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Transforming the Building Industry: Leveraging Big Data and Energy Management for Carbon Reduction

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Abstract

This study investigates the efforts made by the construction industry to tackle the issue of carbon emissions. It specifically focuses on the utilization of big data and energy management systems to decrease carbon emissions. By examining the carbon trends in the building sector, highlighting the urgent need for “two-carbon” targets, and utilizing advanced modeling techniques and energy management systems, we demonstrate the most effective methods to achieve significant improvements in energy efficiency and reductions in carbon emissions. Despite certain limitations, we advocate for collaboration and technological advancements within the industry to accomplish carbon reduction and sustainable building objectives. This research offers valuable insights for professionals and policymakers in the construction field.

Keywords: construction, carbon emissions, two-carbon targets, energy management, large-scale modeling techniques, energy efficiency, sustainable buildings

1. Introduction

With the growing importance of global carbon emissions, the construction industry, being a significant contributor to carbon emissions, is increasingly recognizing its crucial role in attaining climate sustainability objectives. This study aims to investigate the utilization of advanced model technologies and energy management systems to diminish carbon emissions in the building sector. Initially, we will analyze the current carbon emission patterns in the construction industry and emphasize the urgent necessity for the industry to achieve the “dual carbon” objective, which entails balancing carbon emission reduction with carbon emission rights. Subsequently, we will delve into the integration of large-scale modeling techniques derived from big data with energy management systems to optimize energy efficiency and reduce carbon emissions. The research conducted in this field equips the construction industry with valuable tools to aid in the accomplishment of its energy efficiency targets. In the research, we will examine real-life examples to investigate effective strategies and evaluate their impact on enhancing energy efficiency and reducing carbon emissions. Lastly, we will put forth new inquiries and recommendations for future research to advance carbon emission reduction and sustainable development in the construction sector.

2. Carbon Trends in the Construction Industry

The construction sector has become the largest consumer of energy on a global scale, accounting for 32% of total global energy consumption and one-third of the emissions of Greenhouse Gases (Ürge-Vorsatz, D., Cabeza, L. F., Serrano, S., Barreneche, C., & Petrichenko, K., 2015). According to the Global State of Building and Construction Report 2022, carbon dioxide emissions from construction operations reached a record high of around 10 billion tonnes in 2021. This represents a 5% increase from 2020 and a 2% increase compared to the previous peak in 2019. The energy consumption required to operate buildings, as well as the production of building materials and urban development projects, have a significant influence on carbon emissions. Some regions have implemented strategies to reduce carbon emissions in the construction industry by adopting sustainable construction practices, government policies, and innovative technologies. These strategies involve using different materials, processes, equipment, and human resources, as well as utilizing digital simulations to identify optimal solutions and incorporating new materials to promote cleaner processes and reduce resource consumption. These efforts are expected to help the construction sector reduce its carbon footprint and contribute to sustainable global development and the fight against climate change.

3. "Dual Carbon" Targets and the Urgent Need for Green Development in the Construction Sector

3.1 Development of Green Building Under "Dual Carbon"

Promoting the sustainable development of the construction industry is not only crucial for integrating safety and enhancing the well-being and satisfaction of society. It also aligns with the trend toward digitalization and intelligence. Additionally, it serves as a key measure to cultivate and strengthen new impetus for economic development. The construction industry has long been a significant user of energy and is a pivotal sector for meeting the "double carbon" objective. To adequately address carbon emissions from the building sector, we need to consider multiple factors simultaneously, such as the size of buildings, their energy efficiency, and the mix of energy sources used (Xu, W., Sun, D., Dong, J., Huang, S., & Yang, S., 2022). Encouraging the adoption of eco-friendly buildings, technologies, and merchandise is a vital mechanism for promoting environmentally friendly, low-carbon, and sustainable practices in the worldwide construction domain.

