Remote Sensing for Carbon-Neutral Construction: Advancing Sustainability in the Built Environment

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Abstract

The construction industry accounts for a significant portion of global carbon emissions, making decarbonization a critical priority. Remote sensing technologies, including satellite imagery, UAVs, LiDAR, hyperspectral imaging, and thermal infrared sensing, provide large-scale, real-time data for emissions monitoring, sustainable site selection, energy efficiency assessment, and green infrastructure planning. This paper explores key trends, global initiatives, challenges, and strategies for decarbonizing the construction sector, along with how remote sensing technologies contribute to reducing emissions and promoting sustainable practices in the construction industry. Additionally, this paper integrates insights from the UN Global Status Report for Buildings and Construction 2024-2025, which highlights key challenges and actions required for carbon-neutral construction, including energy efficiency retrofits, embodied carbon limits, and financing mechanisms. By leveraging AI-driven analytics, digital twins, and advanced geospatial tools, remote sensing enhances data-driven decision-making, ensuring the construction industry transitions toward sustainable, low-carbon practices.

Keywords

Remote Sensing, Digitalization, Carbon Neutrality, Sustainable Construction, Net Zero

1. Introduction

The construction industry is one of the largest contributors to global carbon emissions, accounting for nearly 39% of total emissions. The construction sector contributes significantly to global warming through energy-intensive material production,

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on-site emissions, and building operations.

Carbon neutrality in construction refers to the reduction of both operational and embodied carbon emissions to net-zero levels by integrating sustainable materials, renewable energy, and energy-efficient design strategies.

The shift towards carbon neutrality is necessary to mitigate climate change, improve air quality, and ensure resource sustainability (IPCC, 2019). Achieving carbon neutrality in construction is crucial for meeting global climate targets, such as the Paris Agreement and the UN Sustainable Development Goals (SDGs). Even the UN Global Status Report for Buildings and Construction (2024-2025) highlights the sector's significant contribution to global emissions (United Nations Environment Programme, 2025). Geospatial technologies, particularly remote sensing, play a pivotal role in achieving this goal by providing large-scale, real-time data for sustainable construction planning, energy efficiency assessment, and environmental monitoring.

1.2 Insights from the UN Global Status Report (2024-2025)

- Buildings contribute 34% of global CO_2 emissions and consume 32% of global energy
- Materials like cement and steel drive 18% of building CO_2 emissions
- Policies are effective but need faster implementation and scaling
- Building energy efficiency retrofits must triple by 2030 to meet decarbonization targets
- Renewable energy adoption must increase from 17.5% to 46% by 2030
- Major carbon-emitting countries must adopt mandatory zero-carbon building energy codes by 2028
- Investment in energy-efficient buildings must double to $522 billion by 2030

1.2 Global Commitments

- Paris Agreement: Global commitment to limit temperature rise below 1.5°C
- UN SDGs: Goals 9 (Industry, Innovation, and Infrastructure), 11 (Sustainable Cities and Communities), and 13 (Climate Action)
- COP26 and COP28 Targets: Emphasis on decarbonizing infrastructure and accelerating green building adoption
- Paris Agreement Goals: Net-zero emissions by 2050
- Net Zero by 2050 Roadmap (IEA)

1.3 The Current State of Carbon Emissions in Construction

The construction industry significantly contributes to global carbon emissions, with both operational and embodied carbon playing crucial roles. Operational emissions arise from energy consumption in heating, cooling, and lighting buildings, while embodied carbon results from material extraction, production, transportation, and construction activities. Cement and concrete production alone account for nearly 8% of global emissions, while steel and aluminum manufacturing further add to the industry's carbon footprint (IEA, 2022). Additionally, fossil fuel-powered construction machinery and building operations, particularly HVAC systems and lighting, intensify emissions. In response, global initiatives like the EU Green Deal, the U.S. Inflation Reduction Act, and China's Carbon Neutrality Pledge promote

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net-zero policies and stringent energy efficiency mandates.

