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An Integrated Risk Management Framework for Construction and Operational Phases of Hyperscale Data Centres in India

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***Abstract:** Hyperscale data centres form the backbone of India's digital ecosystem, and managing risks during both the construction and operational phases is essential to ensuring their long-term performance and resilience. This paper introduces an integrated risk management framework that systematically captures, evaluates, and prioritizes key risks encountered throughout these critical phases. From design and site readiness to commissioning and continuous operation, the framework addresses a range of issues, including compliance delays, technical failures, inter-agency coordination gaps, and environmental sensitivities. Special attention is given to developing a connected approach that moves beyond isolated checklists, leveraging visual and analytical tools to enhance clarity in both risk assessment and response planning. While the tools themselves are detailed within the study, the emphasis remains on delivering a structured, scalable model that adapts to the evolving needs of hyperscale projects across India. The outcome is a practical and forward-looking guide intended to support a wide range of project stakeholders like developers, consultants, operators, and planners in making informed decisions, improving preparedness, and ensuring robust delivery of data centre infrastructure.*

***Keywords:** Hyperscale Data Centre, Bowtie Figure, Construction, Operation, Risk Management, Risk Matrix*

Abbreviations:
IEX: India-Europe Xpress
IT: Information Technology
HSE: Health, Safety & Environmental
IAX: India-Asia Xpress
MEITY: Ministry of Electronics and Information Technology

I. INTRODUCTION

Data centres trace their roots back to the early days of computing when computers were housed in specialized computing centres with specific operational requirements. The term 'data centre' gained prominence, with evolving features and defined operational standards that have shaped the modern data centre landscape [1].

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Initially emerging from IT departments and research labs, data centres have evolved into critical infrastructure components for organizations, institutions, and businesses. Over time, data centre facilities have witnessed advancements in environmental controls, such as temperature and humidity regulation through sophisticated air conditioning systems to ensure optimal equipment performance [1]. In the 21st century, contemporary data centres emphasize energy efficiency, incorporating sustainable practices, green technologies, and advanced cooling mechanisms to enhance operational efficiency and environmental sustainability, classifying themselves into four tiers (by Uptime Institute), namely:

- Tier I: Basic Capacity – Offers basic infrastructure with a single path for power and cooling, suitable for small operations with up to 28.8 hours of annual downtime.
- Tier II: Redundant Capacity – Adds partial redundancy with some backup components, reducing downtime to 22 hours per year, ideal for businesses needing moderate reliability.
- Tier III: Concurrently Maintainable – Provides dual power paths, allowing maintenance without service interruption and achieving only 1.6 hours of annual downtime, suitable for enterprises needing high availability.
- Tier IV: Fault Tolerant – Fully fault-tolerant with 2N+1 redundancy, ensuring maximum uptime with just 26 minutes of downtime per year, ideal for mission-critical operations.

With the digital revolution underway, data centres have become essential infrastructure supporting a wide range of industries, from IT services to finance and healthcare. In recent years, India has emerged as a significant player in the global data centre market, driven by its expanding digital economy, favourable government policies, and rapidly increasing data consumption. According to industry reports, the Indian data centre market is projected to witness significant growth over the next decade, driven by factors such as digital transformation initiatives, cloud adoption, and increased investment in Information Technology (IT) infrastructure.

India's strategic location, relatively low operating costs, and robust government support, such as the Data Centre Policy draft introduced by the Ministry of Electronics and Information Technology (MeitY), have further accelerated interest from global data centre operators. This push is also fueled by the 'Digital India' initiative, which emphasizes creating digital infrastructure to empower citizens. However, establishing a data centre in India is a complex and risk-intensive endeavour, particularly during the pre-construction phase [2]. Challenges such as land acquisition, regulatory compliance, environmental clearances, and technical considerations make it imperative to conduct a thorough risk assessment to enhance project viability and operational efficiency [3].

Hyperscale data centres, typically classified under Tier III and Tier IV, are designed to accommodate massive cloud computing demands, housing hundreds of thousands to millions of servers [4]. These facilities are engineered for large-scale scalability, with the physical server area alone often exceeding 100,000 square meters. To support their extensive operations, hyperscale data centres consume between 100 MW and over 1000 MW of power, ensuring both high efficiency and redundancy in performance.

