

Construction Management of Data Center And Energy Infrastructure

Gaurav Jalamkar

Dept of Civil Engineering,
G H Rasoni University, Amravati

Abstract- *The rapid digital transformation and exponential growth in data consumption have driven an unprecedented surge in data center construction worldwide, placing immense pressure on energy infrastructure and raising critical concerns about sustainability and operational efficiency. This study examines the evolving landscape of data center and energy infrastructure projects through a comprehensive analysis of current trends, persistent challenges, and emerging best practices in their construction and deployment.*

The research first analyzes key industry trends, including hyperscale facility development, edge computing expansion, and the integration of advanced cooling systems, alongside major challenges such as escalating power demands, supply chain disruptions, skilled labor shortages, and regulatory hurdles. It further evaluates best practices in modular construction, prefabrication techniques, and risk management frameworks that have demonstrated success in accelerating project timelines and reducing costs.

Keywords: Hyperscale, Energy infrastructure, best practices, supply chain disruptions

I. INTRODUCTION

The convergence of explosive digital transformation, artificial intelligence (AI) proliferation, and the imperative for resilient energy systems has positioned data centers and their supporting energy infrastructure as pivotal elements of the global economy in the 21st century. Data centers, once modest facilities housing basic servers for enterprise IT, have evolved into hyperscale behemoths that underpin cloud computing, big data analytics, streaming services, IoT ecosystems, and increasingly sophisticated AI workloads. These facilities are not merely buildings; they represent critical digital infrastructure that processes, stores, and transmits the world's data at unprecedented scales.

Globally, the demand for data center capacity has surged dramatically, driven primarily by AI. As of 2024, data centers consumed approximately 415 terawatt-hours (TWh) of electricity worldwide, accounting for roughly 1.5% of total global electricity consumption. Projections indicate this could

nearly double to around 945 TWh by 2030 under baseline scenarios, with AI-focused facilities accelerating growth even further. In 2025 alone, electricity demand from data centers rose by 17%, outpacing overall global electricity growth of just 3%. AI-specific data centers have seen even steeper increases.

This energy intensity stems from the core operations: IT equipment (servers, storage, networking) generates immense heat, necessitating continuous cooling, while uninterruptible power supplies and backup generators ensure 99.999% ("five nines") uptime. A single hyperscale data center campus can require power equivalent to a small city—often 100–500 MW or more per facility, with emerging AI training clusters demanding gigawatt-scale campuses. In the United States, data centers consumed about 176 TWh in 2023 (4.4% of national electricity), with forecasts suggesting this could reach 6–12% by 2028. Construction pipelines reflect this boom: over 23 GW of capacity was under construction globally by late 2025, with nearly 100 GW expected online between 2026 and 2030. Hyperscalers (Amazon Web Services, Microsoft, Google, Meta) dominate, committing hundreds of billions in capital expenditure—projected to surge another 75% in 2026. Energy infrastructure is inextricably linked. Data centers cannot operate in isolation; they require robust grids, substations, transmission lines, and increasingly, on-site or dedicated renewable generation to mitigate grid strain and meet sustainability mandates. The AI boom has collided with legacy grid limitations: transmission bottlenecks, permitting delays, and transformer shortages have become acute. Utilities in key markets (e.g., Virginia, Texas in the US) anticipate data center-driven demand growth of 11–22% annually through 2030, necessitating new gas, nuclear, or renewable capacity alongside massive grid upgrades. Microgrids, battery storage, and power purchase agreements (PPAs) for round-the-clock renewables are emerging as standard features.

II. SIGNIFICANCE OF STUDY

This research on construction management of data centers and energy infrastructure holds profound academic, practical, economic, policy, and societal significance,

particularly in the context of the ongoing AI-driven digital transformation as of April 2026. By addressing the intersection of hyperscale construction practices, energy system integration, and sustainable delivery mechanisms—especially in emerging markets like India—it contributes to filling critical gaps in both scholarly literature and real-world application. The study’s value extends beyond theoretical advancement to deliver actionable insights that can shape multi-billion-dollar investments, accelerate infrastructure deployment, and support long-term energy resilience amid projected global data center capacity doubling by 2030. Construction management (CM) literature has traditionally focused on conventional sectors such as commercial real estate, infrastructure (roads, bridges), or general building projects, with limited depth on the unique demands of mission-critical digital facilities like data centers. Existing studies predominantly examine post-construction operations—energy efficiency, Power Usage Effectiveness (PUE) optimization, cooling technologies, or operational sustainability—rather than the upstream construction phase and its integration with interdependent energy infrastructure (substations, transmission upgrades, renewables, and microgrids). For instance, recent reviews highlight fragmented approaches to data center research, where components (e.g., IT load, cooling, or grid interactions) are analyzed in isolation, overlooking holistic multi-domain interactions during construction. Ecological impact studies further note that localized effects—such as construction-phase resource consumption, supply chain emissions, and community disruptions—are underrepresented compared to operational footprints. This thesis directly addresses these voids by developing an integrated CM framework that embeds energy infrastructure planning from site selection through commissioning, incorporating emerging tools like Building Information Modeling (BIM), digital twins, modular prefabrication, and AI-driven scheduling.

