Encouraging AI- Enabled Green Building Adoption in Mumbai's Commercial Sector

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Abstract

Mumbai's transformation into a smart city emphasizes the need for Artificial Intelligence (AI)-enabled green buildings in the commercial sector to address rising temperatures and sustainability concerns. These buildings use smart technologies like IoT sensors and automated systems to optimize energy use, cut carbon emissions, and improve building performance.

According to the India Meteorological Department (IMD), Mumbai's average temperature has risen by at least 1.6°C over the last century, with a 0.25°C increase per decade over the past 40 years, as reported in "Green City Goals: 7 Ways Mumbai is Creating a Sustainable Future." This gradual but consistent increase highlights the demand for climate-responsive infrastructure and sustainable urban planning.

Despite growing awareness, AI-enabled green building strategies remain limited in commercial buildings. This study identifies key barriers to adopting AI-powered green buildings in Mumbai's commercial sector.

Keywords—Ai-Driven sustainable Architecture, green buildings, Energy Efficient

I. Introduction

Urban commercial buildings are significant contributors to global energy consumption and greenhouse gas emissions, intensifying climate change and resource depletion.

Fig. 1. Global greenhouse gas Emissions from building and construction sector. Source: Global Status Report for Buildings and Construction, 2022 (UNEP, 2022). Chart created by the author

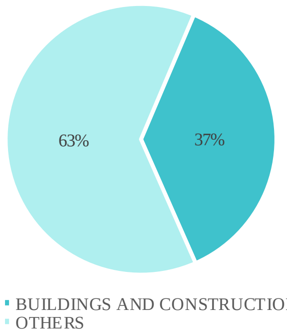
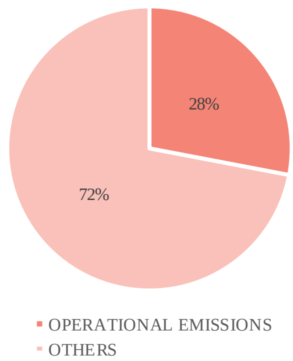


Fig. 2. Emissions from building operations. Source: Global Status Report for Buildings and Construction, 2022 (UNEP, 2022). Chart created by the author



The buildings and construction sector accounts for approximately 37% of global emissions, with 28% from building operations as illustrated in Figure 1 & 2. To mitigate these effects, the concept of green buildings—focusing on sustainable design, construction, and operation—has emerged.

Integrating Artificial Intelligence (AI) into these green buildings—termed AI-enabled green buildings—enhances performance during the construction and operation phase of the building. A study by the **American Council for an Energy-Efficient Economy showed that AI could enable energy savings of up to 20% in commercial buildings.**

Globally, several commercial buildings demonstrates this integration: The **Edge in Amsterdam** uses AI to optimize energy use and occupant comfort. **Shanghai Tower in China** employs AI-based systems to reduce energy consumption, and the **Bullitt Center in USA** operates as a net-zero energy commercial building powered by AI-driven sustainability models.

In India, the adoption of green building is accelerating with over 14,500 IGBC- certified projects covering 12 billion sq.ft as of 2023. One of the example like **Indira Paryavaran Bhavan**, New Delhi's net-zero building uses AI-powered

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energy management. **Infosys campuses** across India have also successfully deployed AI-based monitoring systems. However, in Mumbai, integration of AI-enabled green building technologies in commercial sector remains limited.

a) Background

Mumbai, as India's financial capital, has a rapidly growing commercial real estate sector that significantly contributes to the city's energy consumption and carbon footprint. According to the IMD, Mumbai's average temperature has increased over the past century, emphasizing the need for climate-responsive infrastructure. While global cities have successfully integrated AI-driven green building technologies, Mumbai faces financial, regulatory, and implementation challenges that hinder their large-scale adoption. High initial costs, inadequate policy support, and limited financial incentives act as key barriers, preventing developers from investing in AI-powered energy management systems.

b) Purpose of the Study

This study identifies challenges hindering AI-enabled green building adoption in Mumbai's commercial real estate sector, while exploring global and national examples to highlight potential benefits and explores how similar strategies could be adapted for Mumbai's unique urban and environmental challenges.

c) Scope and Limitations

The research focuses on Mumbai's commercial buildings, examining factors affecting AI-enabled green technology adoption, with global and national case studies used for comparative insights.