II. METHODOLOGY

The research process begins with a focused and comprehensive literature review to explore the current state of knowledge on the construction and early operational phases (6 - 9 months) of data centres. This phase investigates key challenges such as schedule disruptions, safety incidents, coordination lapses among subcontractors, and early system failures. Additionally, the literature review includes an assessment of construction best practices, commissioning standards, health and safety protocols, and performance metrics for early-stage operation, particularly within the Indian context of Chennai and Mumbai. Emphasis is placed on identifying high-risk activities and common failure points that have historically impacted project timelines, budgets, and system readiness. This foundational step helps establish the contextual framework for further research and highlights critical risk areas that require systematic evaluation.

Building on the insights gained from the literature, the next step is to identify underexplored areas in risk management practices during construction and the initial months of data centre operations. Gaps in proactive risk identification, inter-phase risk communication, and post-handover risk tracking are specifically scrutinized [6]. Based on these identified gaps, targeted research questions are developed to examine the types, severity, and timing of risks, along with the methods currently employed to control them. These questions guide the study toward practical risk categorisation, prioritisation based on potential consequences, and the evaluation of mitigation or contingency strategies. This ensures that the research remains grounded in relevant, high-impact areas with direct applicability to ongoing and upcoming projects.

The third phase of the methodology involves systematically compiling a detailed database of risk factors encountered during construction and early operation (6 - 9 months). This is derived from existing project case studies, academic research, and industry guidelines. Risks are classified as structural issues, equipment installation errors, commissioning failures, resource mismanagement, safety incidents, and early facility underperformance [7]. Each risk is recorded along with its frequency of occurrence, contributing factors, and impact severity. The resulting classification enables a structured understanding of recurring problems and supports the creation of a practical knowledge base for further analysis. To supplement literature-based findings, semi-structured interviews were conducted with industry professionals, including project managers (9 respondents), MEP engineers (18 respondents), and license providers (6 respondents), all of whom had 5-12 years of experience in data centre development. A tailored questionnaire is designed to extract insights on on-ground experiences with risk events, their root causes, and the effectiveness of the mitigation measures employed. Specific focus areas include construction coordination, testing and commissioning practices, operational readiness protocols, and lessons learned from early-phase failures. The interviews also explore emerging shifts in project delivery models, digital tools for construction monitoring, and smart operations that may influence future risk profiles.

Qualitative data gathered from the interviews are analysed and categorised in alignment with the risk framework developed earlier. Patterns are identified regarding how specific risks interact, cluster, or propagate through the construction and operational stages. The triangulation of literature-based insights with expert feedback strengthens the study's conclusions and provides validation of observed risk trends. This ensures that the analysis reflects both theoretical and field-based perspectives, making it applicable for real-world implementation. Following this, a risk matrix is developed to visualize and prioritize the identified risks. Each risk is plotted based on its probability of occurrence and the magnitude of its impact on project objectives, such as safety, cost, schedule, and performance. The matrix helps categorise risks as low, medium, or high, allowing decision-makers to focus their attention and resources on the most critical areas. To add depth to the analysis, the study also employs a bowtie analysis, which graphically illustrates the pathways of selected high-impact risks from their causes to their consequences, along with the preventive and mitigative barriers in place [5]. This technique supports a clear understanding of how risks evolve and what new interventions, found through research, are effective at various stages of risk development. The final phase of the methodology examines the changing nature of data centre construction and operation, with a focus on Chennai and Mumbai. It examines how innovations such as prefabricated systems, integrated digital construction platforms, and AI-enabled monitoring tools are likely to influence risk management. The analysis also explores how growing emphasis on energy efficiency, uptime guarantees, and sustainability certifications is reshaping expectations during the operational transition phase.

