CHAPTER 5

Advanced Technologies and Sustainability Practices for High-rise Building Construction

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ABSTRACT

High-rise construction has emerged as a defining features of modern urban development driven by the imperative to accommodate growing population in increasingly dense cities. However, the pursuit of vertical expansion brings significant challenges, including resource scarcity, environmental degradation and need for energy efficiency. This paper explores the integration of advanced technologies and sustainability practices like BIM, Modular construction, Green building design, Energy efficient facades for high-rise building with focusing on achieving energy-efficiency, environment friendly construction. A key focus is comparative analysis of traditional buildings versus sustainable building in terms of environmental, social, economic aspect. This comparison highlights gaps and opportunities for improvement. This analysis offers valuable insights into the relation between technology and sustainability, highlighting a few building examples that represent the next generation of sustainable tall structure, setting trends for future developments.

Keywords Sustainability; High-rise Construction; Prefabrication; Green Materials; Low Carbon Solutions

1.0 Introduction

As urban populations grow, cities must optimize land use while managing environmental and social costs. High-rise buildings offer a solution but contribute to high energy consumption, carbon emissions, and inefficient resource use. According to the United Nations Environment Programme (UNEP, 2023). The construction sector accounts for 37% of global emissions and has the potential to reduce 5-7 billion tons of CO_2 by 2030 (Xiong *et al.*, 2024). Sustainable construction practices address these challenges through advanced technologies like Building Information Modeling (BIM), precast construction, and automation, alongside green materials and energy-efficient systems. The construction industry is shifting toward low-carbon buildings, integrating new methodologies and evolving technologies to enhance sustainability (Akadiri *et al.*, 2012).

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Global standards such as LEED (Leadership in Energy and Environmental Design), BREEAM, and CASBEE evaluate sustainability performance. LEED, developed by the U.S. Green Building Council (USGBC), provides a framework for eco-friendly construction, reducing environmental impact, lowering costs, and improving occupant well-being (Wei & Skye, 2021). It assesses sustainability through energy use, water efficiency, material selection, and indoor environmental quality. Achieving LEED certification signals a commitment to environment responsible and resource-efficient building practices. The aim of this research is to explore and promote sustainable construction practices in high-rise buildings by integrating advanced technologies and environmental standards. It seeks to address the environmental and social challenges posed by traditional construction methods, emphasizing energy efficiency, carbon emission reduction, and resource optimization. By examining global sustainability frameworks such as LEED, BREEAM, and CASBEE, the study aims to highlight the potential of green building certifications in fostering sustainable urban development. Additionally, it underscores the role of innovative construction techniques in transforming the industry towards low-carbon, resource-efficient, and environmentally responsible practices.

2.0 Literature Review

Sustainability, first defined in the Brundtland Report (1987), emphasizes meeting present needs without compromising need of future generations. Sustainability in construction includes environmental, economic, and social dimensions (Yılmaz & Bakış, 2015). Eco-friendly buildings result from long-term environmental policies aimed at reducing natural resource consumption and pollution. Sustainable construction focuses on integrating green materials, efficient resource use, and advanced technologies. Key strategies include site selection, life cycle analysis, material optimization, and energy efficiency (Kumar & Gupta, 2014). However, construction remains one of the least sustainable sectors, facing challenges like high energy consumption, emissions, and unsafe conditions. Prefabrication enhances sustainability by improving quality control, reducing waste, and ensuring safety (Gallo *et al.*, 2021).

Building Information Modelling (BIM) enhances project quality, cost estimation, and scheduling while reducing material waste and energy consumption. However, it is still primarily viewed as a visualization tool rather than a sustainability driver (Bynum *et al.*, 2013). Modular construction, a prefabrication technique, is 40% faster and 10-25% cheaper than traditional methods, offering reduced waste and lower emissions. However, its adoption is hindered by transportation logistics, high setup costs, and regulatory challenges (Hořínková, 2021). Sustainable high-rise buildings incorporate rainwater harvesting, energy-efficient systems, wind turbines, and photovoltaic panels. However, greenwashing remains a concern, as some sustainability claims are exaggerated. The COVID-19 pandemic has further reshaped design trends, emphasizing ventilation, outdoor spaces, and smart energy management (Al-Kodmany, 2022).

