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Systematic Literature Review of Sustainable Construction Projects for Carbon Neutrality

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Abstract: - Construction projects are responsible for significant carbon emissions, accounting for 23% of the world's total emissions. While efforts have been made to reduce these emissions, a comprehensive analysis of these efforts has yet to be conducted, making it difficult to identify research gaps and future directions. This study addresses this gap by conducting a systematic literature review of 208 papers in the Web of Science (WOS) database using Carbon, Emission, and Construction as keywords. The review was categorized into bibliometric and content analysis. The bibliometric analysis reveals that most papers focus on estimating and assessing carbon emissions through Life Cycle Assessment (LCA) (34%). The use of construction technologies, such as prefabrication and BIM, which can directly reduce carbon emissions, was limited to only 7% of the reviewed papers. Furthermore, the review revealed that 67% of the studies were conducted in China. Similarly, content analysis revealed the papers' essential findings and limitations in each selected category. Based on these findings, the study 1) suggests the technology applications in tacking, estimating and reducing carbon emissions in the construction supply chain (CSC) and 2) highlights the need for global attention to reducing carbon emissions in construction projects.

Keywords: Construction, Carbon Emissions, Sustainability, Literature Reviews, Technology

1. INTRODUCTION

Global warming is one of humanity's biggest challenges, and the increase in carbon emissions is one of the major causes of global warming [1,2]. The construction industry is a significant source of carbon emissions, accounting for approximately 20% of global energy consumption. It has incrementally increased its carbon emissions to one-third of the global total [2,3]. This rise in carbon emissions can be attributed to several factors, including the use of energy-intensive materials like concrete and steel, the operation of buildings and the transportation of materials to the construction site [4]. Furthermore, the rapid urbanization occurring in many parts of the world further worsens the situation, increasing construction activity and correspondingly increasing carbon emissions [5].

This increase in carbon emissions is driven by several factors, including increasing demand for buildings and infrastructure, using energy-intensive materials like steel and concrete, and inefficient construction practices [4]. A study conducted by the World Green Building Council found that the construction and operation of buildings account for 39% of global energy-related carbon emissions, with the embodied carbon in materials contributing to around 11% of that total [5]. Furthermore, the rapid urbanization occurring in many parts of the world further worsens the situation, increasing construction activity and correspondingly increasing carbon emissions [5].

To address these problems, many studies have proposed a practical approach to tracking and calculating carbon emissions in the construction industry to help mitigate them. According to Lai et al.[6] LCA is typically the most efficient way to track and calculate embodied carbon emissions in the construction lifecycle. Using LCA methodology, the study tracked and evaluated carbon emissions material extraction, production, transportation, and particularly in the construction stage and found that the most significant amount of embodied carbon is derived from concrete foundation works. Supporting the research, Hoxha [7] calculated the embodied CO2 emissions in construction materials by LCA methodology and concluded that heavy reliance on steel and concrete without insulation in buildings would generate 50% more CO2 emissions than sustainable materials and optimized insulation buildings, further reducing carbon footprint. These studies conclude the importance of tracking and monitoring carbon emissions, which can help to reduce carbon emissions in the construction industry.

Considering the above methods, many studies have developed a system framework to manage carbon emissions effectively in the construction industry [8–10]. Transportation of construction materials is one of the most carbon-emitting activities in the construction phase, accounting for 16% of emissions in the project [8]. To develop a framework for managing transportation emissions, Xiang et al. [9] developed a bin-packing algorithm and modal analysis model to estimate the carbon emissions in the transportation stage of prefabrication construction projects. Further, Sun et al.[10] developed an evolution cloud model and found that Prefabricated buildings can reduce carbon emissions using a combination of steel formwork reducing wood waste. With the help of different frameworks, it becomes easier to find an actual problem and suggest recommendations based on the findings [11].

These proposed approaches are used to manage and minimize carbon emissions in the construction industry. In addition to the above studies, various studies exist regarding managing and reducing carbon emissions in construction projects. However, despite the valuable findings from the studies, a holistic view has yet to be developed to identify gaps and propose future research directions.

Accordingly, in this study, we collected 208 papers in the Web of Science database using the keywords Carbon, Emission, and Construction. Then, we conducted systematic literature reviews to identify the research gaps and further proposed future research directions based on the identified research gaps. This systematic review focused on emerging technologies, different construction methods, and the different approaches to tracking, estimating, and reducing carbon emissions in the construction industry.

The following research questions are established and answered under the background and purpose of this study.

1) What are the current research trends in reducing carbon emissions in the construction industry?
2) What are the future directions in reducing the overall carbon emissions in the construction supply chain?