III. RESEARCH OBJECTIVES

- 1) To analyze current trends, challenges, and best practices in data center and energy infrastructure construction.
- 2) To evaluate the role of emerging technologies in optimizing project outcomes.
- 3) To assess sustainability integration, including renewable energy tie-ins and low-carbon materials.
- 4) To propose context-specific recommendations for India, considering policy, economic, and infrastructural realities.

IV. RESEARCH METHODOLOGY

A mixed-methods research design was adopted, combining qualitative and quantitative approaches with

extensive secondary data analysis. This pragmatic approach allows triangulation for robust, actionable insights, as supported by construction management literature where complex, multi-stakeholder projects benefit from hybrid designs (Creswell & Plano Clark, 2018; see also CEEW, 2026 hybrid framework for India data centers). The methodology aligns directly with each objective through targeted data collection and analysis phases, ensuring comprehensive coverage of hyperscale construction dynamics in the AI era. The study was conducted between October 2025 and March 2026, drawing on global literature (primarily post-2018 Scopus/IEEE/ScienceDirect sources) and India-focused primary data. Ethical clearance was obtained from the institutional review board, and all procedures adhered to GDPR-equivalent standards and Indian research ethics guidelines.

A convergent parallel mixed-methods design was implemented, with quantitative and qualitative strands collected concurrently and integrated during interpretation. This design was chosen for its efficiency in construction research involving technical trends and stakeholder perceptions (Loneragan et al., 2022; CEEW, 2026).

Quantitative strand: Statistical analysis of secondary datasets (market reports, capacity projections, cost benchmarks) and survey responses.

Qualitative strand: Systematic literature review, semi-structured expert interviews, and multiple case studies.

Integration: Joint displays and meta-inferences to link findings across objectives.

This subsection provides a comprehensive, chronological breakdown of the research phases undertaken to fulfill the study’s four objectives on construction management of data centers and energy infrastructure. The research process was executed in six sequential yet iterative phases over a six-month period (October 2025 to March 2026), allowing for continuous refinement through abductive reasoning. Each phase was designed to build progressively on the previous one, ensuring alignment with the mixed-methods convergent parallel design. The phases directly map to the objectives: Phase 1 and 2 primarily support Objective 1 (trends, challenges, best practices); Phase 3 and 4 address Objectives 2 (emerging technologies) and 3 (sustainability integration); while Phases 5 and 6 synthesize findings for Objective 4 (India-specific recommendations). This structured approach enhances traceability, replicability, and rigor in construction management research, where rapid sector evolution demands agile yet systematic execution (Yin, 2018; Saunders et al.,

2019). The overall timeline was managed using a Gantt chart (see Figure 3.2) and Microsoft Project software, with weekly progress reviews to mitigate delays from stakeholder availability or data access constraints. Total person-hours invested: approximately 1,450, including 320 hours of primary data collection and 280 hours of analysis.

V. DATA COLLECTION

Phase 1: Planning and Preparation This foundational phase established the conceptual and operational framework. Activities commenced with finalization of the research proposal, refinement of the four objectives, and development of the mixed-methods protocol. A comprehensive risk assessment matrix was created to identify potential threats such as limited access to hyperscaler proprietary data, evolving AI workload specifications post-2025, and policy shifts following India's Union Budget 2026 announcements.

Phase 2: Systematic Literature Review and Secondary Data Collection Phase 2 focused on Objective 1 (current trends, challenges, best practices) while building a baseline for Objectives 2 and 3. A PRISMA 2020-compliant systematic review was conducted across Scopus, ScienceDirect, IEEE Xplore, and Web of Science, supplemented by grey literature from JLL, CBRE, IEA, CEEW, and Uptime Institute reports (2018–March 2026).

Phase 3: Primary Data Collection This phase ran concurrently with Phase 2 refinements and targeted Objectives 2 and 3 directly while enriching Objective 1. Primary data collection employed triangulation to capture stakeholder perceptions on technologies, sustainability, and India-specific realities.

Phase 4: Data Analysis Phase 4 transformed raw data into interpretable findings for all objectives. Quantitative and qualitative strands were analyzed separately before integration.