III. ANALYSIS

A. Classification of Risks in Construction and Operational Phases of Hyperscale Data Centres

Data centre projects require meticulous planning to manage a variety of interconnected risks that impact feasibility, execution, and long-term functionality. They differ significantly from standard construction projects due to their unique operational requirements, such as high-power availability, cooling efficiency, and data security [8]. General risks in data centre construction include delays due to supply chain disruptions, cost escalations, technical failures, and environmental challenges. Specific to the Indian context, risks are further compounded by regulatory challenges, diverse climatic conditions, and infrastructural constraints [9]. After the studies mentioned above, a total of 32 risks and their mitigation strategies have been identified in the construction phase, were these risks have been classified under ten stages, mainly: Design & Engineering Risks, Permitting & Regulatory Risks, Site & Geotechnical Risks, Procurement & Supply Chain Risks, Construction Execution & Quality Risks, Workforce & Labor Risks, Health, Safety & Environmental (HSE) Risks, Technology & Integration Risks, Financial & Contractual Risks, and Scheduling & Project Coord. Risks [10]. Similarly, a total of 24 risks have been identified in the operational phase (6 - 9 months), which have been classified under six stages, mainly: Personnel Management Risks, Maintenance & Reliability Risks, Health, Safety & Security Risks, Emergency Preparedness & Response Risks, Planning & Coordination Risks, and Quality Management & Compliance Risks.

B. Forecasting of Future Trends of Hyperscale Data Centres in Chennai & Mumbai

Chennai is a key point on the India-Asia Xpress (IAX) cable, which links Chennai and Mumbai with significant hubs in Southeast Asia. Complementing this is the India-Europe Xpress (IEX) cable, which connects India to Europe, the Middle East, and Africa and intersects with the IAX in Mumbai. This infrastructure provides a solid base for data centres that require bandwidth and minimal latency. (submarinenetworks, pwonlyias). The Tamil Nadu government encourages the adoption of green energy through its Data Centre Policy 2021, which promotes green energy use and offers incentives for green certifications. The policy incentivises data centres to meet at least 30% of their energy needs through renewable sources. In Maharashtra, the installed rooftop solar capacity surpassed 2,000 MW in September 2024, with the MMR contributing approximately. This total has increased by 150 MW and has set an ambitious target to develop 13 GW of solar capacity by 2025. The lower operational expenses in Chennai relative to other major Indian cities further enhance its appeal for long-term data centre investments, contributing to a more favourable total cost of ownership. Mumbai's primary strength lies in its established and dominant ecosystem, bolstered by its status as the financial capital and its leading position in global connectivity with the highest number of submarine cable landings.

IV. RESULT

All of the identified risks (32 in the Const. and 24 in the Operational Phase) have been documented and put together in the Risk Management Framework Model, referred to as ISO 31000 (International Organization for Standards)

A. Risk Management Matrix for Construction Phase

Table-I: Risk Management Matrix for Construction Phase (Source: Author)

Risk ID	Risk Description	Risk Source	Likelihood (SCORE P1-P5)	Impact (Score L1-L5)	Risk Level	Existing Controls	Risk Treatment Plan	Respons Ibility
Design And Engineering (Dc-Cp-Des)								
DC-CP-DES-001	Incomplete Or Inconsistent Design Documentation	Consultant	P4 (80%)	L4 (Major)	16	Design reviews	Conduct detailed design audits	Design Team
Permitting & Regulatory Risks (Dc-Cp-Per)								
DC-CP-PER-006	Changing Government Regulations	Govt.	P2 (40%)	L3 (Significant)	6	Legal compliance	Monitor legal updates, ensure adaptability	Compliance Officer

B. Risk Management Matrix for Operational Phase

Table-II: Risk Management Matrix for Operational Phase (Source: Author)

Risk Id	Risk Description	Risk Source	Likelihood (score p1-p5)	Impact (score l1-l5)	Risk Level	Existing Controls	Risk treatment Plan	Respons Ibility
Personnel Management Risks (DC-OP-PER)								
DC-OP-PER-001	Shortage of skilled Operational staff for data centre maintenance and management	HR & Operations	P4 (80%)	L4 (Major)	16	Training programs, hiring policies	Improve recruitment strategies, establish partnerships with technical institutions	HR Manager

C. Cascading Risks and their Consequences using Bowtie Diagram

Building upon the comprehensive risk matrix, this study enhances the understanding of risk by employing a structured