2. METHODOLOGY

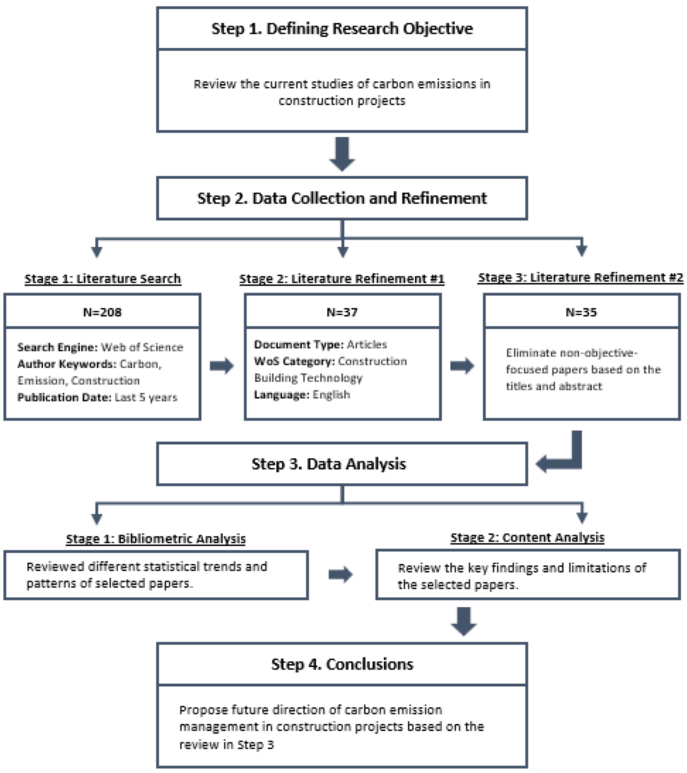


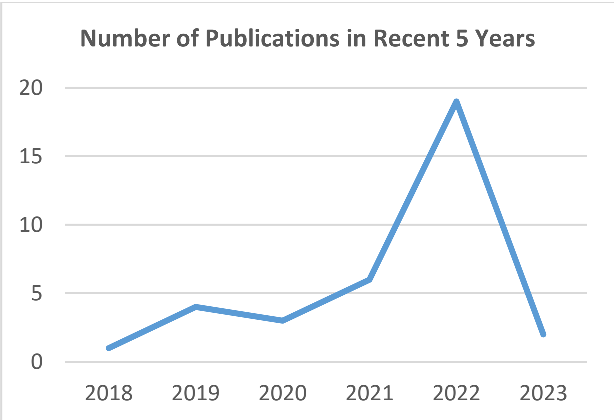
Figure 1. Research Methodology and Flow

This study aims to identify the studies' overall research status and limitations that addressed reducing carbon emissions in construction projects. First, we collected data from a high-quality, multidisciplinary database like the Web of Science. We searched the articles with keywords like Carbon, emission and construction and found around 208 papers. To further narrow the research, we used refining filters like document types (Articles), languages (English), and WOS Categories (Building Technology), reducing the scope to 37 papers. We again screened the refined literature, filtering out the papers based on their scope and objective or evaluating the title and abstract to finalize 35 papers. In the next step, we reviewed key findings and limitations of the identified papers and understood the research gaps in managing carbon emissions in the construction industry. At last, we came up with a conclusion after studying and investigating the current trends in the construction industry for reducing carbon emissions and proposing future directions in using different technologies in construction projects. Fig 1. illustrates the research methodology conducted in four steps.

3. Literature Reviews

3.1.1 *Bibliometric Analysis*

We conducted a bibliometric analysis of the identified 35 papers. From this analysis, we found different statistical trends and patterns of carbon emissions in the construction industry. This section introduces the findings of the trends and patterns.



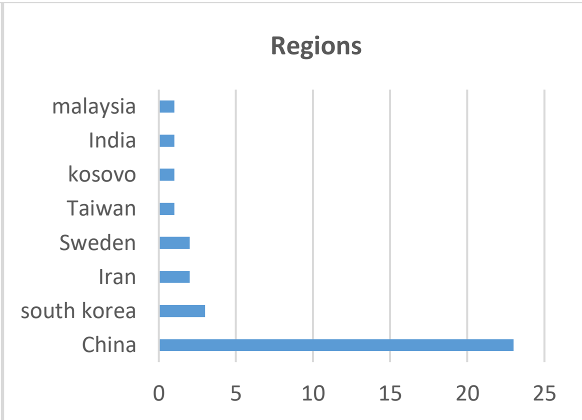


Fig. 1: Explains the selected publication timeline. **Fig. 2:** Region of focus

From the finalized 35 papers from the last five years, we analyzed the timeline and found that the number of published papers sharply grew from 2019 to 2022. In 2022, 19 papers were published, the highest among the considered timelines until the following year, when only two papers were published. There may be many reasons for this decline. One of the evident reasons is that this research only counts papers published until May 2023.