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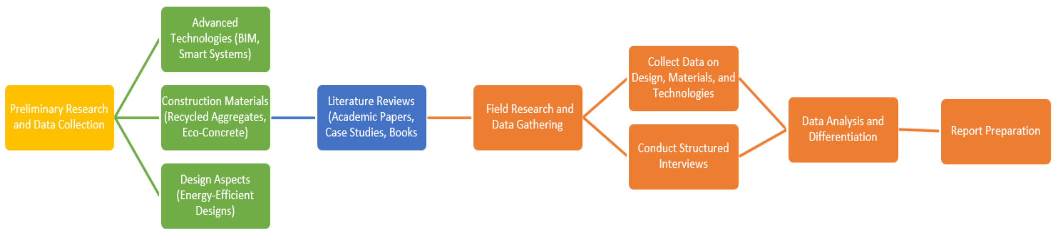
A circular economy approach to prefabricated buildings can cut carbon emissions by 30-50%. However, challenges such as high transportation emissions and inconsistent carbon accounting methods persist (Li *et al.*, 2024). Green buildings help reduce emissions and promote energy efficiency, but adoption barriers include high costs, lack of financial incentives, and regulatory gaps. Government support, financial incentives, and policy standardization are essential for large-scale adoption (Liu *et al.*, 2022). Sustainable materials such as Recycled Aggregate Concrete (RAC) and Eco-Concrete can significantly reduce the carbon footprint of buildings. Cross-Laminated Timber (CLT) has a negative CO_2 footprint. though challenges like fire resistance and market acceptance remain. Addressing these barriers through policy incentives, industry collaboration, and material standardization is crucial (Arnesson, 2019).



3.0 Methodology

The initial stage is dedicated to building a basic comprehension of sustainability criteria pertinent to high-rise building projects. This entails exploring cutting-edge technologies like Building Information Modelling (BIM) and intelligent building systems, alongside examining design strategies, construction materials, and energy generation systems. Essential sustainability metrics are pinpointed, such as energy efficiency, the integration of renewable energy, water conservation, sustainable materials, waste management, indoor environmental quality, site planning, and smart building technologies. This stage lays the theoretical groundwork for research. The second stage involves a detailed comparison of how sustainability criteria are addressed in both Indian and global contexts. This is accomplished through comprehensive literature reviews, encompassing academic research papers, case studies, industry publications, newspaper articles, and online resources. The aim is to discern differences in approaches, standards, regulations, and implementation strategies between India and other nations. This comparative analysis forms a strong basis for subsequent field research and data gathering.

In the third stage, structured interviews are conducted with industry experts to enhance the data collected. Participants include architects, civil and environmental engineers, construction managers, sustainability consultants, building operators, and regulatory officials. These interviews offer valuable insights into the challenges, opportunities, and best practices associated with implementing sustainability measures in high-rise construction. The interview

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data is transcribed, coded, and categorized to identify key themes and patterns. The final stage involves a comprehensive analysis of all gathered data to prepare a detailed comparative report. Identifying gaps and challenges in the construction sector and evaluating the effectiveness of various sustainability strategies. The adaptability of best sustainable practices in the construction sector is assessed, and actionable recommendations are developed to enhance sustainability in high-rise construction. Both qualitative and quantitative techniques are employed to ensure robust and reliable findings. This methodological approach ensures a thorough investigation of sustainability practices in high-rise buildings, enabling meaningful comparisons between Indian certification criteria and international certification criteria contexts and contributing to the advancement of sustainable construction practices that can be adopted.

Figure 1: NICMAR Precast Building

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4.0 Advanced Technology

4.1 precast construction

The NICMAR New Educational Building is a G+13 precast structure designed to integrate modern construction technologies with sustainable building practices. Utilizing precast construction, this project aims to enhance efficiency, cost-effectiveness, and environmental sustainability while ensuring high structural quality. Precast construction involves the off-site manufacturing of structural components, which are then transported and assembled on-site. This method significantly reduces construction time, minimizes material waste, and enhances precision compared to traditional cast-in-situ techniques. The NICMAR Precast Building incorporates pre-engineered slabs, beams, shear columns, and facade walls, ensuring structural durability and faster project execution.

Table 1: General Info. of Ore-cast Building

Name	NICMAR UNIVERSITY BUILDING
City:	Pune Maharashtra
Number of Stories	G+13
Construction type	Precast construction
Height:	50 m/162.5ft
Type of building	Educational
Certification:	IGBC Platinum

Circularity of material: Not only structural material but also partition walls, staircase can be recycled at the end of the building use without losing its performance. Building component and sub-components can be relocated after their use.

Product-process predictability

- Possibility to perform tight quality controlled over the final product.
- Possibility to control the building process (time and costs certainty)

The case study shows that design manufacturing methods used for pre-cast can enhance product process quality control compared to traditional methods of construction. Specially, this possibility is always enabled by the use of file to factory approaches i.e. use of BIM

Just-in-Time (JIT): JIT Principles were being used in NICMAR precast building construction to improve efficiency, reduce waste and lower costs ensuring that the components are produced and delivered precisely when needed.

On-demand precast production: Instead of mass-producing precast elements and storing them, manufacturers produce components (e.g. beams, column, slabs) only when needed based on project schedules. This reduces inventory costs and prevents material degradation.