II. LITERATURE REVIEW

a) Green Buildings and Sustainable Development Goals

Manasi et al. (2021) discuss the significance of green buildings in achieving the Sustainable Development Goals (SDGs). Their study highlights key aspects such as energy efficiency, waste management, and resource conservation, which contribute to environmental and economic sustainability. The paper also examines various green certification systems like LEED and GRIHA, emphasizing their role in promoting sustainable construction practices.

b) Challenges in the Adoption of Green Buildings

Abraham and Gundimeda (2021) analyze barriers to adopting green buildings in India. Their research identifies financial constraints, lack of regulatory enforcement, limited technical expertise, and low awareness among stakeholders as primary challenges. Similarly, Saha et al. (2022) classify these barriers into economic, regulatory, organizational, social, and technological categories, further emphasizing the need for strategic policy interventions to address these issues.

c) Green Building Trends and Performance in India

Malik et al. (2021) highlight the rise of green building development in India through climate-responsive design, energy-efficient technologies, and supportive policy frameworks like ECBC and IGBC. Their study includes case examples demonstrating the use of solar panels, rainwater harvesting, and daylight optimization. A performance analysis of Mumbai's commercial buildings reinforces the role of passive design, high-performance envelopes, and renewable energy integration in significantly reducing energy consumption and promoting sustainable urban construction practices.

d) Mumbai Climate Action Plan and Policy Frameworks

The Mumbai Climate Action Plan (2021) outlines the city's goals to reduce carbon emissions, promote green buildings, and implement climate-responsive infrastructure through supportive regulatory frameworks.

e) Smart Green Building Technologies and AI Integration

Umoh (2022) investigates the integration and impact of AI and IoT in sustainable building designs. Focusing on AI-driven energy management, predictive maintenance, automated climate control, and data-driven sustainability strategies.

Dubey (2022) discusses how AI-driven green technologies like automated fault detection, smart grid integration, and occupancy-based energy optimization, enhance the building's energy efficiency and reduces carbon footprints.

Ge et al. (2022) analyze urban planning and green building technologies based on artificial intelligence. Their research presents global case studies where AI-powered systems improve building operations, optimize resource usage, and support climate resilience in urban environments.

III. IMPORTANCE OF SUSTAINABLE DEVELOPMENT IN URBAN COMMERCIAL SPACES

Urban areas are significant contributors to global economic activity but also account for substantial energy consumption and greenhouse gas emissions. Sustainable development within urban commercial spaces is crucial for several reasons:

TABLE I. IMPACT OF SUSTAINABLE DEVELOPMENT

Reason	Explanation
Environmental Impact Reduction	Lowers carbon footprint, reduces waste, and improves urban air quality.
Economic Advantages	Saves costs through energy efficiency and green infrastructure investments.
Enhanced Quality of Life	Adds green spaces, improves air quality, and boosts urban liveability.
Resource Conservation	Promotes responsible water, energy, and material use.
Climate Change Mitigation	Reduces emissions and integrates renewable energy.

By focusing on sustainable development in urban commercial spaces, cities can address environmental challenges while fostering economic growth and improving the well-being of their inhabitants.

To achieve sustainable development in urban commercial spaces, integrating advanced technologies like AI can play a crucial role. AI-enabled green buildings leverage smart solutions to drive sustainability and efficiency.

IV. AI-Enabled Green Buildings:

AI-enabled green buildings integrate technologies with green building practices to enhance energy efficiency, resource management, and overall environmental performance. These buildings utilize AI-driven systems. Table II highlights key features of AI-enabled green buildings:

TABLE II. KEY FEATURES OF AI-ENABLED GREEN BUILDINGS

Feature	Description
Smart Energy Management	AI optimizes lighting, HVAC, appliances, and renewable energy systems by adjusting usage based on real-time occupancy and weather for maximum efficiency.
Predictive Maintenance	AI predicts equipment failures and schedules maintenance, reducing energy wastage and downtime. Predictive maintenance powered by AI reduces breakdowns by up to 70%.
Automated Building Systems	Smart IoT sensors and adaptive systems regulate air quality, temperature, water use, shading, and ventilation to enhance comfort and reduce energy consumption.
Sustainable Resource Management	AI monitors and manages water, waste, and material efficiency during construction and operation.
Carbon Footprint Reduction	AI analyzes energy patterns and simulates building designs to predict environmental impact and suggest emission-reduction strategies before construction.

