars was not evident in doing research focusing on the contexts of developing countries. Therefore, there is a timely research requirement to explore the constraints which hinder the development and delivery of low-energy/carbon buildings in the contexts of developing countries and to determine feasible strategies to overcome these constraints.

Considering the publication years, most of the publications (136 papers) were published during the years 2020-2024. Articles published in early years from 2001-2012 focus on constraints related to more generic aspects such as green buildings, sustainable buildings, policy-related issues, organizational issues etc. However, in recent years research on more specific and low energy/ carbon focus has been published. Along with that, more scholars have focused on identifying the barriers, challenges, constraints, issues and obstacles in life cycle carbon emission, adaptation of technology, energy/ carbon calculations and information management in energy/ carbon reduction programs. In addition to that, in recent publications, many researchers have studied more net zero energy/ carbon buildings focusing on different perspectives. Therefore, according to the review findings, research had been started with a broad area and gradually it has broken into more specific areas.

4.1 LIST OF CONSTRAINTS IDENTIFIED THROUGH LITERATURE REVIEW

Constraints to deliver low energy/carbon buildings were extracted after examining the content of the 115 screened papers (out of 220) from the literature search. The final and summarized list of 92 constraints under 9 categories is indicated in Figure 5 below. Constraint categories were also determined through the literature review. Different literatures had covered different categories and after retrieving data from each article, 9 different constraint categories were identified. When there was no indication of the category of a particular constraint, the most suitable one was selected from the identified list of categories and grouped accordingly.

Among the above-identified constraints, policy-related constraints, economic-related constraints, knowledge-related constraints, and technology-related constraints are the most highlighted categories of constraints. Accordingly, most scholars have proven that the overall progress and delivery of low-energy/ carbon buildings are significantly affected by these constraints. According to Yeatts et al., (2017) and Kangas et al., (2018) most of the micro-level constraints come under those categories. Concerning the present study, the radar chart (Figure 5) shows the number of studies which reported the constraints under each category, as well as the number of specific constraints reported under each category. Most scholars have paid attention to financial constraints, policy-related constraints, technical constraints, knowledge, skills and awareness-related constraints. Accordingly, 74 studies have reported from the financial area of constraints, 65 studies on policy-related constraints, 61 studies from knowledge, skills and awareness-related constraints, and 55 studies focused on technology-related constraints. Figure 04 shows the number of studies that have been conducted under each category of constraints.