Scheduled deliveries to site: Precast components are transported to the construction site 2 days before when they are needed for installation, preventing site congestion and optimizing workflow efficiency while workforce and equipment are managed to match components arrival, reducing idle time improving productivity.

Reduction of material waste:

- Optimization of material use in manufacturing process
- Optimization of orders

From an ecological perspective, the advantage of prefabricated construction can be in a simplified way separated into benefits associated to waste generation and construction process affected on building environment. Prefabricated structure produces less waste as compared to traditional structure. It helps manufacturer to forecast the need of material for given task due to its repeatability. It is found that by using prefabricated component can reduce 60-70 % reduction in waste generation. Another reason for lower the waste production is that reuse of element for other structure after properly dismantle element without any defect.

Speed of construction:

- Reduction of construction time compared to traditional buildings.
- Optimization of construction lifecycle & increases productivity.

One of the prefabricated structure advantages is results from less time for manufacturing and assembly. This will result in quick return on cost, reduction in overhead, indirect cost and other cost. Quick and operative construction bring a number of advantages. This reduction in construction time is mainly due to relocation of most work under the control condition where manufacturing process is not limited by adverse climatic condition. Due to rapid assembly the duration of noise and vibration impacting the surrounding construction site is minimized during assembly phase. Additionally, prefabricated structure does not contribute to increase dust or green house emission in the area.

Safety: Most of component are manufacturing in factory, workers operate safer, controlled, setting with reduced exposure to on-site hazard such as extreme weather, falling object and unstable surfaces. As minimum construction activity required at the site, there is a lower risk of accident related to heavy machinery, reducing equipment related risk. Pre-cast allows for more structured and ergonomics work environment, reducing physical strain and fatigue, which are common cause of accident in traditional construction

Transportation of prefab structure: Lager and longer component need to transport most of manufacturing unites are located out of city or away from construction site so in this case, it is necessary to obtain permits and arranging accompanying vehicle which increases cost of pre-cast construction cost transport of prefabricated structure need to be planned logistics thoroughly .need to choose such rout from the plant to the construction site where there are no restriction in terms of pass ability.

4.1.1 Limitation of Pre-cast technology:

Dependence on Large Volumes: Precast construction is most cost-effective when producing components in large quantities. Its economic viability relies on high production volumes, making it less suitable for smaller projects where costs per unit may be higher.

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Challenges in Transportation: Due to their significant weight and size, precast elements require specialized transportation from the manufacturing facility to the construction site. This adds to logistical complexities and increases overall transportation costs.

Heavy Equipment Requirements for Installation: The installation process for precast elements involves the use of heavy machinery, such as cranes and lifting equipment. Deploying such machinery in densely populated or space-restricted areas can be challenging and may result in additional costs.

Table 2: Traditional vs Pre-cast Building

Aspect	Traditional Construction	Pre-cast Construction	Sustainability Impact
Material Waste	Generates Significant waste due to on-site cutting and excess material usage.	Minimize Waste through precise factory production and reduced on-site adjustments.	Pre-cast align with sustainable practices by reducing landfill contribution.
Energy Usage	High energy demands for on-site activities like mixing and curing	Energy-efficient due to controlled factory processes and reduced on-site work.	Pre-cast construction lowers overall energy use and carbon emissions.
Construction timeline	Longer construction time due to sequential on-site process.	Faster construction as pre-cast components manufactured off-site and assembled quickly.	Shorter timelines reduce energy use and environmental disruption.
Quality control	Variable quality due to reliance on on-site labour and weather conditions.	Consistency in quality as components are made in controlled environment in factory	Higher quality reduces material defects and long term maintenance needs.
Carbon footprint	Higher carbon emission due to longer construction timeline.	Lower carbon emissions due to optimized manufacturing and reduced construction time.	Pre-cast contributes to lower greenhouse gases emission.
Resource Efficiency	Less efficient use of materials due to over ordering and on-site adjustments	Efficient use of materials due to precise manufacturing and reduce over-ordering	Pre-cast supports sustainable end-of-life practice.
Water usage	High water usage for on-site mixing, curing and cleaning.	Lower water usage as most processes occurs in factories with water recycling systems.	Pre-cast conserves water resources.
Air and Noise pollution	High noise and dust pollution on-site, affecting workers and surrounding communities	Minimal on-site pollution as most work is done off-site.	Reduction in air and noise pollution

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Complexity in Maintenance and Repairs: Although precast structures are known for their durability, repairs and modifications can be more complicated compared to traditional cast in-place methods, often requiring specialized techniques and materials.

Design Constraints: The size and shape of precast components are often limited by transportation and handling capabilities. Custom designs may require specially fabricated molds, leading to increased costs and extended production timelines. Additionally, modifying precast elements after manufacturing is difficult and can be expensive.