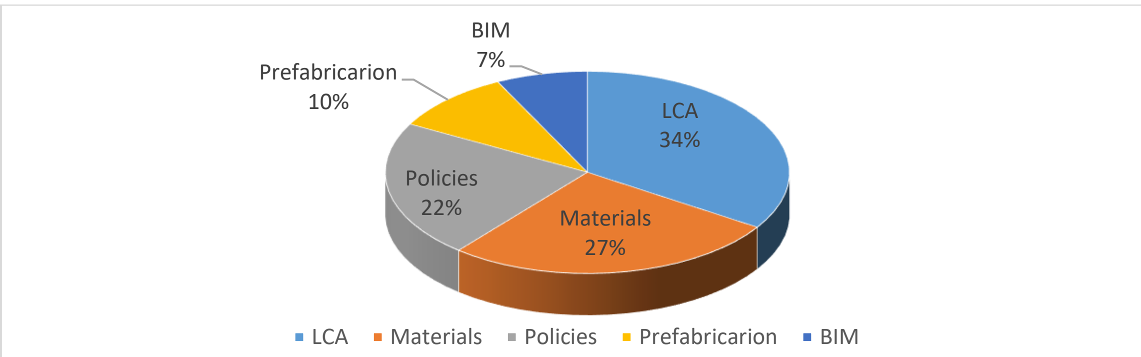


Fig. 3: Various topics of study were categorized

Further diving deep into the research, we found out that the research is more focused on a specific region, such as China and South Korea, where the impact of CO2 emissions is enormous. Significantly, China is the highest carbon emitter in the world due to its rapid nationwide growth. Fig.2 shows that around 67% of 23 papers were from the region of China, where the researchers conducted possible studies on reducing carbon emissions in the construction industry.

Another finding is that the reviewed papers can be categorized into five focus areas, including LCA, Construction Materials, Carbon Policies, Prefabrication, and BIM (Fig. 3). These focused areas give us an idea about the current research trends about carbon emissions in the construction industry. Most papers focused on selecting LCA (around 34%) as their research methodology as it covers different aspects of the lifecycle in construction. From the findings, the research regarding carbon emission in the construction industry is diverse and changes according to the needs of specific regions.

As mentioned, most studies were covered by Lifecycle assessment (LCA), and from the papers, it was found that LCA has different stages: Product stage, Process stage, use stage, End-of-life cycle stage, and Benefits and load stage. However, more than 75% of the papers focused on the first two stages, as in Fig 4. This figure illustrates the subsections in the five stages from A1 to D, which are the from and LCA structure of the European standard of lifecycle assessment. (B.S. EN 15978:2011) [12]

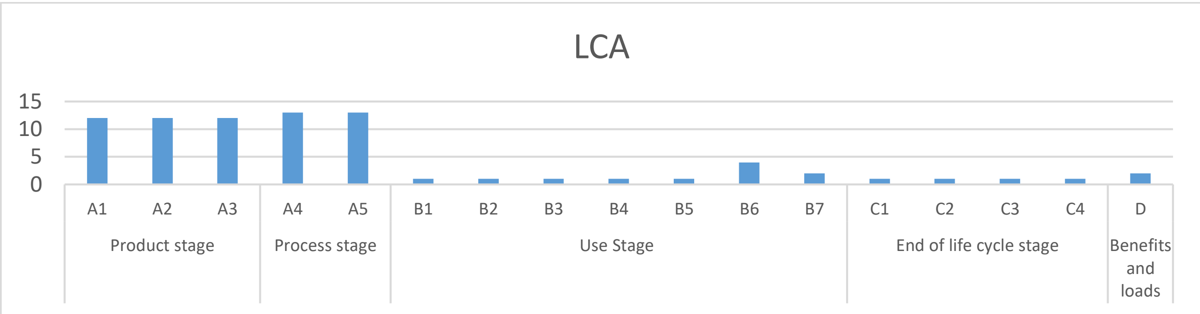


Fig. 4: - LCA-based focuses of the selected papers

3.2 Contents Analysis

Based on the bibliometric analysis, we also conducted a content analysis of the identified papers based on the criteria such as Construction Materials, Life Cycle Assessment (LCA), Prefabrication Construction, Building Information Modeling (BIM), and government policies and strategies, based on the content analysis of abstract (Table 1). In the following subsections, we reviewed the essential findings and limitations of the papers in each category.