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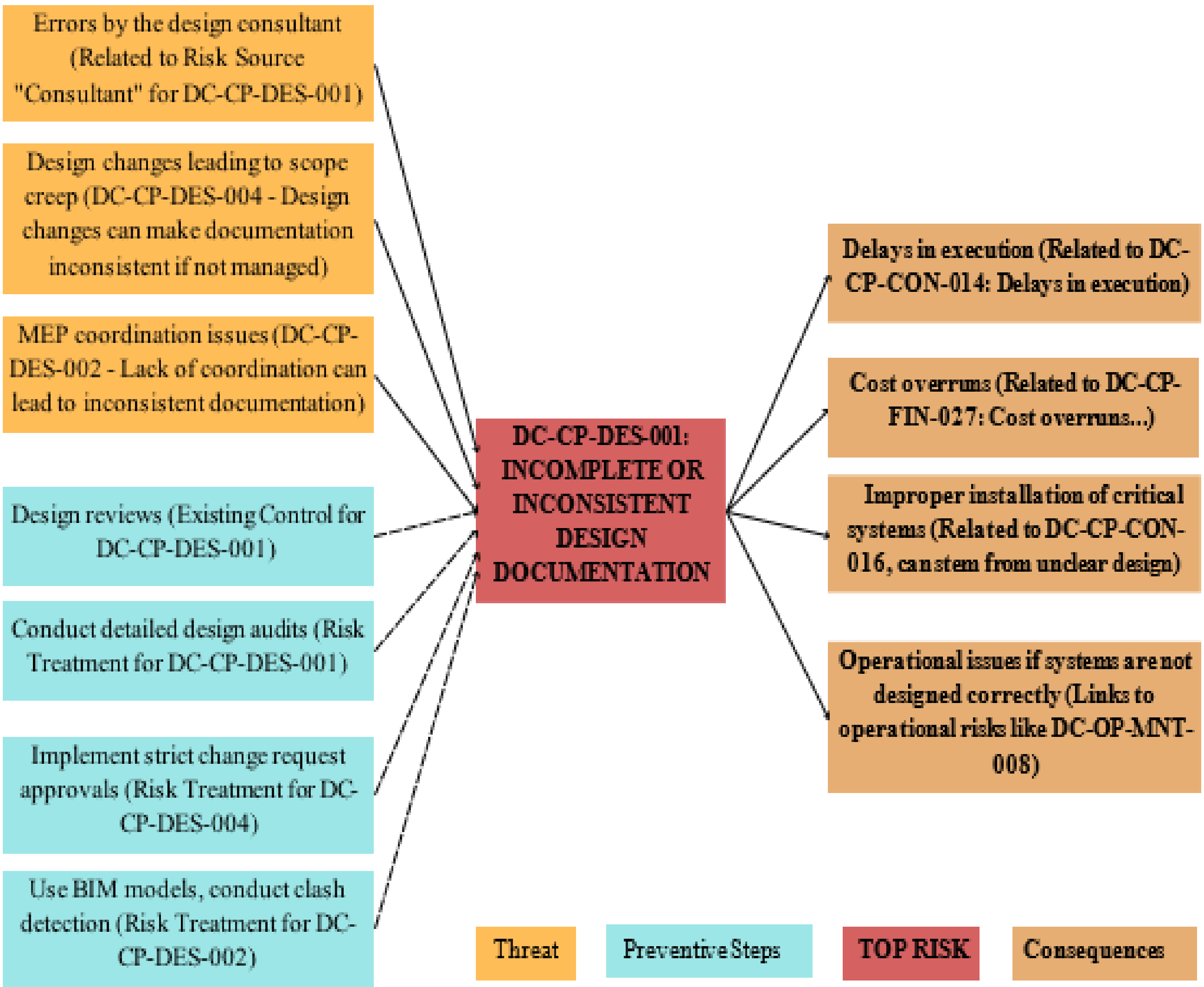
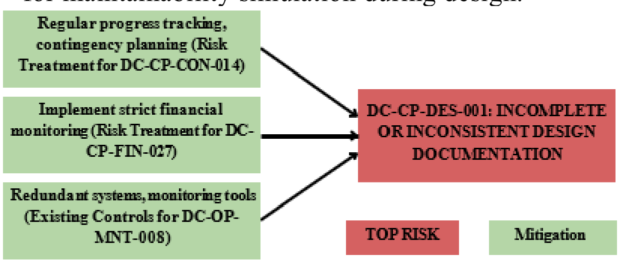
analytical approach, conceptually aligned with the Bowtie methodology. This method provides deeper insights into the relationships between key risks across the construction and operational phases of hyperscale data centres. By mapping the causes, consequences, and associated barriers for selected risks, this analysis clearly illustrates interconnected pathways and interdependencies, particularly highlighting the significant linkages that span across different project stages. This structured examination contributes to a more comprehensive view of risk propagation and informs the development of integrated risk management strategies. The following section details this analysis for a selection of key critical risks, demonstrating their interconnected nature and the potential for cascading effects.