V. Case Study

a) The Edge – Amsterdam, Netherlands

a.1) Overview:

Architects: PLP Architecture
Completion Year: 2014
Height: 40m (13 floors)
Function: Office Building (HQ of Deloitte Netherlands)
Sustainability Rating: BREEAM Outstanding (98.36%)

Fig. 3. Elevation of The Edge
Source: EDGE Technologies. Retrieved from https://edge.tech/buildings/the-edge

a.2) Architectural and Design Features:

1. As shown in figure 4, the building has an atrium that maximizes natural light and ventilation and acts as a buffer zone, reducing the impact of cold winter winds.

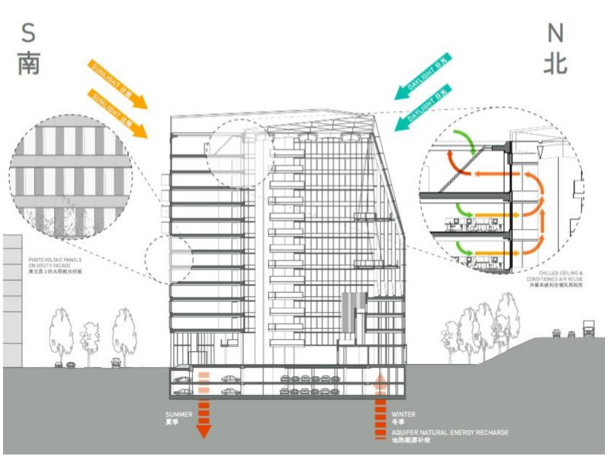
Fig. 4. Atrium View of The Edge
Source: EDGE Technologies. Retrieved from https://edge.tech/buildings/the-edge

2. Building façade and orientation help reduce heat loss during cold seasons.
3. Open-plan workspaces designed for flexible work environments.
4. Smart façade with automated sun shading to optimize daylight use.
5. High-performance triple-glazed glass reduces energy consumption.

a.3) Benefits of The Edge's Orientation

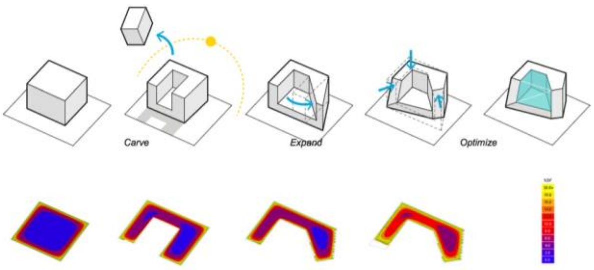
1. Building Positioning: The main atrium faces south, optimizing natural daylight penetration as shown in Figure 5, and Solar panels on the roof and neighboring structures are positioned for maximum solar gain.
2. Glazing and Sunlight Optimization: Triple-glazed windows reduce heat loss while allowing ample natural light. External shading and automated blinds minimize glare and overheating in summer.
3. Thermal Comfort: The aquifer thermal energy storage (ATES) system helps regulate indoor temperature. South-facing orientation balances heat gain in winter and shading in summer.

Fig. 5. Section of The Edge by PLP Architecture, illustrating the building's design and layout.
Source: Retrieved from https://www.archdaily.com/



a.4) Sustainability and Smart Technology:

Fig. 6. Heat Gain and 3-D Massing Conceptual Diagram of The Edge by PLP Architecture, illustrating the building's design and layout.
Source: Retrieved from https://www.archdaily.com/



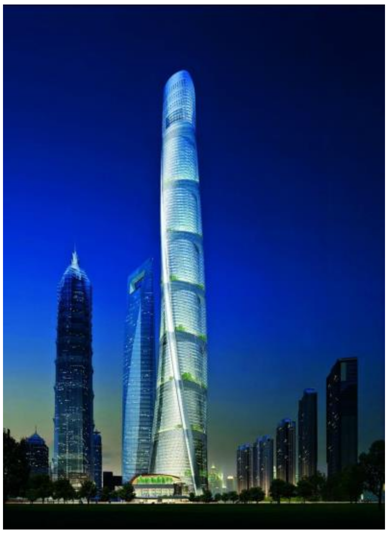
1. Energy Efficiency: Rooftop and nearby solar panels generate more energy than it consumes. A thermal energy storage system (ATES) stores summer heat for winter use. LED lighting with Ethernet integration reduces energy consumption by 80%.
2. Smart Building Systems: A mobile app lets employees control lighting, temperature, and workspaces. Sensors monitor occupancy and energy to maximize efficiency.
3. Water Management: Rainwater collection and greywater recycling for non-drinking uses.