Furthermore, the construction industry is at the forefront of digital intelligent advancement in an era of economic growth driven by the information sector, and the construction industry is at the forefront of digital intelligent advancement. Several developed nations have released consecutive plans to develop their construction industries, focusing on digital technology. These include the United States' Strategic Plan for Infrastructure Renewal, the United Kingdom's "Construction 2025" strategy, and Japan's "Construction Site Productivity Revolution" plan. China, as a developing nation, has also established the overarching objective of becoming a world leader in intelligent construction by 2035. This objective was outlined in the "Guiding Opinions on Promoting the Synergistic Development of Intelligent Construction and Construction Industrialisation" issued by the government. The construction industry must expedite the digital and intelligent transformation of the sector and take control of future technological advancements in the industry.

Lastly, the implementation of eco-friendly measures and low-carbon initiatives within the construction sector is set to revolutionize the industry's product forms, business models, production techniques, management styles, and supervision modes. Furthermore, this will spawn new industries and modes while affording opportunities for cross-sector integration and cultivating new forms of energy.

3.2 Energy Saving and Carbon Reduction as an Industry Consensus

Energy saving and carbon reduction are widely recognized as crucial goals in the building industry. Conserving energy is a crucial step towards safeguarding the environment and promoting sustainable progress (Chen, M., Su, Y., Piao, Z., Zhu, J., & Yue, X., 2023). It has the potential to generate numerous direct and indirect advantages for economic growth while also ensuring a more favorable ecosystem and access to resources (Trotta, G., 2018). In 2021, 23 countries/regions revised their Nationally Determined Contributions (NDCs) to prioritize energy efficiency and resilience in building construction. Achieving ultra-low or zero emissions in the building sector is essential for reaching carbon neutrality. This involves considering all aspects of building construction, such as design, materials, energy conservation, and waste management. The industry is actively embracing advanced technologies and innovative methods to improve energy efficiency, reduce carbon emissions, and promote environmental awareness in every aspect of building projects. Government policies and the increasing use of environmentally friendly building certification standards are also driving this consensus. By working together, the construction sector is committed to creating a more eco-friendly and sustainable built environment for a sustainable future.

4. Combined Use of Modelling Techniques and Energy Management Systems

4.1 Big Modeling Techniques in Architecture

4.1.1 Basic Concepts of Large Modelling Techniques

In the field of architecture, the use of computer-generated 3D or virtual models to simulate, analyze, and visualize different aspects of building projects is known as big model technology. These models incorporate important data such as structural, design, and functional information, allowing architects, engineers, designers, and other stakeholders to understand and manage all aspects of a building project. The concept of "Digital Intelligence" combines the power of "Big Data" and "Artificial Intelligence" to greatly enhance the ability to generate building designs automatically (Chou, J. S., & Bui, D. K., 2014). Big model technology has become an important tool in modern building design and construction, providing numerous benefits in project planning, design, implementation, and maintenance.

4.1.2 Methodology for the Application of Large Modeling Techniques

Large-scale modeling technologies are extensively utilized in the construction sector, specifically in the areas of building design, planning, and construction management. During the building design phase, these technologies offer virtual modeling and visualization tools that empower architects to construct intricate 3D models and envision the aesthetics, structure, and functionality of the buildings. Furthermore, these technologies provide features for design optimization and clash detection, allowing architects to identify the most optimal solution.