i. Cascading Risks & Proposed Mitigation Strategy for DC-CP-DES-001



[Fig.1: Cascading Risks and their Consequences for DC-CP-DES-001 (Source: Author)]

- **Stakeholder Accountability Framework:**
  i. *Construction Lead:* Design Team (Responsible for producing complete and accurate design).
  ii. *Operation Lead:* Facility Management Team (Responsible for operating & maintaining the built facility).
  iii. *Joint Action:* Joint participation in early design reviews and sign-offs; shared access to and review of design documentation and BIM models throughout construction; joint development of a "maintainability review" checklist used during design phases.
- **Proposed Mitigation Strategies:** Integrated design reviews with operational stakeholders and use of BIM for maintainability simulation during design.



[Fig.2: Proposed Mitigation Strategy for Cascaded Risk DC-CP-DES-001 (Source: Author)]

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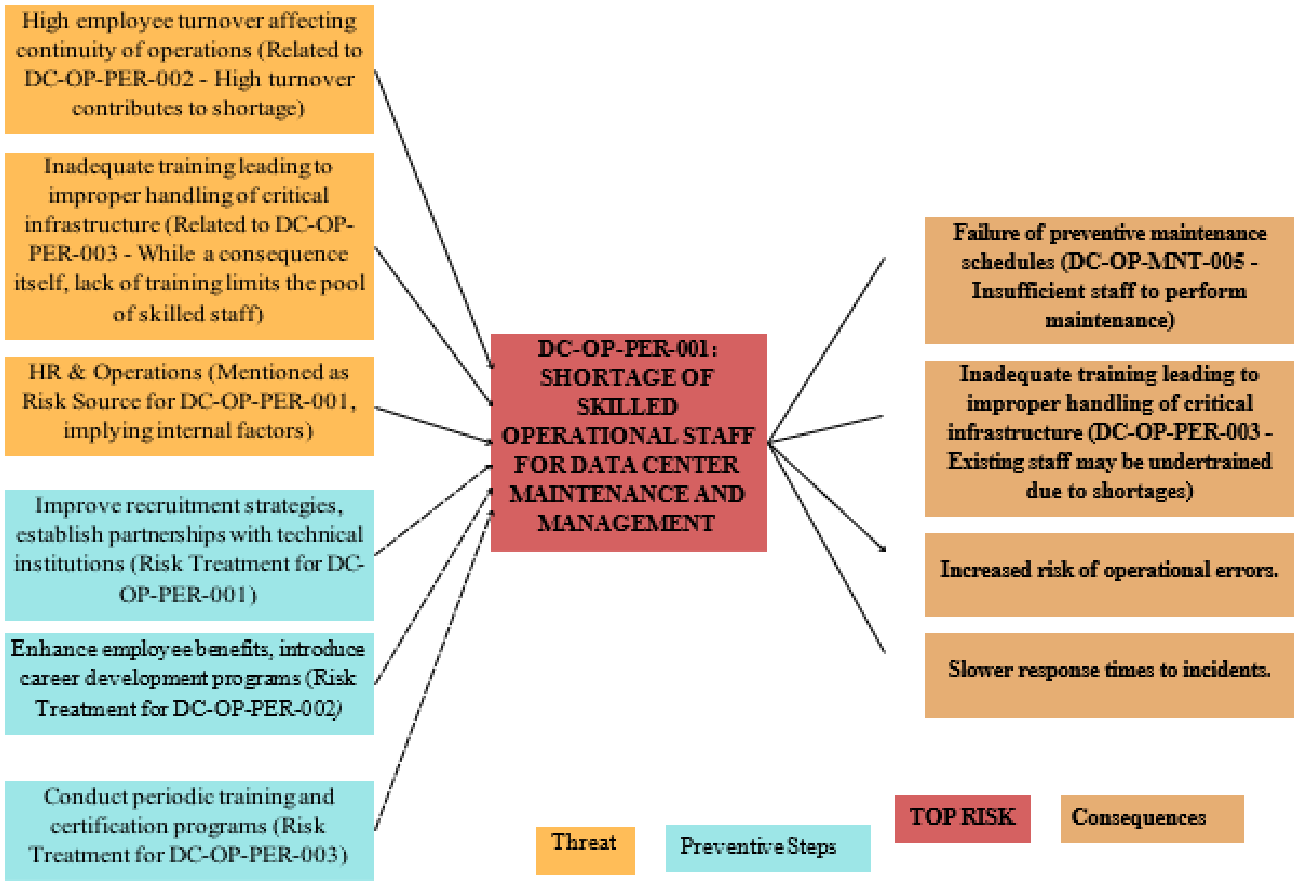
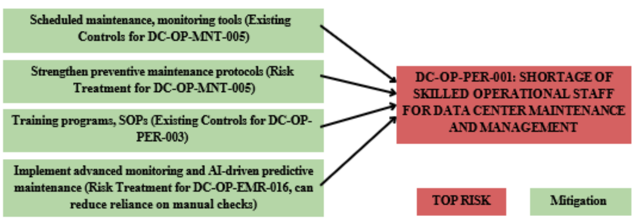
ii. Cascading Risks & Proposed Mitigation Strategy for DC-OP-PER-001