4.1.2 Difference between traditional and pre-cast building

Building integrated photovoltaic: In context of high-rise buildings as they have limited roof space cause rooftops of skyscrapers are often occupied by essential mechanical systems or by service shafts. Because of these limitations building integrated photovoltaic (BPIV) is an innovative technology that integrates solar panel directly into the building envelops, such as the façade, roof or windows, rather than mounting them as an add-on gaining importance.

Table 3: Traditional Solar vs BIPV

Sr. No	Features	Traditional Solar Panel	BIPV
1.	Integration into buildings	Installed on buildings or any other structure using racks and mounts.	Integrated into the design of building (ex. Windows, walls)
2.	Installation	Can be added to existing structures without major modification to building	Installed during construction as they part of building's design.
3.	Functionality	Focused on electricity generation & do not contribute to building's structural integrity	Serve a dual-purpose generating electricity while acting as a structural component
4.	Cost	Generally, cost effective and widely used due to standardized designs and mass production	Typically, more expensive due to customization, integration, and dual functionality.
5.	Application	Suitable for retrofitting existing buildings or installations where cost and efficiency are the main concerns.	Ideal for new construction projects of major renovations where aesthetics and multi functionality are priorities (commercial buildings, modern homes.)

BIPV system serves a dual purpose they generate electricity while also functioning as a part of building's structure. This makes BIPV particularly suitable for high-rise buildings, where the space optimization and energy efficiency are critical. The AL-Rehan building in Mumbai showcases India's tallest building integrated photovoltaic (BIPV) façade, with solar panel

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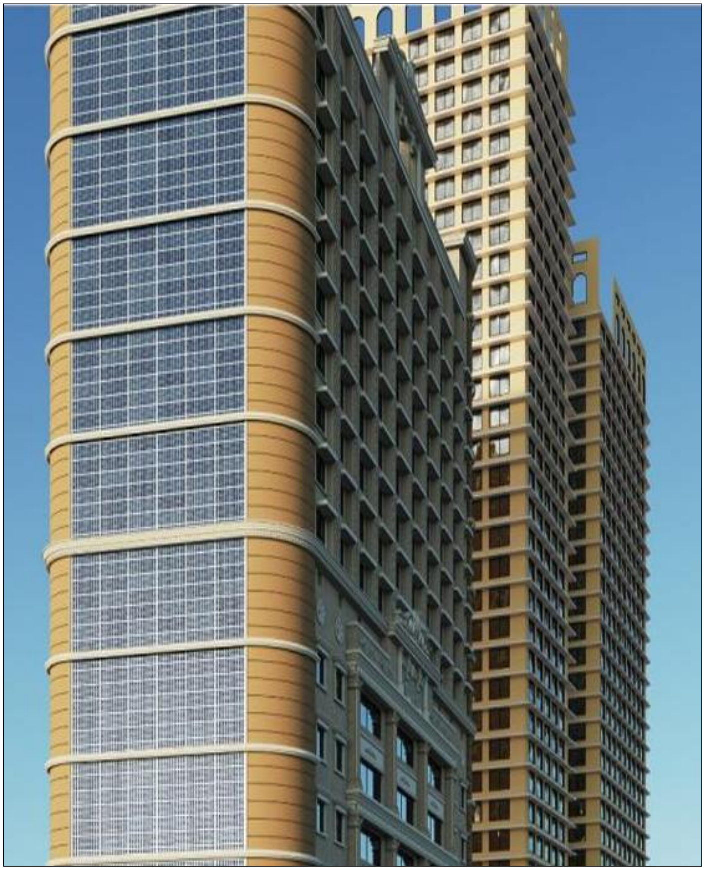
through-fully integrated into its southern exterior to optimise energy production. In one of the studies on solar PV façade in mumbai provides information of potential energy generation. The study estimated that a 1000 kWp solar PV façade required approximately 8000 square meters of façade area and can generate about 1319 MWh of electricity annually.

Figure 2: AL – Rehan Building Mumbai



Source: https://www.aestheticdesigns.in/sbut/d-wing/, n.d.

Smart Building Systems: While smart construction technologies offer numerous benefits, their adoption varies significantly across the world. Major global economies—including China, the United States, the United Kingdom, Germany, and Japan—are taking the lead in the adoption of BIM, robotics, and the IoT, supported by robust infrastructure developments and a skilled workforce. This system is an important part of human civilization and has a major influence on the environment, economic growth, and standard of living. A

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sustainable environment system has the following essential elements: resource conservation, which includes the utilization of natural resources such as atmosphere, water, land, energy, material, and biodiversity (i.e., a wide variety of species); cost efficiency of the constructed projects in all stages (i.e., initial cost, cost in use, and recovery cost); and design for human adaptation, which could include the minimization of production waste, keeping water and air clean, and protecting human interaction with the environment.