Data-driven approaches are gaining popularity in the building sector due to the increasing availability of building operational data in modern building automation systems (BAS) (Fan, C., Xiao, F., & Yan, C., 2015). The rapid advancement of big data analytics offers the opportunity to utilize big data in BAS effectively. It combines technologies from information science, computational science, and control theory (Xiao, F., & Fan, C., 2014). BAS enables real-time automated monitoring and control, making modern buildings smarter. Typically, energy consumption during the operational phase accounts for a significant portion of the building's overall energy consumption (Ramesh, T., Prakash, R., & Shukla, K. K., 2010). Improving the operational performance of buildings is crucial for energy saving in the building sector. A recent report suggests that implementing advanced building automation technologies in the European building sector could potentially save 22% of energy by 2028 (Waide, P., Ure, J., Karagianni, N., Smith, G., & Bordass, B., 2013). Deep learning, a powerful machine learning technique known for its success in pattern recognition, is a prominent and promising example (Schmidhuber, J., 2015; LeCun, Y., Bengio, Y., & Hinton, G., 2015). Deep learning has the potential to predict the distribution of cooling loads in buildings by uncovering complex patterns in big data. It can be used to develop predictive models through supervised learning or extract meaningful features from raw data through unsupervised learning (Fan, C., Xiao, F., & Zhao, Y., 2017). Utilizing unsupervised deep learning on model inputs can significantly enhance the accuracy of building cooling load prediction. The study's findings offer valuable insights and present a flexible and effective solution for building energy prediction.

Additionally, in the field of urban planning and transportation, advanced modeling techniques are employed to simulate cities and road networks. This helps us enhance urban planning strategies and optimize traffic flow. Additionally, these techniques are also applied in construction management to track project schedules, allocate resources effectively, and resolve any conflicts that may arise. By utilizing these modeling methods, we can ensure projects are delivered on time, improve efficiency, and reduce costs. Overall, the use of large-scale modeling methods in construction greatly contributes to enhancing project quality, efficiency, and sustainability.

4.1.3 Potential Contribution of Large Modeling Techniques to Building Energy Efficiency

The potential impact of large modeling techniques on building energy efficiency must be considered. Big model technology allows architects to conduct detailed simulations and analyses during the design phase, which helps identify optimal design solutions that reduce energy consumption. This includes testing the energy efficiency of different design choices, such as building aesthetics, material selections, lighting, and ventilation systems. With big model technology, it is possible to simulate a building's actual energy usage and identify opportunities for energy savings and wastage. Integration of intelligent systems, like smart lighting and thermostat systems, is also possible, resulting in automatic adjustments in energy use for improved efficiency.

Additionally, big model technology aids in analyzing the energy performance of various building materials to select more energy-efficient options. Real-time monitoring allows building managers to track energy consumption and make adjustments to reduce waste, enabling more intelligent and sustainable management of building energy efficiency. Additionally, building energy modeling is beneficial because it provides valuable information for policy decisions on existing and new buildings. It accurately measures energy consumption and predicts the impact of retrofits, new materials, and technologies. This allows policymakers to make informed decisions on energy procurement, incentivize retrofits and efficiency measures, and establish building codes for different climatic zones (Maaouane, M., Chennaif, M., Zouggar, S., Krajačić, G., Amrani, S., & Zahboune, H., 2023). As a result, the potential for big model technology to enhance building energy efficiency becomes apparent.

4.2 Functionality and Implementation of the Energy Management System

In recent decades, researchers in the field of construction have been focused on enhancing the energy efficiency of buildings. One particular area of interest is building energy prediction, which is crucial for developing strategies to improve energy performance (Fan, C., Xiao, F., & Wang, S., 2014). This includes identifying fault detection and diagnosis (Li, X., Bowers, C. P., & Schnier, T., 2009) as well as demand-side management for smart grids (Potter, C. W., Archambault, A., & Westrick, K., 2009). And managing energy consumption in smart grids. Energy management systems play a vital role in the building sector by performing various functions such as real-time data collection and energy usage monitoring, data analysis and reporting, cost analysis, energy-saving recommendations, optimization, and real-time monitoring with alerts. These systems gather information from different energy sources within a building, like electricity, water, and natural gas, using sensors and monitoring devices. Building management systems (BMS) are commonly used for automated monitoring and control of HVAC systems to collect data (Sun, Y., Wang, S., Xiao, F., & Gao, D., 2013). The collected data is stored in a central database for comprehensive management and analysis, providing building managers with insights into energy usage trends and cost distribution.