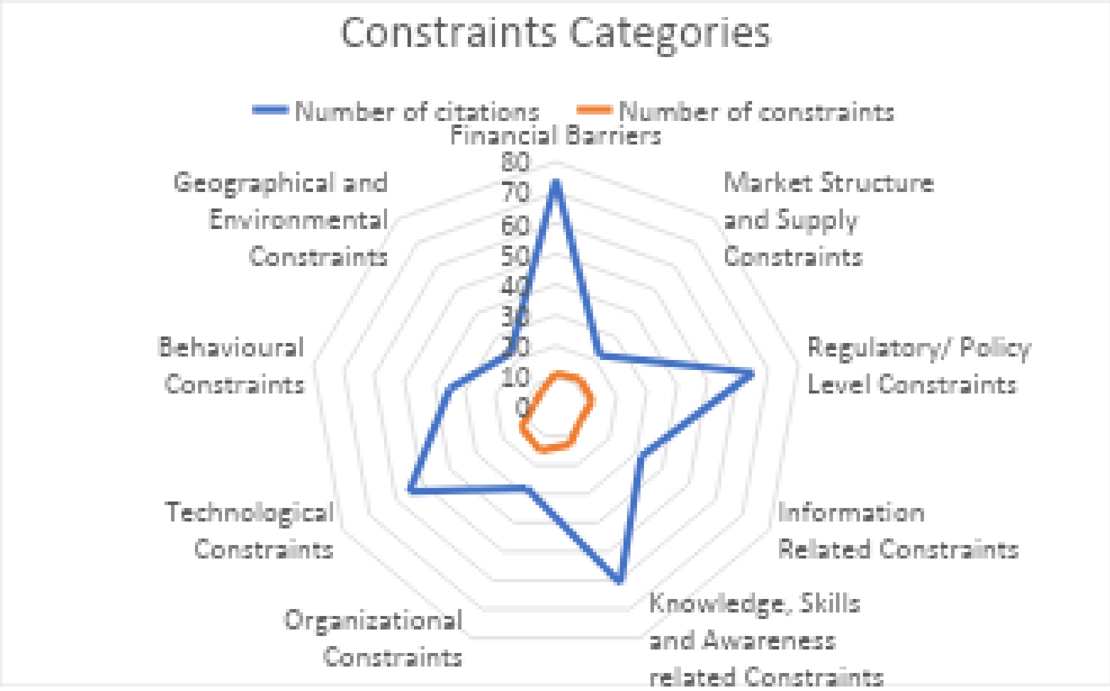

Figure 4: Constraint categories

Figure 5 shows the illustration of all the identified constraints under each category.

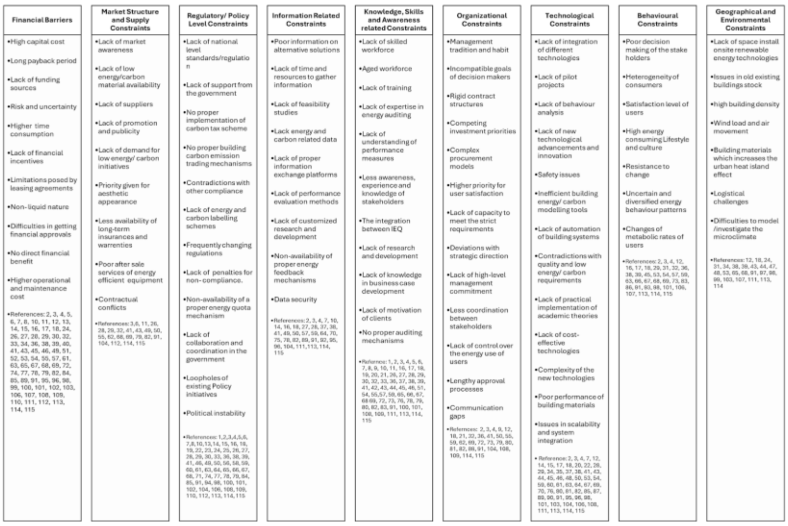

Figure 5: List of constraints identified through the systematic review

List of citations for the respective numbers of publications:

1- (Cattano et al., 2013), 2- (Afshari et al., 2016), 3- (Zhang and Wang, 2013), 4-(Du et al., 2014), 5- (Sudhakara Reddy, 2013), 6-(Baek and Park, 2012), 7-(Wang et al., 2016), 8-(Tuominen et al., 2012), 9-(Gerrish et al., 2017), 10-(Persson and Grönkvist, 2015), 11-(Olazabal and Pascual, 2015), 12-(Bertone et al., 2018), 13-(Andrić et al., 2019), 14-(Zhang et al., 2012), 15- (Abdellah and Masrom, 2018), 16-(Cherrafi et al., 2017), 17-(Iwaro and Mwasha, 2010), 18-(Rock et al., 2019), 19- (Biekša et al., 2011), 20-(Ucci and Yu, 2014), 21-(Jiang and Tovey, 2010), 22-(Attia et al., 2017), 23- (Thollander et al., 2016), 24- (Williams and Dair, 2007), 25-(Pitts, 2017), 26-(Shen et al., 2018), 27-(Häkkinen and Belloni, 2011), 28- (Li et al., 2019), 29- (Zhang et al., 2017), 30- (Nižetić, 2016), 31-(Oregi et al., 2015), 32-(Ng et al., 2013), 33-(Paiho and Ahvenniemi, 2017), 34- (Dadzie et al., 2018), 35-(Geissler et al., 2019), 36-(Kangas et al., 2018), 37-(Pan et al., 2019), 38-(Yeatts et al., 2017), 39-(Alam et al., 2019), 40-(Szumilo and Fuerst, 2017), 41-(Gupta et al., 2017), 42-(Yu et al., 2016), 43-(Masrom et al., 2017), 44-(Yu et al., 2015), 45-(Cagno et al., 2014), 46-(Vogel et al., 2015), 47- (Xing et al., 2018), 48-(Zhao et al., 2015), 49-(Palm & Bryngelson, 2023), 50-(Prieto et al., 2024), 51-(Pérez-Navarro et al., 2023), 52-(Kazemi & Kazemi, 2022), 53-(Carvajal Quintero, 2022), 54- (Carvajal Quintero, 2022), 55-(Khafiso et al., 2024), 56-(Cabeza et al., 2021), 57-(Y. Chen et al., 2022), 58-(Formolli et al., 2021), 59-(Madhusanka et al., 2022), 60-(Huang et al., 2023), 61-(Ohene et al., 2022), 62-(Cerić & Ivić, 2023), 63-(X. Chen et al., 2024), 64-(Xi & Cao, 2022), 65-(Brown et al., 2024), 66-(Liu et al., 2023), 67-(Bui et al., 2023), 68-(Pan & Pan, 2021), 69- (Antoniou & Mageiropoulos, 2024), 70-(Ala-juusela et al., 2021), 71-(Gluckman & Bardsley, 2022), 72-(Mustaffa & Kudus, 2022), 73-(Unuigbe et al., 2023), 74-(Rauniyar et al., 2024), 75-(Himeur et al., 2021), 76-(Moudgil et al., 2023), 77-(Attia et al., 2022), 78-(Ghasemi et al., 2024), 79-(Jaradat et al., 2024), 80-(Lane et al., 2024), 81-(Le Dréau et al., 2023), 82-(Blomqvist et al., 2022), 83-(Kazemi & Udall, 2023), 84-(Cristino et al., 2021), 85-(Mapfumo et al., 2024), 86-(Banfi et al., 2024), 87-(Nair et al., 2022), 88-(Vimal et al., 2022), 89-(Carlander & Thollander, 2023), 90-(Osuizugbo et al., 2024), 91-(Kumaraswamy et al., 2023), 92-(Kamel, 2022), 93-(Simó-Solsona et al., 2021), 94-(Alabid et al., 2022), 95-(Poyyamozhi et al., 2024), 96-(Mir et al., 2021), 97-(Zahir et al., 2023), 98-(Akbarinejad et al., 2023), 99-(Gabrielli et al., 2023), 100-(Ohene et al., 2023), 101-(Keser & Kerestecioğlu, 2024), 102-(Rostami & Heravi, 2022), 103-(Cielo & Subiantoro, 2021), 104-(Cielo & Subiantoro, 2021), 105-(Albrecht & Hamels, 2021), 106-(Noh et al., 2024), 107-(Taylor et al., 2021), 108-(Gajaba & Dissanayake, 2024), 109-(Xiaoxiang et al., 2024), 110-(Chen et al., 2024), 111-(Hafez et al., 2023), 112-(Gholami et al., 2021), 113-(Siddique et al., 2021), 114-(Lassandro et al., 2024), 115-(Imran Khan et al., 2024)

The absence of mandatory standards at the national level and lack of regulations for carbon emission reduction and energy management in buildings have been identified as key policy and regulatory constraints caused by mitigation of the adaptation of low energy/ carbon initiatives (Afshari et al., 2016). The lack of incentives from the government and financial institutions for the owners and the investors of low-energy/ carbon projects has reduced the motivation of those parties to adopt the low-energy/ carbon initiatives (Andrić et al., 2019).

The high initial cost is another significant factor that hinders the delivery of low-energy/ carbon buildings, and it has been highlighted by several authors. Therefore, investors do not tend to invest in low carbon/ energy projects due to uncertainty of the return on investment for their investment (Andrić et al., 2019; Du et al., 2014). In addition to the high capital cost, varied expenses, different responsibilities and time taken to low energy/ carbon compliance, documentation and reporting cost, high operational and maintenance cost of low carbon emissioning and energy saving equipment, labour cost and expenses for experts to consult on the implementation and management of low energy/ carbon buildings are some of most highlighted expenses that hinder the delivery of low energy/ carbon buildings (Shen et al., 2018; Wang et al., 2016).