This study highlights how the integration of AI, IoT, and sustainable design inspires smart offices for future net-zero energy buildings and enhancing workspace productivity.

b) Shanghai Tower – Shanghai, China

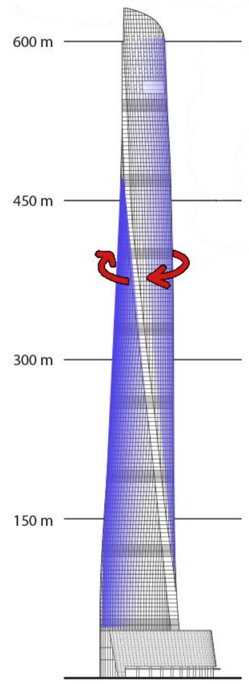
b.1) Overview:
Architects: Gensler
Completion Year: 2015
Height: 632m (128 floors)
Function: Mixed-use
Sustainability Rating: LEED Platinum

Fig. 7. Shanghai Tower within the Lujiazui skyline.
Source: Retrieved from https://www.archdaily.com/



b.2) Architectural and Structural Features:

Fig. 8. Twisting Elevation of Shanghai Tower.
Source: Retrieved from https://www.designingbuildings.co.uk



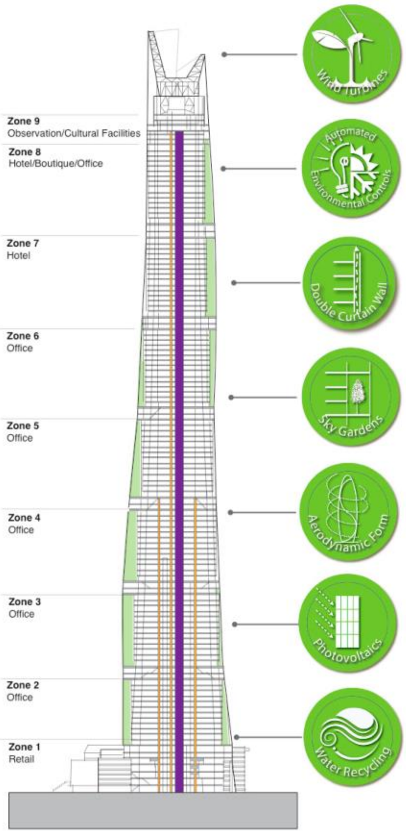
1. Unique twisting form reduces wind loads by 24%, saving material costs.
2. Double-skin façade creates an insulating air layer, reducing energy use.
3. Houses nine vertical zones, each acting like a self-contained city.
4. Sky gardens at various levels enhance natural ventilation.

b.3) Building Orientation & Shape

1. The twisting, aerodynamic form is designed to reduce wind loads by up to 24%, making it stable against strong typhoon winds.
2. The tower rotates 120° from base to top, optimizing wind deflection and reducing vortex shedding, which can cause structural sway.
3. The south-facing façade maximizes exposure to natural light and reduces direct heat gain through high-performance glazing.

b.4) Sustainability and Smart Systems:

Fig. 9. Elevation Showing Space Division at Different Levels.
Source: Retrieved from https://www.mdpi.com



1. Energy Efficiency: Wind turbines generate on-site electricity. A combined heating and power system (CHP) improves efficiency. The double-skin façade reduces cooling needs by 50%.
2. Water Management: Rainwater harvesting and greywater recycling supply 50% of water needs. Uses natural wastewater treatment with bio- filtration systems.
3. Innovative Technologies: Second-fastest elevators in the world (20.5 m/s). Building automation system monitors temperature, humidity, and lighting.