Table 1. Selected Categories and the reference papers

No.	Categories (Criteria)	References
1	Construction Materials	[7,13–16]
2	Life cycle assessment (LCA)	[13–25]
3	Prefabrication construction	[9,10,16,26,27]
4	BIM	[13,14,26,28–30]
5	Government policies and strategies	[11,31–33]

3.2.1 Construction Materials

The building and construction sector accounted for 36% of energy use and 39% of energy and process-related CO2 emissions. 11% of these emissions resulted from manufacturing building materials and products such as steel, cement, and glass [4]. Several studies have been conducted to track down and reduce carbon emissions in building materials. A study by Alotaibi et al. [13] found that Proper decarbonization strategies for material manufacturing can reduce material emissions by 27–35% and energy emissions by 70–75%. Further, to focus more on material selection, a study by Pakdel et al. [14] Compared Traditional techniques and materials (TTM) with Conventional systems and materials (CSM) in Iranian construction. They mentioned that materials selection is also crucial because embodied and operational energy of TTM was 43% and 88% lower than CSM during their life span, and carbon emissions, for corresponding values, were 48% and 81% lower for TTM than CSM. Regarding material selection, a study conducted by Lin et al.[15] and Zhao et al.[16] different sustainable construction materials were used, and it was found that concrete foundation works of wooden constructions can contribute significantly to embodied carbon. Using bamboo instead of conventional reinforced concrete structure would reduce energy consumption by 3%~to 5% and CO2 emissions by 7%~to 20%.

Therefore, selecting building materials is essential when considering their effect on embodied carbon emissions in the construction industry. However, the cost-effectiveness of using sustainable building materials is still a question and should be addressed while considering the use of sustainable materials.

3.2.2 Life Cycle Assessment

In recent years, more and more research has gradually shifted to reducing embodied carbon, as it also accounts for a large part of the life cycle carbon emissions [17]. A World Business Council for Sustainable Development report found that the embodied carbon associated with the construction, maintenance, and end-of-life stage accounts for nearly 50% of life cycle carbon emissions [18]. To identify this topic, some of the selected papers leveraged LCA to calculate the carbon emission in the life cycle of construction projects. LCA integrates software like BIM and Revit, advancing open-click LCA plugins for accurate assessment. The author Amoruso et al. [19] recommends using these software and plugins in his study for efficiency and accuracy. With the help of this software, many studies have adopted the LCA methodology for different studies in modular, prefabrication, and different construction materials like timber, bamboo, and Reinforced concrete [13,15,16,20,21]. Based on this, Jang et al. [20] used the LCA methodology and found that modular construction reduces carbon emissions by 36% compared to the RC method. The LCA has different sectors like LCC (Life cycle costing) and ELCCA (Extended life cycle cost assessment), which further explains the in-depth evaluation of carbon cost assessment [22,23]. Based on LCC findings, a study by Nydahl et al. [22] and Amoruso et al. [23] mentions that building renovations can be more cost-effective and environmentally sustainable by considering the financial and environmental implications of different design and material choices. As this study explains, the ELCCA approach provides a more holistic approach to life cycle assessment that is easy to understand and decide based on cost as a primary concern in renovation scenarios where climate and cost-efficient alternatives compared to new construction.

The LCA methodology is widely used in different sectors; however, according to Lu et al. [24,25], accurately measuring and managing building lifetime carbon remains a complicated task despite advancements in emission reduction measures.