In addition to that, the absence of technical advancements and innovations for convenient operation and implementation of low-energy/ carbon buildings is another significant barrier that has been identified by many researchers (Gupta et al., 2017; Vogel et al., 2015). The lack of production technologies to produce products cost-effectively has caused the unavailability of low-energy/ carbon products in the market. In addition to that, the complexity of technologies to install energy-efficient equipment and the incompatibility with other technologies restrict the opportunities to implement low-energy/ carbon buildings (Masrom et al., 2017; Rock et al., 2019).

Lack of customized research and inability to effectively transfer the research outputs into practical scenarios are some of the reasons for slowing down the adaptation of low energy/

carbon initiatives and reducing the effectiveness of implemented projects (Vogel et al., 2015). Lack of knowledge, awareness and expertise of the project management and facilities management professionals in this area is another significant issue which hinders the delivery of low energy/ carbon buildings. Due to a lack of technical understanding of low energy/ carbon initiatives, many projects lose the opportunity to adapt these sustainable practices (Du et al., 2014; Wang et al., 2016; Yeatts et al., 2017). Lack of training and knowledge-sharing programs restricted industry professionals from improving the skills required to work with low-energy/ carbon buildings (Afshari et al., 2016). Due to the lack of collaborative design practices, industry professionals have reduced the chance to share the knowledge and experience of these technologies (Häkkinen & Belloni, 2011).

According to the findings of the study, constraints to deliver low-energy/ carbon buildings vary with the economic condition of the country. Many scholars highlighted that lack of finance to invest in low energy/ carbon projects, outdated laws and regulations and unavailability of raw materials to implement energy efficient programs as challenges to achieving energy efficiency in buildings in developing countries (Gajaba & Dissanayake, 2024; Mapfumo et al., 2024). In addition to that, a lack of access and awareness related to technological integration and innovation has restricted the delivery of energy-efficient initiatives in developing countries (Osuizugbo et al., 2024). However, low electricity costs, split incentives, lack of standard procedures, conservatism in the industry and lack of information have been identified by scholars as challenges to implementing low energy/ carbon initiatives in developed countries (Palm & Bryngelson, 2023).

During the early years from 2001 to 2012, there were no significant studies that have been conducted on low-energy/ carbon buildings. In that period, the lack of awareness of the stakeholders on environmental sustainability, knowledge barriers and lack of research are the most highlighted challenges between 2001 and 2012 (Williams & Dair, 2007). Lack of finance, regulatory constraints and challenges related to market structure and the supply chain are the most identified challenges during 2013-2015 (2013; Du et al., 2014; Zhang & Wang, 2013). Organizational constraints such as lack of coordination and alignment of strategic goals with sustainable goals, behavioural challenges, and higher expectations of the building occupants have highly identified constraints during 2015-2020 (Gupta et al., 2017; Masrom et al., 2017). However, informational barriers such as data security, unavailability of reliable information, technological barriers such as lack of cost-effective technologies and lack of compatibility of different building systems with new energy-efficient systems can be identified during 2021-2024 (Lassandro et al., 2024; Siddique et al., 2021).

5. Conclusion

In recent years, low-energy/ carbon buildings have gained considerable attention worldwide as a more effective solution to reduce energy consumption and carbon emissions. However, a systematic review on identifying constraints in delivering low-energy/carbon buildings is still lacking. Therefore, this paper aimed to review relevant journal publications from 2001 to 2024 and identify the constraints in delivering low-energy/ carbon buildings.

Primarily 220 papers published in journals were identified and after the screening process, 115 papers were selected for the review. Among them, 95 papers were from economically developed countries while only 20 papers were from developing countries highlighting the greater focus of developed countries to deliver low energy/carbon buildings to achieve sustainable development goals. After reviewing papers, 92 constraints were identified under 9 categories such as financial, market and supply constraints, policy and regulatory, knowledge, skills and awareness related, technical, information related, organizational, behavioural, geographical and environmental related constraints. In recent years more research has been conducted on advancement in technology and innovation, system integration in low energy/ carbon buildings, net zero energy buildings and information management in energy management systems.