This model demonstrates how skyscrapers can reduce environmental impact while setting a precedent for the future of urban architecture.

c) 22 Bishopsgate – London, UK

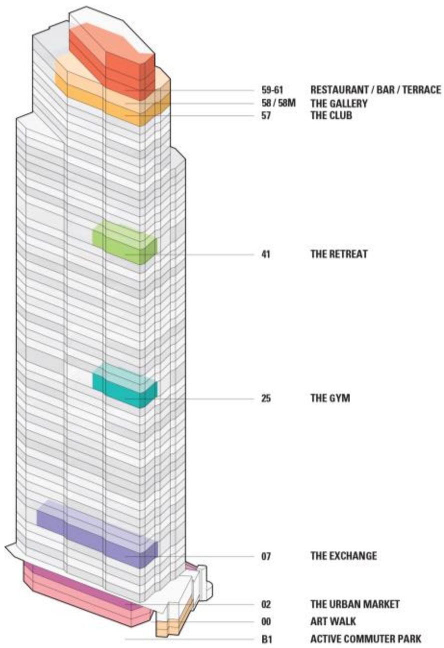
c.1) Overview

Location: London, UK
Architects: PLP Architecture
Completion Year: 2020
Building Type: Commercial Office Tower
Height: 278 meters (912 feet)
Floors: 62
Certification: Designed for BREEAM Excellent and WELL Building Standard certification

Fig. 10. Elevation of 22 Bishopsgate.
Source: Retrieved from https://www.skyscrapercenter.com

c.2) Architectural and Design Features

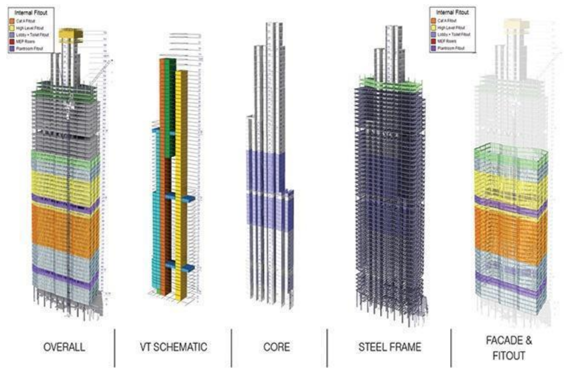
Fig. 11. Mass Model of 22 Bishopsgate.
Source: Retrieved from https://plparchitecture.com



1. Faceted Glass Form & Urban Context: The 23-sided faceted glass design blends with London's skyline, maximizes daylight and minimizes heat gain, reducing lighting and cooling energy use.
2. 22 Bishopsgate is designed as a self-contained urban hub, with over 100,000 sq. ft. of amenities for its occupants.
3. Human-Centric Design: Designed to WELL standards, the building features advanced acoustic insulation and optimized floor layouts for natural light, flexible and healthy workspaces.

c.3) Sustainability and Smart Systems

Fig. 12. BIM Model of 22 Bishopsgate.
Source: Retrieved from https://www.building.co.uk



1. Triple-glazed façade with automated blinds reduces solar heat gain by up to 60% while maintaining 55% daylight. Smart shading and ventilation adapt to weather, lowering cooling and lighting demand.
2. An AI-IoT-integrated BMS manages energy in real-time. AI monitors air quality, while facial recognition and QR access enhance security. A mobile app controls lighting, temperature, and facility bookings.
3. Green mobility is supported through extensive cycling facilities, all-electric HVAC, rainwater harvesting, greywater recycling, and smart waste systems to reduce carbon emissions and resource use.

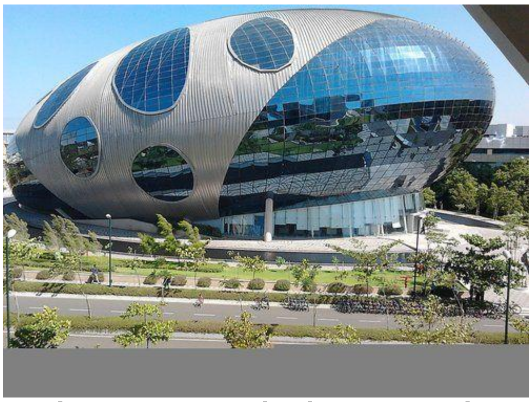
Bishopsgate, London's first AI-enabled sustainable skyscraper, combines all-electric operations, predictive AI maintenance, and smart tech for climate control and personalization, creating a flexible, human-centric "Vertical Village" with office, wellness, and cultural spaces.