3.2.3 Prefabrication Construction

Several studies have considered prefabrication a sustainable approach to reducing carbon emissions [9,10,16,26]. Prefabrication Construction (PC) is divided into production, transportation, and site construction [10]. Based on this study, Liu et al. [26] developed a system that provides real-time carbon emission monitoring with the help of various sensors. With installed sensors, it could monitor carbon emissions throughout the process of prefabricated building construction, resulting in overall data accuracy and reduced labor costs. Further, Sun et al.[10] developed a cloud model-based evaluation method that can assess the whole life cycle phases of a prefabricated building. The building supply chain can be used to evaluate the effect of prefabricated buildings on carbon emission reduction and conclude that prefabricated buildings can reduce carbon emissions using a combination of steel formwork and wood waste. Lastly, the transportation of prefabricated materials is one of the significant sources of carbon emissions in the overall supply chain. Xiang et al. [10] propose a model to calculate carbon emission based on a bin-packing algorithm and a modal model to study its effects. He discovered that the BP algorithm-based method is more suitable for micro-level Carbon emission calculations and can provide more sustainable transportation plans. The model also provides the contractor with a detailed packing solution, which can reduce transportation costs and construction fees. In conclusion, prefabricated construction shows promising studies for carbon reduction thanks to its material efficiency and low energy needs. Even though there were several studies of carbon emission tracking in PC projects, there has yet to be a holistic system that enables all the stakeholders in the PC supply chain to track carbon emissions. In addition, a practical system or pilot test of the proposed tracking systems still needs to be done to validate its effectiveness. The construction fees or the cost factor on the enterprise participation in building carbon reduction is generally not considered a factor affecting the choice of prefabricated assembly technology to reduce carbon emissions. To study this factor, Gro et al. [27] proposed a dual-objective method to optimize cost and carbon emissions using the improved optimization algorithm to solve the problem. He found that when enterprises decide on a 35–40% prefabrication range, they can obtain the maximum carbon-reduction effect with the minimum cost. This can further provide the government with suitable policies for energy conservation and emission reduction in prefabricated buildings and also provide enterprises with a decision-making tool based on the selection between carbon emission reduction and cost.

Even though there were several studies of CE tracking in PC projects, there has not yet been a holistic system that enables all the stakeholders in the PC supply chain to track carbon emissions. In addition, a practical system or pilot test of the proposed tracking systems has not yet been done to validate its effectiveness.

3.2.4 Building Information Modeling (BIM)

BIM is a three-dimensional virtual model that can reduce the time and labor needed to manage building data [14,26,29]. Some studies from the selected paper used BIM software like Revit and Onclick LCA to manage carbon emissions from construction projects. These studies assessed and evaluated embodied carbon emissions based on BIM modeling [13,28,30]. According to the study by Alotaibi et al. [13], BIM modeling has numerous parameters and online inventory data for optimal material selection for sustainable construction. Secondly, Deng et al.[30] proposed a new method of integrating multi-source IFC data in the design stage for accurate carbon footprint data sharing, facilitating collaboration and optimization. Lastly, Shi et al. [28]proposed a BIM-based system considering Construction and Demolition Waste (CDW), one of the significant reasons for carbon emissions, for efficient recycling and reuse integrating with Reverse logistics, considering environmental and economic benefits.

While these approaches are promising, integrating BIM across the building lifecycle is still challenging because of the low level of collaboration, data transparency, and management issues among the different stakeholders.

3.2.5 Effects of Government Policies and Strategies in Construction

High carbon emissions are an issue for rapidly developing nations, with construction significantly contributing [31,32]. Governments worldwide are implementing research-based policies to tackle this problem, concentrating on specific tactics like carbon taxes [11,31–33]. These studies evaluate the effectiveness of earlier policies and programs and recommend modifications for future implementation. For instance, Yu et al. [32] study emphasizes that China has lowered carbon emission intensity, despite continuous development around eastern, central, and western China from 2009 to 2019, because of successful policies and regulations. In their proposal for a policy solution, author Mustaffa et al. [33] highlight the importance of tackling industrial difficulties like limited knowledge and resistance to change, suggesting policy options like carbon credits and cap-and-trade systems. Lastly, a study by Xu et al. [31] proposed a model to assist the government and stakeholders in selecting suitable construction materials, favoring the sustainable approach, and even assisting the suppliers in taking environmental initiatives by increasing their production and sales of sustainable products and assisting local authorities in achieving their emissions reduction targets. He further recommended some policies based on the results to assist the government and regional authorities in controlling carbon emissions in the construction industry

Therefore, given such research outcomes regarding the positive impact of policies and strategies in reducing carbon emissions, we must consider how to facilitate them and make them much more effective.

4. Conclusions

Currently, efforts to reduce carbon emissions in the construction industry have long been the subject of research in academic journals. Accordingly, to provide an holistic view of the current research trends and projects and their research gaps and limitations, we conducted a systematic reviews of 208 academic papers through bibliometric and content analysis. Tha analysis revealed the trend and patterns of the identified papers and provided a comprehensive understanding of the exisintng approaches to managing carbon emission in the CSC and their limitations and gaps. These findings can be a solid foundation for future research on a transformative approach to tracking, estimating, and reducing CO2 emissions in construction projects. This study contributes to the body of knowledge by suggesting that the production and processing stages of building construction prefabrication optimization, newer material innovations, LCA advancements, government policy effectiveness and integration of advanced sensors, monitoring systems, and improving BIM integration while addressing its challenges to enhance accuracy in reducing carbon emissions in construction projects.

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