Policy and regulatory impact assessment and development of a context-specific strategical framework to overcome the identified issues are suggested as future research directions. Moreover, the provided list of constraints will be useful for relevant stakeholders such as policymakers, managers, government institutions and so on to implement strategies to overcome the constraints to promote low energy/ carbon buildings.

6. References

Afshari, H., Issa, M. H., & Radwan, A. (2016). Using failure mode and effects analysis to evaluate barriers to the greening of existing buildings using the Leadership in Energy and Environmental Design rating system. *Journal of Cleaner Production*, *127*, 195–203. https://doi.org/10.1016/J.JCLEPRO.2016.03.140

Andrić, I., Koc, M., & Al-Ghamdi, S. G. (2019). A review of climate change implications for built environment: Impacts, mitigation measures and associated challenges in developed and developing countries. *Journal of Cleaner Production*, *211*, 83–102. https://doi.org/10.1016/J.JCLEPRO.2018.11.128

Baek, C., & Park, S. (2012). Policy measures to overcome barriers to energy renovation of existing buildings. *Renewable and Sustainable Energy Reviews*, *16*(6), 3939–3947. https://doi.org/10.1016/J.RSER.2012.03.046

https://doi.org/10.1080/15623599.2022.2110642

Chan, H. W. E., & Grace, L. K. L. (2006). *Design-led sustainable urban renewal approach for Hong Kong*. https://hkapi.lib.cuhk.edu.hk/handle/msO8s77aBT/17933

Dino, I. G., & Meral Akgül, C. (2019). Impact of climate change on the existing residential building stock in Turkey: An analysis on energy use, greenhouse gas emissions and occupant comfort. *Renewable Energy*, *141*, 828–846. https://doi.org/10.1016/j.renene.2019.03.150

Du, P., Zheng, L. Q., Xie, B. C., & Mahalingam, A. (2014). Barriers to the adoption of energy-saving technologies in the building sector: A survey study of Jing-jin-tang, China. *Energy Policy*, *75*, 206–216. https://doi.org/10.1016/J.ENPOL.2014.09.025

Gajaba, P. A. P. Y., & Dissanayake, D. M. P. P. (2024). Barriers to implement energy efficiency strategies to heating, ventilation, air conditioning of airside system in commercial buildings in Sri Lanka. *International Journal of Construction Management*. https://doi.org/10.1080/15623599.2024.2417627

Gupta, P., Anand, S., & Gupta, H. (2017). Developing a roadmap to overcome barriers to energy efficiency in buildings using best worst method. *Sustainable Cities and Society*, *31*, 244–259. https://doi.org/10.1016/J.SCS.2017.02.005

Hafez, F. S., Sa'di, B., Safa-Gamal, M., Taufiq-Yap, Y. H., Alrifaey, M., Seyedmahmoudian, M., Stojcevski, A., Horan, B., & Mekhilef, S. (2023). Energy Efficiency in Sustainable Buildings: A Systematic Review with Taxonomy, Challenges, Motivations, Methodological Aspects, Recommendations, and Pathways for Future Research. *Energy Strategy Reviews*, *45*. https://doi.org/10.1016/J.ESR.2022.101013

Häkkinen, T., & Belloni, K. (2011). Barriers and drivers for sustainable building. *Building Research & Information*, *39*(3), 239–255. https://doi.org/10.1080/09613218.2011.561948

Hu, Y., Chan, A. P. C., Le, Y., & Jin, R. (2013). From Construction Megaproject Management to Complex Project Management: Bibliographic Analysis. *Journal of Management in Engineering*, *31*(4), 04014052. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000254

Huang, N., Bai, L., Wang, H., Du, Q., Shao, L., & Li, J. (2018). Social Network Analysis of Factors Influencing Green Building Development in China. *International Journal of Environmental Research and Public Health 2018, Vol. 15, Page 2684*, *15*(12), 2684. https://doi.org/10.3390/IJERPH15122684

Isiadinso, C., Goodhew, S., Marsh, J., & Hoxley, M. (2011). Identifying an appropriate approach to judge low carbon buildings. *Structural Survey*, *29*(5), 436–446. https://doi.org/10.1108/02630801111182457