Figure 3: Smart Building Techniques

Source: Alhassan et al., 2024

In recent times, the building industry has placed a heightened emphasis on sustainability due to the significant energy consumption and greenhouse gas emissions attributed to buildings. The emergence of advanced technology and smart systems opens up substantial opportunities for enhancing building sustainability. Smart buildings leverage technology to control and optimize their functions, leading to more efficient resource utilization and lessened environmental footprint. One of the most significant contributions of smart systems to green buildings is intelligent energy management. Traditional buildings might run heating or cooling systems at full capacity regardless of actual occupancy or needs. Smart buildings, however, use occupancy sensors and predictive algorithms to adjust energy usage dynamically. For example, when sensors detect that a conference room is empty, the system can automatically adjust temperature settings, turn off lights, and reduce ventilation. The system might even learn that this particular room is rarely used on Friday afternoons and pre-emptively reduce conditioning in advance. Water management in smart green buildings goes far beyond low-flow fixtures.

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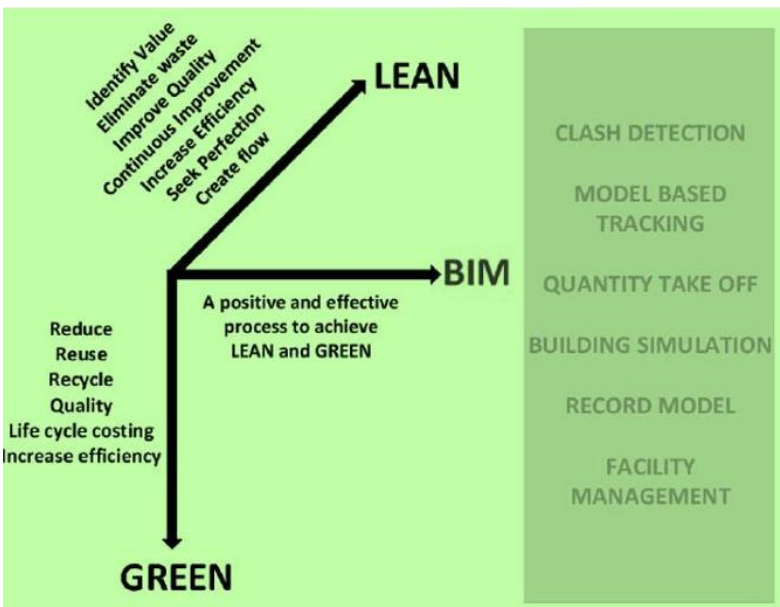
Smart systems monitor water usage patterns to detect anomalies that might indicate leaks or inefficiencies. Some advanced systems can even predict potential issues before they become problems. In commercial buildings, smart water meters can provide granular data on usage patterns, helping facility managers identify opportunities for conservation that might otherwise go unnoticed.

BIM Technology: BIM software allows architects and engineers to simulate various design scenarios to determine the most energy-efficient options. This includes analysing the building's orientation, natural lighting, and ventilation strategies Energy analysis tools in BIM software help in assessing the energy performance of the building, allowing designers to make informed decisions about energy-efficient systems and materials. BIM databases can store detailed information about building materials, including their environmental impact, life cycle analysis, and energy efficiency. This data helps designers select eco-friendly materials and products BIM tools can compare different materials based on their environmental attributes, allowing designers to choose materials with lower carbon footprints and higher sustainability ratings. BIM enables precise quantity take-offs and accurate construction planning. By minimizing material wastage and optimizing construction processes, BIM contributes to reducing construction-related waste. Designers can use BIM to create efficient panelling and cutting plans, minimizing off-cuts and material waste during the construction phase.

Figure 4: Integration of LEAN, BIM & GREEN



Source: www.google.com, n.d.