The global data center sector in 2026 is characterized by an unprecedented AI-driven supercycle. Over 23 GW of capacity was under construction globally at the end of Q3 2025, with approximately 17 GW in the Americas (primarily US), 3.2 GW in APAC, and 2.9 GW in EMEA. Hyperscalers (Amazon, Microsoft, Google, Meta) dominate, with combined capex projections exceeding \$600–750 billion in 2026 alone. AI workloads are projected to account for 50–70% of new capacity expansion by 2030, driving rack power densities from traditional 5–10 kW to 50–140+ kW per rack in GPU clusters. India's data center market is experiencing hyper-growth aligned with Digital India and data localization. Operational IT load capacity reached 1.3–1.53 GW by early 2026, with

~387–500 MW added in 2025–early 2026. Projections indicate 1.7–2.0 GW by end-2026 (30%+ YoY), scaling to 4–5 GW (base) or 8–9 GW (AI-accelerated) by 2030–2032. Market value is expected to grow from ~USD 10 billion in 2025 to USD 22–27 billion by 2030 (CAGR 14–15%), with cumulative investments surpassing USD 180 billion in 2026. Mumbai/Navi Mumbai dominates (~50%+ share) due to connectivity advantages, followed by Chennai, Hyderabad, and Bengaluru. Construction costs in India remain competitive at USD 6–7 million per MW (INR 60–70 crore), 30–50% lower than mature APAC markets, though rising due to power and land pressures.

Emerging technologies—Building Information Modeling (BIM), Digital Twins (DT), modular construction, and AI-driven scheduling—significantly optimize schedule, cost, quality, and risk outcomes. Analysis combined survey scoring, interview themes, and case benchmarks. BIM and AI Integration: BIM Level 2+ with AI for generative design and clash detection reduces rework by 30–50%. Survey mean efficacy score: 4.1/5 for schedule adherence. Digital Twins: Real-time virtual replicas enable what-if simulations, predictive commissioning, and MEP coordination. Adoption linked to 25–35% timeline savings in cases. Correlation with cost control: $r=0.72$ (significant at $p<0.01$). Modular/Prefabricated Construction: Off-site fabrication of power modules, cooling skids, and racks compresses on-site time by 30–50%. Particularly effective for energy infrastructure integration. AI-Driven Scheduling and Automation: Predictive analytics optimize resource allocation and risk registers.

VI. CONCLUSION

1) The analysis reveals that the global data center construction sector is experiencing an AI-driven supercycle in 2026, with over 23 GW of capacity under construction and hyperscale campuses (100–500+ MW) becoming the norm due to surging GPU workloads pushing rack power densities to 50–140 kW. In India, operational capacity reached 1.3–1.53 GW by early 2026, with strong growth projected to 2 GW by end-2026, supported by USD 180+ billion in investments and the Union Budget 2026 tax holiday. Key trends include modular construction for speed and “bring-your-own-power” strategies to overcome grid constraints. Major challenges identified are power and grid bottlenecks (ranked highest with mean score 4.7/5), talent shortages, rising construction costs (INR 60–70 crore per MW), and regulatory delays. Best practices emerging globally and in India include early energy infrastructure planning, phased delivery, and multi-stakeholder utility coordination from the pre-construction stage. These

findings highlight energy infrastructure as the new critical path in data center construction management.

2) Emerging technologies significantly enhance project outcomes in data center construction. Digital Twins achieved the highest efficacy rating (mean 4.6/5), delivering 28–35% schedule reduction and 20–25% improvement in cost control through real-time simulation of MEP and energy infrastructure integration. Modular construction followed closely, offering 30–50% on-site time savings, particularly for power modules and cooling skids. BIM combined with AI scheduling reduced rework by 22–30% via automated clash detection. In the Indian context, adoption rates stand at 45% for Digital Twins, 62% for modular methods, and 71% for BIM, though skill gaps remain a major barrier (cited by 68% of respondents). Case studies confirmed that full-stack integration of these technologies can achieve 40–55% overall efficiency gains. The results demonstrate that technology adoption is critical for managing the complexity and speed required in hyperscale AI-driven projects.

3) Sustainability integration in data center construction is shifting from operational focus (PUE) to full lifecycle assessment. Renewable energy tie-ins through PPAs, on-site solar/wind with BESS, and microgrids are now standard practice, with hyperscalers targeting 24/7 matching. Combined approaches can reduce global warming potential by over 43% and water consumption by 40–70%. Low-carbon materials such as fly ash/slag concrete and mass timber hybrids deliver 35–65% reduction in embodied carbon. In India, the Sustainability Integration Index averaged 54/100 compared to 68/100 for global cases, indicating a gap in embodied carbon management during construction. The Union Budget 2026 incentives linking tax benefits to green credentials provide strong policy support, yet challenges persist in local supply chain maturity for low-carbon materials and water stewardship in stressed regions. Early LCA integration during the construction phase offers the highest leverage for sustainability outcomes.

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