Kangas, H. L., Lazarevic, D., & Kivimaa, P. (2018). Technical skills, disinterest and non-functional regulation: Barriers to building energy efficiency in Finland viewed by energy service companies. *Energy Policy*, *114*, 63–76. https://doi.org/10.1016/J.ENPOL.2017.11.060

Khosla, R., Sagar, A., & Mathur, A. (2017). Deploying Low-carbon Technologies in Developing Countries: A view from India's buildings sector. *Environmental Policy and Governance*, *27*(2), 149–162. https://doi.org/10.1002/EET.1750

Lassandro, P., Devitofrancesco, A., Bellazzi, A., Cascardi, A., De Aloysio, G., Laghi, L., & Malvezzi, R. (2024). Facing the Constraints to the Deep Energy Renovation Process of Residential Built Stock in European Markets. *Sustainability (Switzerland)*, *16*(1). https://doi.org/10.3390/SU16010294

Li, Y., Li, S., Xia, S., Li, B., Zhang, X., Wang, B., Ye, T., & Zheng, W. (2023). A Review on the Policy, Technology and Evaluation Method of Low-Carbon Buildings and Communities. In *Energies* (Vol. 16, Issue 4). MDPI. https://doi.org/10.3390/en16041773

Liu, F., Meyer, A. S., & Hogan, J. F. (2010). *Mainstreaming Building Energy Efficiency Codes in Developing Countries : Global Experiences and Lessons from Early Adopters*. https://doi.org/10.1596/978-0-8213-8534-0

Madhusanka, N., Pan, W., & Kumaraswamy, M. (2020). Social Network Analysis of Building Energy and Carbon Policy Networks in Developing Countries. *IOP Conference Series: Earth and Environmental Science*, *588*(2), 022004. https://doi.org/10.1088/1755-1315/588/2/022004

Mapfumo, E. T., Emuze, F., Smallwood, J., & Ebekozien, A. (2024). Appraising challenges facing Zimbabwe's building retrofitting for energy efficiency using structural equation model approach. *International Journal of Building Pathology and Adaptation*, *42*(7), 76–92. https://doi.org/10.1108/IJBPA-05-2024-0105

Masrom, M. A. N., Rahim, M. H. I. A., Ann, S. C., Mohamed, S., & Goh, K. C. (2017). A Preliminary Exploration of the Barriers of Sustainable Refurbishment for Commercial Building Projects in Malaysia. *Procedia Engineering*, *180*, 1363–1371. https://doi.org/10.1016/J.PROENG.2017.04.299

McCarthy, M. P., Best, M. J., & Betts, R. A. (2010). Climate change in cities due to global warming and urban effects. *Geophysical Research Letters*, *37*(9). https://doi.org/10.1029/2010GL042845

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J. A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J. J., Devereaux, P. J., Dickersin, K., Egger, M., Ernst, E., Gøtzsche, P. C., … Tugwell, P. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Annals of Internal Medicine*, *151*(4), 264–269. https://doi.org/10.7326/0003-4819-151-4-200908180-00135/SUPPL_FILE/PRISMA_FIGURE-S1.DOC

Ng, S. T., Skitmore, M., & Cheung, J. N. H. (2013). Organisational obstacles to reducing carbon emissions in Hong Kong. *Habitat International*, *40*, 119–126. https://doi.org/10.1016/J.HABITATINT.2013.03.004

Olanipekun, A. O., Xia, B. (Paul), Hon, C., & Hu, Y. (2017). Project Owners' Motivation for Delivering Green Building Projects. *Journal of Construction Engineering and Management*, *143*(9). https://doi.org/10.1061/(asce)co.1943-7862.0001363

Osmani, M., & O'Reilly, A. (2009). Feasibility of zero carbon homes in England by 2016: A house builder's perspective. *Building and Environment*, *44*(9), 1917–1924. https://doi.org/10.1016/J.BUILDENV.2009.01.005

Osuizugbo, I. C., Orekan, A. A., Omer, M. M., & Simon, R. F. (2024). An exploratory factor analysis on technological-related barriers to the construction of zero-energy buildings in Nigeria. *International Journal of Building Pathology and Adaptation*. https://doi.org/10.1108/IJBPA-05-2024-0091