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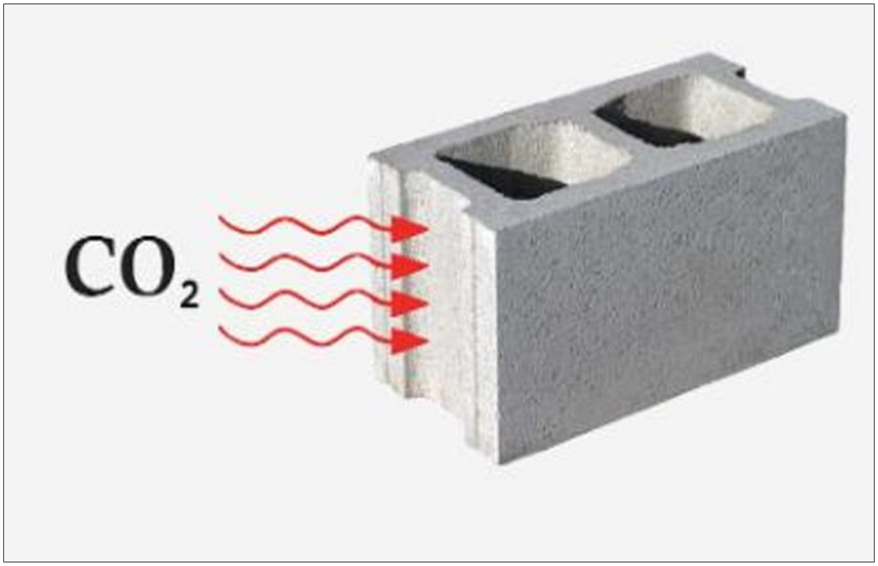
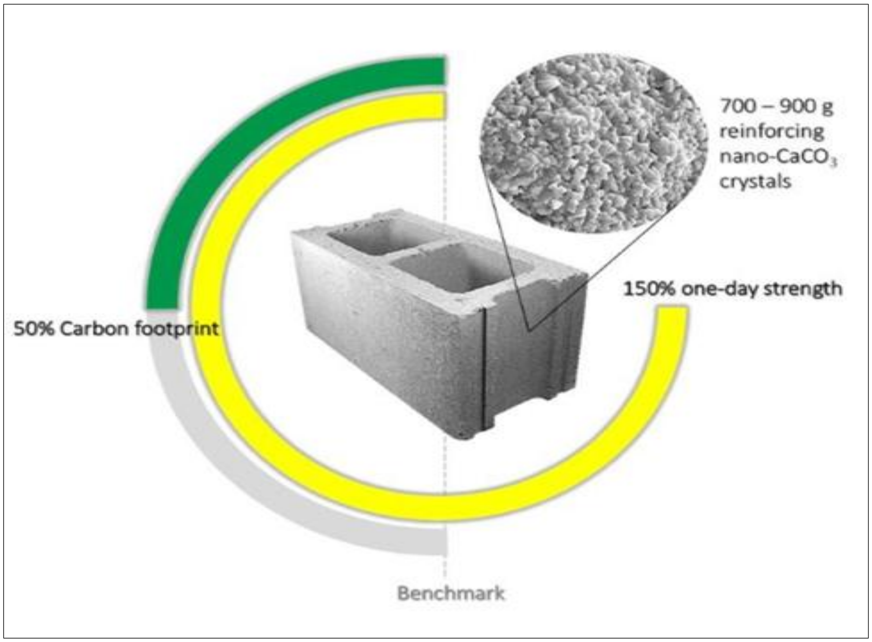
Figure 5: Carboclave Block



Source: (https://www.carboclave.com/, n.d.)

Figure 6: Carboclave block



Source: (https://www.carboclave.com/, n.d.)

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BIM can be used to assess the feasibility of integrating renewable energy sources such as solar panels, wind turbines, and geothermal systems into the building's design. By simulating energy production and consumption within the BIM environment, designers can optimize the placement and efficiency of renewable energy systems. BIM models are valuable for facility management, enabling building operators to monitor energy usage, occupancy patterns, and equipment performance. This data helps in optimizing the building's operations for energy efficiency. Predictive maintenance and energy monitoring tools integrated into BIM can assist in long-term sustainability by ensuring that the building's systems operate at peak efficiency.

Sustainable Material: Carboclave concrete blocks are a type of building material that incorporates carbon dioxide (CO2) into the curing process. This innovative method involves using CO2 to enhance the strength and durability of concrete, making it a more sustainable option. Guaranteed minimum CO2 utilization of 0.23 kg per 20 cm unit. Carboclave products reach design strength and are ready to ship just one day after production, eliminating the need for yard storage. The high strength also ensures fewer chips and cracks during handling and transportation, reducing waste. Carboclave products are greener because they avert the use of energy and water during curing, sequester CO2 that would otherwise be released into the atmosphere, and have an embodied carbon footprint that is at least 50% lower than conventional benchmarks. Its standard Manufacturing practice imposes no deviations from existing processes and mix designs and does not necessitate the use of special material feedstock or additives.

Improved performance relative to conventional block, including:

1. Higher compressive strength (limestone/granite family)
2. Better freeze-thaw resistance
3. Improved sulphate attack resistance
4. Consistent colour in production
5. Greater resistance to drying
6. Atmospheric shrinkage
7. Reduced permeability
8. Reduced efflorescence effect

Its Adoption demonstrates a commitment to greener and more sustainable best-practices and offers the opportunity to turn a plant into a net-negative carbon footprint operation. The consumption of both energy and water is eliminated throughout curing, since the use of steam is completely averted. Carboclave products are regarded as premium for being stronger, greener and more durable than conventional benchmarks.