Furthermore, the real-time monitoring and alerting capabilities of energy management systems help identify energy wastage or equipment failure promptly, enabling necessary corrective actions. Moreover, these systems provide building managers with data-driven energy-saving recommendations that optimize equipment operation and maintenance schedules, ultimately improving energy efficiency (Fan, C., Xiao, F., & Wang, S., 2014). It is important to note that processing large-scale data can be challenging and time-consuming. However, by applying advanced data mining techniques like integrated learning, composite models can be developed to enhance the accuracy and stability of predictions. These techniques enable the construction industry to manage complex and non-linear operational processes effectively.

5. Case Studies

5.1 Shenzhen International Low Carbon City Convention and Exhibition Centre — The First Venue in China to Belong to the Near-Zero Energy Category

As one of China’s eight pilot low-carbon cities, Shenzhen International Low Carbon City operates as both a leader and a demonstrator. Low Carbon City Exhibition Hall (Hall A), Low Carbon International Conference Hall (Hall B), and Low Carbon Building Technology Trading Hall (Hall C), encompassing a total area of 86,000m². The project utilizes fundamental technology methods, including passive design, active technology, renewable energy, and building intelligence, to tackle carbon emissions.

Implementing passive design measures, like incorporating a systematic sun-shading design, using grey-green perforated aluminum panels for external cladding, and installing green walls with plants, can help decrease the energy consumption of air-conditioning during the summer. This can be achieved while still allowing for natural lighting and ventilation. Additionally, these measures minimize solar radiation without obstructing the elements above. The project has implemented 1.08MWP of solar photovoltaic panels to generate approximately 1,279,100 kWh of electricity annually and decrease carbon emissions by roughly 57.71 tonnes of renewable energy. Additionally, a 2MWH energy storage system has been incorporated. The active technology employed Maglev air-conditioning mainframes with a combined energy efficiency of up to 13 and power savings of 50%. Moreover, the implementation of the smart park system and energy management system facilitates all-encompassing intelligence, enhancing energy efficiency via distinctive cooling and lighting.

The project presents various strategies for incorporating low-carbon technology in the design, construction, operation, and management processes. It outlines a total of 13 advanced technologies and 120 scalable and replicable technologies. The main goal of the project is to regulate energy usage and reduce carbon emissions by implementing practical energy reduction methods. Additionally, the project aims to achieve near-zero carbon emissions through the use of renewable energy sources, energy conservation management, and promoting behavioral changes. The project meticulously controls carbon emissions, with a detailed yearly operational carbon emission of 401.94tC02, a carbon emission intensity of 4.64kgC02/m² per unit of land area, and a per capita carbon emission intensity of 146kgCO2/person-year.

The Shenzhen International Low Carbon City project not only serves as a prototype for zero-energy buildings but also acts as a pilot initiative for the Near-Zero Carbon Emission Zone in Shenzhen. Through tangible actions, the concept of sustainable development anchored in low-carbon principles is put into practice.

5.2 Mexico's First Net-Zero Energy Airport — Guadalajara's New Airport Terminal Building

The new terminal at Guadalajara Airport boasts impressive design and sustainability features. Its roof is a unique, wooden, porous structure shaped like a wave. This design not only enhances the building’s aesthetic appearance but also serves multiple purposes. The wave-like roof filters sunlight and lowers indoor temperatures, creating a more enjoyable traveler experience. Furthermore, the building features white columns that resemble tree branches, providing an artistic flair while also supporting the roof and optimizing the use of space.

To achieve the goal of achieving net-zero energy, a variety of environmentally friendly measures were introduced at the airport to decrease energy usage and carbon emissions greatly. These methods include advanced daylighting systems, insulation techniques, glare control, sun shading facilities, natural ventilation, and economizer cooling. High-performance mechanical systems and intelligent building management systems were also utilized to enhance energy efficiency further.