d) Infosys Pune – SDB 1 (Maharashtra)

d.1) Overview:
LEED Certification: LEED Platinum
Location: Pune, Maharashtra
Built by: Infosys Limited
Architect**:** Hafeez Contractor
Completion Year**:** 2016
Building Type**:** IT & Corporate Office

d.2) Architectural & Design Features:

Fig. 13. Elevation of SDB 1
Source: Retrieved from https://www.glassdoor.co.in



1. Oriented to minimize solar heat gain and maximize daylight, with overhangs, shading devices, and double-skin facades to improve thermal insulation.
2. Radiant Cooling Technology: Chilled water pipes in floor slabs enable passive cooling, cutting HVAC energy use by up to 60%.
3. Triple-glazed Low-E glass minimizes heat gain and maximizes daylight; smart glass adjusts transparency for comfort.
4. Operable windows and atriums enable cross-ventilation, reducing reliance on mechanical systems.
5. Roof gardens and water features lower ambient temperatures and enhance cooling.

d.3) sustainability and smart systems:
1. AI-Based Smart Energy Management: AI and IoT sensors optimize lighting, HVAC, and power use in real time based on occupancy.
2. Solar-Powered Energy Efficiency: solar panels with on-site battery backup ensure continuous renewable energy supply.
3. Water Conservation & Waste Management: Zero-discharge STP, rainwater harvesting, groundwater recharge, drip irrigation, and greywater recycling reduce freshwater use and support greenery.

Achieving 88% energy reduction and 40% lower water usage, this building is recognized as one of the most energy-efficient commercial structures globally, contributing to long-term sustainability.

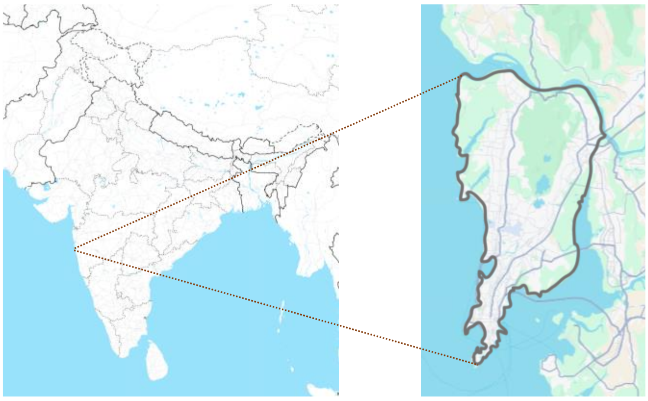
e) Case Study Analysis

TABLE III. CASE STUDY ANALYSIS

Feature	The Edge, Amsterdam	Shanghai Tower, China	22 Bishopsgate, London	Infosys Pune, India
Architect	PLP Architecture	Gensler	PLP Architecture	Hafeez Contractor
Completion Year	2014	2015	2020	2016
Building Type	Office Building	Mixed-Use Skyscraper	Commercial Tower	IT/Corporate Campus
Height	73m	632m	278m	~42m
Floors	15 floors	128 floors	62 floors	9 floors
Total Area	40,000 sq. m	420,000 sq. m	125,000 sq. m	3.6 million sq. ft
Certifications	LEED Platinum	LEED Platinum & China Green Building Label	BREEAM Excellent	LEED Platinum
Architectural Features	Smart façade, open-plan workspaces, solar-integrated roof	Twisting form to reduce wind loads, double-layer façade for insulation	Low-carbon construction, panoramic views, smart workplace design	Passive cooling, daylight harvesting, self-sufficient campus
Sustainability & Green Technologies	Net-zero energy, IoT-based workspace optimization, rainwater collection	AI-managed ventilation, wind turbines, greywater recycling	AI-powered waste management, temperature control, energy-efficient façade	100% solar-powered, rainwater harvesting, AI-driven HVAC & lighting
Smart AI-Enabled Features	AI-driven real-time workspace allocation, IoT smart lighting	AI-controlled airflow, smart glass windows, real-time energy monitoring	AI-integrated building access, smart elevators, tenant experience app	AI-powered climate control, energy analytics, automated HVAC
Energy & Water Management	Energy-positive building, excess power returned to the grid	35% reduction in energy consumption, rainwater harvesting	Reduced energy use by 30% with AI-management	40% energy savings via AI
Workplace Efficiency	AI-powered desk allocation, smart meeting rooms	Smart elevators, adaptive lighting, real-time environment monitoring	AI-driven indoor air quality sensors, occupant tracking	AI-optimized air conditioning, low-carbon footprint
Impact & Innovation	"World's greenest office", setting sustainable benchmarks	Tallest green skyscraper	First AI-integrated tower in London with fully digital operations	Model for self-sustaining IT campuses in India
Conclusion	Buildings can generate more energy than they consume.	Optimizes wind resistance, renewable energy, and AI-driven automation.	AI reduces carbon footprint and improves occupant experience	Self-sustaining corporate campuses.