Decarbonizing construction materials is a growing trend, with innovations such as low-carbon concrete, mass timber (e.g., cross-laminated timber), and circular economy practices promoting material reuse, prefabrication, and modular construction (Global ABC, 2023). Energy-efficient buildings incorporate passive design, AI-driven monitoring, and advanced HVAC solutions to optimize consumption. Renewable energy integration—including on-site solar, wind, geothermal, and district energy systems—is expanding. Electrification of construction processes through electric and hydrogen-powered equipment, AI-driven robotics, and off-grid renewable-powered sites is reducing fossil fuel dependence. Digitalization, including BIM, digital twins, and blockchain, enhances sustainability, while geospatial technologies aid in emissions mapping and energy-efficient urban planning.

1.4 Global strategies and solutions

Global strategies and solutions for achieving carbon neutrality in construction involve industry-wide commitments, corporate strategies, and regional initiatives. The UN Race to Zero Campaign, along with initiatives like the Global Cement & Concrete Association (GCCA) Roadmap and the World Green Building Council's (WGBC) Advancing Net Zero project, encourages corporations to set net-zero goals. Certification frameworks such as LEED, BREEAM, Passive House, EDGE, and WELL promote sustainable building practices (UNFCCC, 2023; World Bank, 2021; WGBC, 2023). Corporations are adopting strategies like carbon offsetting and insetting through afforestation, carbon credits, and direct air capture, while supply chain decarbonization focuses on low-carbon procurement and local sourcing. Life Cycle Assessment (LCA) is increasingly integrated into net-zero design guidelines to assess emissions across a building's lifespan. Regionally, the EU Green Deal's Renovation Wave and Carbon Border Adjustment Mechanism (CBAM) drive sustainability in Europe. At the same time, New York City's Local Law 97 and the U.S. Inflation Reduction Act provide net-zero construction incentives in North America. In Asia, China's Carbon Neutrality Pledge (2060 Goal) and India's Energy Conservation Building Code (ECBC) promote energy-efficient infrastructure, while the Middle East showcases ambitious carbon-neutral urban projects like Masdar City in the UAE. These strategies collectively contribute to reducing emissions and advancing sustainability in the built environment.

2. Methodology

This study adopts a qualitative, literature-based methodology to examine how remote sensing technologies support the global transition to carbon-neutral construction. The research was guided by a thematic literature review framework that synthesizes findings from peer-reviewed academic journals, international policy reports, and technical publications from over a decade, published between 2010 and 2025. Sources were identified using keyword-driven searches on databases such as Scopus, ScienceDirect, Google Scholar, and the UNEP GlobalABC Knowledge Hub. Some of the search terms included "remote sensing for construction," "carbon-neutral buildings," "sustainable construction," "thermal remote sensing," "construction emissions mapping," and "UAV LiDAR in urban planning", etc.

The selection of literature was strategically aligned with global climate initiatives, including the Paris Agreement, the United Nations SDGs (SDGs 9, 11, 12, and 13), the EU Green Deal, the COP26 and COP28 frameworks, and the UN Global Status Report for Buildings and Construction (2024–2025). These frameworks provided an evaluative lens for analyzing how remote sensing technologies contribute to global decarbonization goals. The analysis focused on categorizing the role of satellite, UAV, LiDAR, hyperspectral, thermal sensing, and other geospatial technologies across various stages of the construction workflow and lifecycle, from pre-construction site selection to demolition and recycling. Additionally, the review evaluated the integration of emerging digital technologies such as AI, IoT, and Digital Twins within remote sensing workflows to enhance carbon monitoring and climate-responsive design.

3. Role of Remote Sensing for Carbon Neutrality in Construction

Remote sensing technologies play a crucial role in carbon-neutral construction by providing large-scale, high-resolution data for monitoring land use and land cover (LULC) to guide sustainable development, assessing embodied and operational carbon emissions in urban areas, and optimizing site selection to minimize deforestation and environmental degradation. Additionally, thermal remote sensing helps track energy efficiency in buildings, while urban heat island (UHI) detection supports climate-responsive designs. Furthermore, remote sensing aids in estimating vegetation cover and carbon sequestration potential, contributing to effective emissions offsetting strategies (Rashed & Jürgens, 2010; Voogt & Oke, 2017; Weng, 2023).