The new airport terminal in Guadalajara is not only an impressive architectural achievement but also a testament to sustainable engineering. It demonstrates how innovative design can integrate with ecological technologies to achieve low-carbon objectives. This terminal is both a work of art and a model of sustainability and efficiency, making it an extraordinary example of sustainable architecture.

6. Limitation

The use of large-scale modeling techniques holds considerable promise in the construction sector, but it also comes with certain limitations and risks. Primarily, the efficacy of these techniques hinges on the quality of the data input; hence, ensuring the accuracy and consistency of data is paramount. The effectiveness of spatial scale design in the floor plan generated by “Digital Intelligence” technology must be improved, which in turn affects the precision of selecting optimized designs (Shekhawat, S., & Saxena, A., 2020). Appropriate measures like data cleansing and validation are essential procedures for managing data quality. Secondly, the use of big models often demands extensive computing resources, leading to costly investments in both hardware and software. Therefore, organizations should evaluate their computing resource requirements beforehand and plan accordingly before opting for big model technologies. To tackle this challenge, explanatory tools and algorithms can enhance the transparency of modeled decisions. Additionally, when handling large amounts of sensitive data, big modeling techniques must be mindful of privacy and security protection to prevent misuse or leakage of data.

To effectively address these limitations and risks, organizations can implement various risk control measures. This plan encompasses the management of data quality, planning for computational resources, utilization of interpretive tools, implementation of privacy and security measures, as well as the creation of transparent processes for model management and regulations. Taken together, while large-scale modeling technologies can contribute significantly to energy efficiency and environmental improvements in the construction sector, it is crucial to acknowledge and address their potential limitations and risks to ensure their successful implementation. By implementing a comprehensive risk control strategy, the construction industry can fully leverage the potential of large-scale modeling technologies for attaining sustainability and low-carbon objectives.

7. Discussion

Under the requirements of low-carbon standards, the construction industry has been able to achieve significant reductions in carbon emissions by incorporating advanced technology models and energy management systems. The use of big data modeling technology provides valuable insights and precise data analysis, allowing building managers to have a comprehensive understanding of energy consumption and make adjustments accordingly to reduce carbon emissions. Additionally, the implementation of energy management systems optimizes energy consumption, reduces energy waste, and improves overall energy efficiency by synchronizing various operational processes within the building. This research represents notable advancements compared to previous studies in the literature. While traditional carbon reduction methods focused on passive building performance, such as thermal insulation and ventilation (Arumugam, P., Ramalingam, V., & Vellaichamy, P., 2022), this study introduces big modeling technology and an energy management system for smarter and more refined energy consumption, thereby enhancing energy utilization efficacy.

Although this investigation has yielded impressive results, there are still several limitations to consider. Firstly, the use of big model technology requires a significant amount of data, which may be difficult for small and medium-scale enterprises to obtain. Secondly, implementing an energy management system requires a substantial initial investment, which can be financially challenging for enterprises with limited resources. To address these issues, the possible solution could be the creation of a shared data platform to assist small and medium-sized enterprises in accessing the necessary data support. Additionally, financial assistance from the government and industry associations could mitigate the costs of implementing energy management systems and encourage wider adoption of this technology.

The construction sector continues to face various challenges in reducing carbon emissions. Future research should focus on improving the intelligence and adaptability of big model technologies to meet the needs of the building industry better and promote the use of renewable energy technologies to reduce reliance on fossil fuels in construction. While the construction sector has made significant progress in achieving low-carbon goals, there is still a need for ongoing efforts and innovation to enhance the industry’s ability to meet future sustainability requirements.

8. Conclusion

In conclusion, the research emphasizes the importance of the construction industry in addressing the goals of reducing carbon emissions and achieving ‘dual carbon’ objectives. By using a combination of modeling techniques and energy management systems, significant energy savings and reductions in carbon emissions can be achieved, leading the construction sector towards a more sustainable and environmentally friendly direction. While there are challenges to overcome, there is a belief that advancements in technology and collaboration within the industry can make further progress in meeting sustainability targets and embracing a greener future.

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