5.1 Recycle aggregate concrete

Recycled Aggregate Concrete (RAC) is a type of concrete that incorporates recycled aggregates derived from construction and demolition waste (CDW). The demand for RAC has been increasing due to its potential to minimize waste and contribute to sustainable construction practices. RAC is produced by recycling construction and demolition waste (CDW), reducing

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the environmental impact of concrete production. It involves processing waste concrete through separation, crushing, and impurity removal, with mobile and stationary recycling plants available. Only 1% of the aggregates used worldwide in structural construction come from recycled concrete, indicating huge potential for expansion. RAC reduces natural resource 50 depletion, but its mechanical properties are slightly weaker the conventional concrete.

Table 4: Carboclave Block Contribution to LEED Credit

LEED® Credit	Credit Points	Carboclave Block Contribution
EAp2: Minimum Energy Performance (option 1) & EAc1: Optimize Energy (option 1)	BD + C[2]: up to 19 ID + C[3]: n/a	• Thermal mass from exposed exterior and interior masonry walls absorbs and releases heat slowly, which moderates temperatures to reduce heating and cooling loads, energy consumption, and equipment size
MRc2: Construction Waste Management	BD + C: up to 2 ID + C: up to 2	• Modularity of masonry minimizes waste • Demolition & construction concrete masonry unit waste can be crushed & recycled
MRc4: Recycled Content	BD + C: up to 2 ID + C: up to 2	• Carboclave normal-weight blocks contain ±4% pre-consumer recycled content (slag cement, CO_2) • Carboclave light-weight blocks contain ±69% pre-consumer recycled content (expanded slag aggregate, slag cement, CO_2)
MRc5: Regional Materials	BD + C: up to 2 ID + C: up to 2	• Carboclave blocks are produced in Cambridge, Ontario, and are typically shipped by truck within 800 km radius
RPc1: Durable Building	BD + C: 1 ID + C: n/a	• Concrete masonry units are a proven material for the durability credit based on demonstrated effectiveness.
Innovation in Design - Building Product Innovation	BD + C: 1 ID + C: 1	• Concrete Carboclave block may be considered for an Innovation and Design point • Boehmers will provide the documentation required for credit submission
Innovation in Design - MRpc63: Building life-cycle impact reporting	BD + C: 1 ID + C: n/a	• Pilot credit is based on LEED v4 MR credit *Building life-cycle impact reduction (option 4)* • Data from the CCMPA EPD may be used in whole-building LCA assessments
Alternative Compliance Path (ACP) - <u>MRpc84: v4 MR credit category for v2009 projects</u> *This pilot credit permits pursuing the entire LEED v4 Materials and Resources category in place of the MR credits from LEED v2009. Carboclave block qualifies for the following MR credits:*	BD + C: 3 ID + C: n/a	**<u>Building life-cycle impact reduction (option 4)</u>** • Data from the CCMPA EPD may be used in whole-building LCA assessments • CCMPA EPD data included in the *Impact Estimator for Buildings* LCA software
	BD + C: 1 ID + C: n/a	**<u>Building product disclosure and optimization - environmental product declarations (option 1)</u>** • Boehmers was a participant in the Canadian Concrete Masonry Producer Association (CCMPA) industry-wide environmental product declaration EPD[4] . • EPD valued as one half (1/2) of a product for credit calculation
	BD + C: up to 2 ID + C: n/a	**<u>Construction and demolition waste management</u>** • Modularity of masonry minimizes waste • Demolition & construction masonry waste can be crushed & recycled

Source: https://www.carboclave.com/, n.d.

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5.2 Eco concrete

Eco-concrete is a sustainable alternative to conventional concrete, aiming to reduce greenhouse gas (GHG) emissions by minimizing cement usage and incorporating environmentally friendly substitutes. Cement Reduction and Substitutes Eco-concrete incorporates supplementary cementations materials (SCMs) like fly ash, granulated blast furnace slag (GBFS), and limestone powder to replace traditional cement. These SCMs have lower GHG emissions compared to Portland cement. The optimization of the water-cement ratio is a crucial factor, as reducing water content enables the use of less cement without compromising strength. Eco-concrete is a modified concrete mixture designed to reduce CO2 emissions while maintaining the strength and durability of conventional concrete. It is particularly relevant for high-rise buildings, where sustainability and structural integrity are both essential. Lower cement content uses 180kg / (CUM) of cement, compared to 275kg / (CUM) in conventional concrete. Includes fly ash (90kg / (CUM) and limestone powder (119kg / (CUM)) to replace a portion of cert, reducing carbon emissions. The water-to-cement (w / c) ratio is optimized at 0.81, using super plasticizers to maintain workability (Arnesson, 2019). Implementation in High-Rise Construction can be manufactured into precast wall elements, reducing on-site waste and emissions.