Palm, J., & Bryngelson, E. (2023). Energy efficiency at building sites: barriers and drivers. *Energy Efficiency*, *16*(2). https://doi.org/10.1007/S12053-023-10088-7

Pérez-Navarro, J., Bueso, M. C., & Vázquez, G. (2023). Drivers of and Barriers to Energy Renovation in Residential Buildings in Spain—The Challenge of Next Generation EU Funds for Existing Buildings. *Buildings*, *13*(7). https://doi.org/10.3390/BUILDINGS13071817

Pickering, C., & Byrne, J. (2014). The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. *Higher Education Research & Development*, *33*(3), 534–548. https://doi.org/10.1080/07294360.2013.841651

Rock, S., Hosseini, M. R., Nikmehr, B., Martek, I., Abrishami, S., & Durdyev, S. (2019). Barriers to "green operation" of commercial office buildings: Perspectives of Australian facilities managers. *Facilities*, *37*(13–14), 1048–1065. https://doi.org/10.1108/F-08-2018-0101/FULL/XML

Sartori, I., & Hestnes, A. G. (2007). Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and Buildings*, *39*(3), 249–257. https://doi.org/10.1016/J.ENBUILD.2006.07.001

Shen, W., Tang, W., Siripanan, A., Lei, Z., Duffield, C. F., & Peng Hui, F. K. (2018). Understanding the Green Technical Capabilities and Barriers to Green Buildings in Developing Countries: A Case Study of Thailand. *Sustainability 2018, Vol. 10, Page 3585*, *10*(10), 3585. https://doi.org/10.3390/SU10103585

Siddique, A. H., Tasnim, S., Shahriyar, F., Hasan, M., & Rashid, K. (2021). *Renewable Energy Sector in Bangladesh: The Current Scenario, Challenges and the Role of IoT in Building a Smart Distribution Grid*. https://doi.org/10.3390/en14165083

Urge-Vorsatz, D., Petrichenko, K., Staniec, M., & Eom, J. (2013). Energy use in buildings in a long-term perspective. In *Current Opinion in Environmental Sustainability* (Vol. 5, Issue 2, pp. 141–151). https://doi.org/10.1016/j.cosust.2013.05.004

Vogel, J. A., Lundqvist, P., & Arias, J. (2015). Categorizing Barriers to Energy Efficiency in Buildings. *Energy Procedia*, *75*, 2839–2845. https://doi.org/10.1016/J.EGYPRO.2015.07.568

Wang, T., Li, X., Liao, P. C., & Fang, D. (2016). Building energy efficiency for public hospitals and healthcare facilities in China: Barriers and drivers. *Energy*, *103*, 588–597. https://doi.org/10.1016/J.ENERGY.2016.03.039

Williams, K., & Dair, C. (2007). What is stopping sustainable building in England? Barriers experienced by stakeholders in delivering sustainable developments. *Sustainable Development*, *15*(3), 135–147. https://doi.org/10.1002/SD.308

Yeatts, D. E., Auden, D., Cooksey, C., & Chen, C. F. (2017). A systematic review of strategies for overcoming the barriers to energy-efficient technologies in buildings. *Energy Research & Social Science*, *32*, 76–85. https://doi.org/10.1016/J.ERSS.2017.03.010

Zhang, Y., & Wang, Y. (2013). Barriers' and policies' analysis of China's building energy efficiency. *Energy Policy*, *62*, 768–773. https://doi.org/10.1016/J.ENPOL.2013.06.128

Zou, P. X. W., & Couani, P. (2012). Managing risks in green building supply chain. *Architectural Engineering and Design Management*, *8*(2), 143–158. https://doi.org/10.1080/17452007.2012.659507

Zou, P. X. W., Xu, X., Sanjayan, J., & Wang, J. (2018). Review of 10 years research on building energy performance gap: Life-cycle and stakeholder perspectives. *Energy and Buildings*, *178*, 165–181. https://doi.org/10.1016/J.ENBUILD.2018.08.040