Remote sensing plays a crucial role in carbon-neutral construction by providing large-scale monitoring of emissions, land use changes, and sustainability efforts. Satellite remote sensing tracks carbon emissions from construction and urban expansion, using programs like Landsat, Sentinel, MODIS, and Copernicus to assess land conversion and sequestration potential. UAVs (drones) capture high-resolution imagery for monitoring material use, construction waste, and pollution, while LiDAR technology enables precise 3D mapping for carbon offset planning and vegetation assessments (Do et al., 2021; Ghosh & Ghosh, 2023; Zhang et al., 2023). Hyperspectral and multispectral imaging aid in identifying low-carbon materials, assessing surface reflectivity, and tracking vegetation health. Thermal infrared remote sensing supports urban heat island (UHI) detection and passive cooling strategies. Beyond emissions tracking, remote sensing optimizes sustainable site selection, energy-efficient building design, renewable energy integration, and green infrastructure planning (Goyal et al., 2020; Milošević & Lukić, 2021; Iacovidou & Purnell, 2022; Li & Zhang, 2024). It also enhances construction waste management by detecting illegal dumping and tracking recyclable materials, while NDVI-based carbon sequestration monitoring helps in urban reforestation and conservation of natural carbon sinks. Table 1 shows how various remotely sensed data help in carbon-neutral construction at every stage of the workflow, supporting global actions.

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Table 1: Remote Sensing Data and Applications Across Construction Workflow

Construction Workflow Stage	Remote Sensing Data & Technology	Remote Sensing Application for Carbon Neutrality	Alignment with UN Global Action
Pre-Construction Planning	Satellite Imagery, LiDAR, Thematic Data (NDVI, NDBI, NDWI, etc.)	Identifying sustainable sites, minimizing environmental impact, assessing land suitability, and carbon offset planning	Major carbon-emitting countries must adopt zero-carbon energy codes by 2028.
Site Analysis & Land Surveying	UAV (Drones), LiDAR, Multispectral Imaging	Monitoring topography, soil stability, and vegetation cover to prevent deforestation and habitat destruction	Circular construction practices: Recycled materials must increase beyond 18% of construction inputs.
Design & Material Selection	Hyperspectral Imaging, Thermal Infrared Data	Selecting energy-efficient and low-carbon building materials, optimizing insulation	Embodied carbon limits must be adopted in building codes by 2030.
Construction & Resource Management	UAV (Drones), Air Quality Sensors, IoT	Monitoring emissions, tracking material usage, reducing construction waste, and enforcing sustainability regulations	Renewable energy adoption must triple in buildings by 2030.
Energy Efficiency & Building Operations	Thermal Infrared, IoT Sensors, Digital Twins	Assessing energy efficiency, detecting heat loss, optimizing HVAC systems, improving passive design strategies	The rate of building energy efficiency retrofits must triple by 2030.
Urban Planning & Heat Island Mitigation	Thermal Imaging, GIS Mapping, UHI Analysis	Identifying heat-prone areas, implementing green spaces, reflective surfaces, and tree plantations	Annual energy improvement needs to double to meet 2030 targets.
Demolition & Recycling	LiDAR, Hyperspectral Imaging, Waste Tracking Sensors	Identifying reusable materials, tracking demolition waste, and promoting circular economy strategies	Circular construction practices must be scaled to lower emissions.

The future of remote sensing in carbon-neutral construction lies in the integration of advanced technologies to enhance monitoring, analysis, and decision-making. AI-driven remote sensing will enable automated carbon footprint assessments, improving the accuracy and efficiency of emissions tracking. Real-time monitoring through UAVs and satellite constellations will provide continuous data on construction activities, pollution levels, and land-use changes. Digital twin integration will allow for predictive modeling of carbon emissions, enabling proactive strategies to minimize environmental impact (Alizadehsalehi et al., 2023). Additionally, advanced material classification using remote sensing will

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facilitate the selection of low-carbon construction resources, promoting sustainability in building projects. These innovations will strengthen data-driven decision-making, helping the construction industry transition toward net-zero carbon emissions.

4. Challenges for achieving Carbon Neutrality in Construction

Achieving carbon neutrality in construction faces several challenges. Economic and financial constraints, such as high upfront costs of low-carbon technologies and limited incentives, hinder progress, especially in developing countries. Regulatory gaps include the absence of unified global carbon accounting standards and inconsistent policies across regions. Technological limitations slow the adoption of renewable energy and highlight the need for a skilled workforce in sustainable construction. Remote sensing challenges include low-resolution satellite data, cloud interference, and the need for better integration with BIM and IoT (Xu, Zhang, Teng, & Pan, 2023; Ullah et al., 2024; Li et al., 2025). Additionally, the high cost of advanced technologies like LiDAR and hyperspectral imaging limits widespread implementation. Major challenges for achieving Carbon Neutral Construction are shown below in Table 2.