VI. MUMBAI: A DYNAMIC LANDSCAPE

Fig. 14. Location Map of Mumbai
Source: https://www.google.com
Graphics created by Author



Mumbai, India's financial capital, offers a compelling context for urban and commercial development research due to its rapid growth, real estate trends, and sustainability challenges.

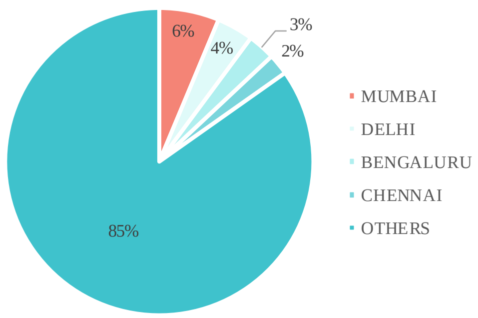
a) Population and Urban Density

With over 20 million residents, Mumbai ranks among the world's most densely populated cities, straining infrastructure and demanding efficient, sustainable building solutions.

b) Economic Significance & Growth Trends

Contributing nearly 6% of the country's GDP Mumbai hosts major corporate headquarters, stock exchanges, and business districts, making it a crucial driver of national and global commerce. Its growing commercial sector fuels a rising demand for energy-efficient infrastructure.

Fig. 15. Contribution of Indian Cities to Country's GDP
Source: https://en.wikipedia.org
Chart created by Author



c) Real Estate & Urbanization Trends

Mumbai's real estate sector has shown significant growth, with over 141,000 property registrations recorded in 2024. This surge, reflects a booming urbanization trend.

d) Climate & Sustainability Challenges

Mumbai faces mounting environmental challenges which emphasize the need for sustainable building practices.

Urban Heat Island Effect: Mumbai’s dense urban fabric and heat-absorbing materials like concrete and asphalt elevate local temperatures. Built-up areas can reach 34°C, compared to 28°C in less urbanized zones, highlighting the climatic impact of rapid urbanization.

Per Capita Emissions: A September 2024 report by Mongabay India indicates that Mumbai's per capita carbon emissions were approximately 2.0 tonnes, the highest among major Indian cities.

Mumbai’s economic significance, rapid urbanization landscape, commercial real estate expansion, and critical sustainability challenges collectively establish it as a high-priority location for research.

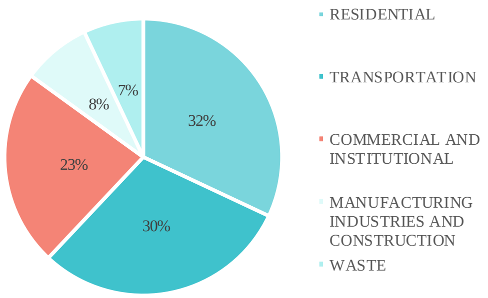
VII. Mumbai’s Commercial Sector: A Hub of High Energy Demand

Mumbai’s commercial buildings significantly drive energy use and emissions. Rising demand, thermal power reliance, and future projections stress the urgent need for AI-enabled sustainable solutions in this sector.

a) High Energy Consumption and GHG Emissions

The Energy & Buildings sector accounts for over 60% of Mumbai’s GHG emissions, with commercial and institutional buildings contributing around 23% due to high electricity use for lighting, cooling, and operations.

Fig. 16. Contribution of Indian Cities to Country’s GDP
Source: https://mcap.mcgm.gov.in
Chart created by Author



b) Future Projections and Sustainability Concerns

Without intervention, GHG emissions from buildings may increase 3.3 times by 2050, worsening environmental and infrastructure challenges—highlighting the urgent need for sustainable commercial development.

c) Mumbai’s Energy Mix and Heavy Reliance on Thermal Power

Mumbai's electricity demand ranges from 3,400 to 3,600 MW, with 95.34% of supply from thermal power, contributing heavily to emissions.