[Fig.3: Cascading Risks and their Consequences for DC-OP-PER-001]

- **Stakeholder Accountability Framework:**
  - *i. Construction Lead:* HR Department (Involved in initial project staffing and potential recruitment support)
  - *ii. Operation Lead:* HR Manager / Facility Manager (Responsible for operational staffing)
  - *iii. Joint Action:* Joint workforce planning meetings during project handover; shared initiatives for recruiting and training operational staff; joint review of operational staffing needs based on facility design and technology.

- **Proposed Mitigation Strategies:** Establish a partnership with local technical colleges to create a specialized data center operations and maintenance technician program. Offer internships and apprenticeships during the late construction/commissioning phase to provide hands-on training on the specific data centre infrastructure, creating a direct pipeline of skilled local talent for operational roles.



[Fig.4: Proposed Mitigation Strategy for Cascaded Risk DC-OP-PER-001]

V. CONCLUSION

The developed framework provides a structured approach for identifying, assessing, and managing risks throughout both the construction and operational phases of hyperscale data centres in India. This integrated lifecycle perspective is crucial for addressing the unique complexities of these critical infrastructure projects. The analysis revealed significant interconnectedness; risks in one phase, such as construction quality or labour shortages (e.g., P3/60% likelihood), can directly cause high-impact issues (e.g., L4/Major) during operations. Understanding these cross-phase dependencies is key to preventing problems from cascading. Prioritizing risks by considering their interdependencies, in addition to likelihood and impact scores, is crucial for identifying systemically critical risks that can trigger cascading failures. This approach helps project managers focus resources on risks that pose the greatest threat to overall project and operational success. Integrated, cross-phase mitigation strategies are essential to address interconnected risks effectively, bridging the gap between construction and operational planning and controls. Implementing solutions like joint quality programs or integrated maintenance systems ensures that vulnerabilities are addressed proactively across the project lifecycle. Establishing clear stakeholder accountability across construction and operational teams ensures these integrated

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risk management strategies are implemented and monitored consistently. This fosters collaboration and prevents critical risks from falling into organizational gaps during project handover and ongoing operations. Implementing this comprehensive framework enhances the resilience of hyperscale data centres, enabling project managers to navigate complex challenges and contribute to successful project delivery and reliable operations in the Indian context. A proactive, integrated, and accountability-driven approach is essential for building and maintaining a robust data centre infrastructure.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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