Table 2: Major challenges for achieving Carbon Neutrality in Construction

Economic and Financial Constraints	• High upfront costs of low-carbon technologies and materials • Limited financial incentives in developing countries
Regulatory and Policy Gaps	• Lack of unified global carbon accounting standards • Inconsistent policies across regions
Technological and Infrastructure Limitations	• Slow adoption of renewable energy in construction sites • Need for skilled workforce in carbon-neutral construction techniques
Challenges in Remote Sensing Carbon Neutrality	• Some satellite data lack high resolution for precise tracking • Optical remote sensing struggles in cloudy regions • Needs better linkage with Building Information Modeling (BIM) and IoT-based smart sensors • High-resolution LiDAR and hyperspectral imaging require significant investment

5. Recommendations & Roadmap to Net-Zero Construction

Achieving net-zero construction requires a multi-faceted approach encompassing policy, technology, finance, and industry collaboration. To accelerate the process to achieve net-zero construction, approaches/attempts can be focused on nine categories as given below in Table 3.

Table 3: Multi-faceted Approach to Net-Zero Construction

Policy & Governance Actions	**Material Innovation and Sustainable Sourcing**	**Electrification of Construction Machinery & Processes**
• Enforcing Embodied	• Transition	

Carbon Regulations • Strengthening Carbon Pricing Mechanisms • Expanding Financial Incentives	to bio-based, recycled, and carbon-sequestering materials • Development of ultra-low-carbon cement and alternative aggregates	• Transition from diesel to electric and hydrogen-powered construction equipment • Off-grid renewable-powered construction sites
Encouraging Private Sector Participation • Incentivizing corporate sustainability commitments • Expanding ESG (Environmental, Social, Governance) investments	**Industry Best Practices** • Encouraging Cross-Sector Collaborations • Adopting Modular Construction • Implementing Closed-Loop Recycling in Construction Supply Chains	**Green Finance & Carbon Pricing Mechanisms** • Government incentives for net-zero projects • Carbon trading schemes and carbon offset mechanisms
Accelerating Innovation & Research • Investment in Carbon-Negative Concrete • Development of Energy-Efficient Construction Techniques • Scaling Hydrogen-Powered Construction Equipment	**Enhancing Education & Workforce Training** • Integrating net-zero construction training in engineering and architecture curricula • Upskilling workers in new sustainable building techniques	**Role of Digital & AI Technologies** • BIM and Digital Twins for Efficiency Gains • AI-Driven Carbon Footprint Analysis in Design • Blockchain for Carbon Credit Verification • Geospatial Technologies for overall construction management

6. Conclusion

Remote sensing technologies have emerged as indispensable tools in achieving carbon neutrality within the construction industry. This paper demonstrates that when aligned with global sustainability frameworks such as the UN SDGs and the Paris Agreement, these technologies can significantly advance emissions monitoring, sustainable material use, and energy-efficient urban development. The ability of satellite imagery, UAVs, LiDAR, and other remote sensing technologies and platforms to capture real-time, large-scale environmental data enables precise site analysis, urban heat island mitigation, emissions tracking, and circular construction practices. By integrating geospatial insights with data of emerging technologies like AI, IoT, and Digital Twins, remote sensing empowers decision-makers with actionable intelligence across the entire building lifecycle.

Despite their transformative potential, the full-scale adoption of remote sensing technologies is challenged by high implementation costs, data resolution limitations, regulatory inconsistencies, and skill shortages, especially in developing regions. Addressing these barriers requires stronger international cooperation, standardized carbon accounting frameworks, and investments in capacity-building and innovation. Future pathways should focus on making remote sensing more accessible, interoperable with other digital systems, and embedded in construction policy and regulation. As the world accelerates toward a net-zero built environment, remote sensing will remain a central pillar in shaping resilient, inclusive, and sustainable infrastructure worldwide.

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