5.3 Difference between LEED and IGBC

Table 5: Key Difference between IGBC and LEED

Feature	IGBC	LEED
Origin	Developed by Confederation of Indian Industry (CII)	Developed by U.S. Green Building Council (USGBC)
Regional Focus	Specifically tailored for Indian climate, regulations, and construction practices	Global approach with some regional adaptations, primarily designed for developed countries
Certification Levels	Certified (50-59%), Silver (60-69%), Gold (70-79%), Platinum (80-100%)	Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), Platinum (80+ points)
Key Categories	Site Selection & Planning, Water Conservation, Energy Efficiency, Materials & Resources, Indoor Environmental Quality, Innovation & Design	Location & Transportation, Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, Innovation, Regional Priority
Energy Baseline	Uses Energy Conservation Building Code (ECBC) of India	Uses ASHRAE standards
Water Efficiency Focus	Greater emphasis reflecting India's water scarcity issues	Standard emphasis across all projects globally
Material Sourcing	Higher points for materials sourced within 400km	Larger radius for regional materials
Documentation Process	More straightforward, adapted to Indian construction industry capabilities	More rigorous technical submissions required

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Certification Cost	Generally, more affordable, designed for Indian market	Higher registration and certification fees
Market Recognition	Excellent within India, preferred for local projects	Stronger international recognition, preferred for global visibility
Vernacular Design	Specific recognition for traditional Indian architectural practices	Limited recognition of regional architectural traditions
Administrative Body	Indian Green Building Council	U.S. Green Building Council
Typical Applications	Local Indian projects, government buildings	International projects, multinational corporate facilities
Technical Expertise	Can typically be met with locally available expertise	Often requires specialized consultants
Point Distribution	More balanced across categories	Heavily weighted toward Energy & Atmosphere (30%)

6.0 Government Incentives for Green Building

As the global push for environmental sustainability intensifies, governments worldwide are implementing incentives to encourage sustainable practices. These initiatives aim to reduce carbon footprints, enhance energy efficiency and promote the use of eco-friendly materials in the build environment. Effective regulations not only ensure safety and performance standards but can also act as powerful levers to promote environmental sustainability and innovation in material technologies. By crafting policies that directly address the challenges and opportunities within the sustainable materials sector, governments can significantly influence the rate and manner of their adoption. By offering financial support, tax benefits, and regulatory advantages these incentives make it easier for developers, contractors and property owner to invest in green building technologies.

6.1 Who pays who gain

Table 6: Beneficiaries of Sustainable Practices

LEED Topic	Users	Owners	Developers	Green Industries	Society at large and Environment
Energy and Atmosphere	Reduce utility bills	Incur higher upfront construction costs but gain lower operational costs	Gain tax incentives and funding opportunities	Gain profit by selling systems parts and equipment	Reduce carbon emissions protect the environment and combat climate change
Water efficiency	Reduce utility bills	Incur higher up-front construction costs but gain lower operational costs	Gain tax incentives and funding opportunities	Gain profit by selling systems parts and equipment	Reduce chances of urban flooding and amount of grey water and sewage that needs to be channelled to treatment plants

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Indoor Environmental Quality	Enjoy healthier environment	Incur higher upfront construction costs but gain higher rental and occupancy rates	Gain tax incentives and funding opportunities	Gain profit by selling systems parts and equipment	
Materials and resources	Educating about the necessity to preserve natural resources	Incorrect higher upfront construction cost	Gain tax incentives and funding opportunities	Gain profit by selling systems parts and equipment	Reduce emissions, preserve natural resources and help in combating climate change
Sustainable sites	Enjoy and educate about indigenous vegetation and biodiversity	Gain efficient system	Gain tax incentives and funding opportunities	Gain profit by selling systems parts and equipment	Respect and value the natural environment reduces flooding and promote biodiversity
Location and transportation	Facilitate convenience and foster healthy habits such as daily working and biking	Gain higher rental and occupancy rates			Reduce emissions protect the environment and combat climate change
Innovation	Inspire educate and promote innovation	Gain fame	Gain expertise and fame	Advance science and technology	Advanced science and technology
Regional priority					Meet local environmental social equity and public health priorities

7.0 Conclusion

The construction sector is at a pivotal moment where sustainability and advanced technologies are essential for eco-friendly, cost-effective, and inclusive high-rises. This research explores innovations like BIM, prefabrication, renewable energy, eco-friendly materials, and advanced façades to reduce emissions and enhance efficiency. Case studies, including. AL-Rehan Building, showcase successful green building strategies. Government incentives for LEED certification and tax benefits drive adoption, despite challenges such as high costs and industry resistance. With continued investment, policies, and collaboration, transitioning to low-carbon, smart high-rises is both feasible and essential for sustainable urban development.

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