Mumbai’s commercial sector, a major energy consumer and emission contributor, requires AI-enabled green buildings to improve energy efficiency, reduce emissions, and support sustainability goals, aiding the fight against climate change.

VIII. Challenges in Adopting AI- Driven Green Buildings in Mumbai’s Commercial Sector

The integration of AI in green buildings could transform Mumbai’s commercial sector by enhancing energy efficiency and sustainability. Despite their potential to enhance sustainability, the adoption of AI-driven green building technologies in Mumbai’s commercial sector is hindered by financial, technical, regulatory, and market-related challenges.

TABLE IV. Analysis of Literature Review on Barriers to AI-Enabled Green Buildings

Barrier Category	Challenges Identified	Literature Sources
Financial	High initial investment costs and uncertain return on investment (ROI) deterring stakeholders.	Saha et al. (2022), Abraham & Gundimeda (2021)
Technical	Limited technical expertise and skilled workforce to implement newer technologies.	Rodríguez-Gracia et al. (2022), Ge et al. (2022)
Regulatory	Absence of strong AI and green building regulations, lack of incentives for AI integration.	Mumbai Climate Action Plan (2021), Manasi et al. (2021)
Infrastructure & Data	Challenges in integrating AI with existing building infrastructure, lack of standardized data frameworks	Umoh (2022), Dubey (2022)
Market & Adoption	Resistance from developers and building owners due lack of awareness regarding benefits.	Malik & Bhat (2021), Saha et al. (2022)
Security & Privacy	Concerns over data privacy and cybersecurity risks in AI-driven building automation.	Rodríguez-Gracia et al. (2022), Ge et al. (2022)

Addressing these barriers requires a combination of government incentives, industry awareness programs, investment in technical training, and robust regulatory frameworks.

IX. Methodology

This research studies reports, policies, and past research to understand the challenges of using AI in green buildings in Mumbai's commercial sector. It follows a structured approach to gather and analyze information.

Fig. 17. Methodology Process
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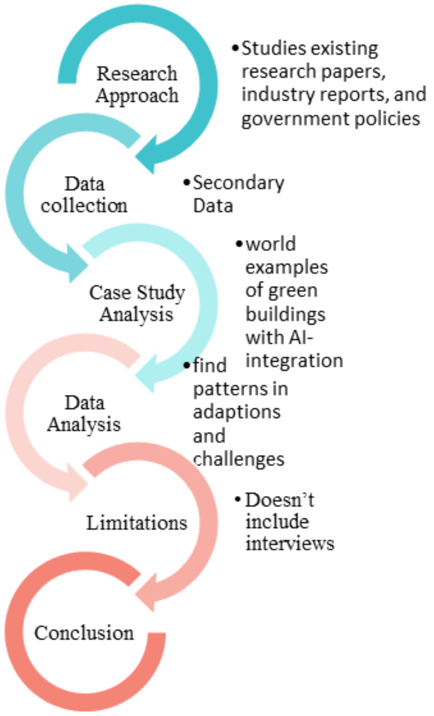

a) Research Approach

The study is based on a literature review, which means it collects and studies existing research papers, industry reports, and government policies about AI in green buildings.

b) Data Collection

Secondary Data: The study uses information from global sustainability organizations like LEED, IGBC, and GRIHA, as well as the Mumbai Climate Action Plan (2021).

Selecting Studies: Research papers were chosen based on their relevance to AI in green buildings, adoption challenges, and sustainable practices.

Case Studies: Real-world examples of green buildings with AI- integration were studied to understand success factors and challenges.

c) How the Data Was Used

Relevant research papers *to find patterns in challenges* and case studies of AI-enabled green buildings, both globally and in India, were analyzed to identify success factors and obstacles.

d) Limitations

The study does not include primary research, like interviews or on-site visits.

X. Conclusion

This research emphasizes the importance of AI-enabled green buildings in Mumbai's commercial sector to achieve sustainability, energy efficiency, and smart urban development. It identifies key barriers to adoption, including high costs, technical gaps, and regulatory challenges, while highlighting successful strategies from India and global case studies.

The paper calls for stronger incentives, better regulations, and industry collaboration to overcome these challenges.

Future studies can explore more case studies, develop policy frameworks, and investigate emerging AI technologies for enhanced green building integration.

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