CHAPTER 10

Delay Analysis and Risk Mitigation in Indian Infrastructure Projects: An Empirical Study

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ABSTRACT

Infrastructural projects have a very important role to play on economic development, yet they are still faced by delays and cost overrun, which is particularly true in the developing economies like India. This empirical study paper will discuss the primary causes of delays, the current practices on the ways to reduce risks, and the implementation of innovative technologies. Our methodology was mixed because we balanced both the in-depth literature review and the responses of 36 industry participants in the form of surveys. Findings show that administrative delays (government approvals, land acquisition) are the most deplorable determinants of delay with 47.2 percent of the projects experiencing 10-30 percent schedule overruns. The moderate effectiveness is seen with the Critical Path Method (CPM) and with Risk Assessment Matrices (52.8% rating) and there appear to be high adoption barriers to BIM (41.7%), AI/ML (8.3%), and blockchain (2.8%). The approval delays have been found to be the most important factor by the Relative Importance Index (RII) analysis of the approval delays (RII=0.81). We propose a risk management model, which is dependent on technology integration, which bridges the gap between reactive and proactive project governance and the data-driven project governance.

Keywords: Infrastructure delays, Risk mitigation, Relative Importance Index, Digital construction, Project management, India.

1.0 Introduction

1.1 Background and problem context

The development of infrastructure is the key contributor to the economic development, social advancement and national competitiveness.

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Effective project delivery has become the most important in India with the rapid urbanization process and projects such as the National Infrastructure Pipeline and PM Gati Shakti. Nonetheless, the efforts are compromised by the continued delays. According to the Ministry of Statistics and Programme Implementation (MoSPI, 2023), approximately 40% of central sector infrastructure projects face time and cost overruns, with average delays exceeding 40 months in some sectors. Such delays are not just the scheduling failures but instead they create the domino effect of escalation of the budget (it is normally escalated by 15-30 percent), wastage of resources, poor quality and loss of faith in the government. The economic costs are mind-blowing, as it is estimated that project delays cost the Indian economy 1-2 per cent of GDP per year due to lost productivity and wasting the resources on the capital.

1.2 Research fap and significance

Even though no shortage of literature exists on construction delays internationally, most research on the subject in India lacks depth in terms of empiricism concerning the impact of traditional practices of risk management and novel digital applications. Moreover, existing studies have not conducted a quantitative study in terms of frequency and severity on the ranking of delay factors in the Indian context. This paper compensates these gaps through presenting empirical confirmation of delay determinants and evaluating risk management digital transformation preparedness.

1.3 Research objectives

This study aims to:

- Identify and quantitatively rank the causes of delays in Indian infrastructure projects using dual metrics of frequency and severity.
- Evaluate the effectiveness of current risk mitigation practices and their organizational integration.
- Analyze the adoption levels and barriers for advanced digital tools in delay mitigation.
- Develop a framework for integrating traditional and technological approaches to proactive risk management.

2.0 Literature Review

2.1 Global perspectives on construction delays

The research on construction delay has a long history of more than 40 years, and the ground-breaking contributions from the field of research have laid the frameworks in various geographical and economic settings. An overview of the main foreign research demonstrates that there are general obstacles and local peculiarities in delay causation and mitigation (refer Table 1).

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Table 1: Global Studies on Construction Delay Factors

Researcher(s)	Country	Key Delay Factors Identified	Methodology
Kumaraswamy & Chan (1998)	Hong Kong	Poor site management, unforeseen ground conditions, design delays	Survey, RII Analysis
Odeh & Battaineh (2002)	Jordan	Contractor incompetence, owner interference, poor communication	Questionnaire, Ranking
Assaf et al. (2006)	Saudi Arabia	Change orders, payment delays, contractor planning	Frequency and Severity Indices
Frimpong et al. (2003)	Ghana	Inflation, payment delays, price fluctuations	Case Study Analysis
Faridi & El-Sayegh (2006)	UAE	Poor planning, design changes, labor productivity	Statistical Analysis

Source: Created by authors

The meta-analysis of these and other studies shows that there are certain variables that depend on the region that they are supported, but there are still common themes, such as administrative inefficiencies, financial constraints, design deficiencies, and resource management problems. The algorithms that it uses, including the Relative Importance Index (RII) and the frequency-severity analysis, have become common methods of carrying out systematic analysis of delay factors.

2.2 Indian context and emerging challenges

Infrastructure initiatives in India have their own distinctive challenges in the form of complex regulatory frameworks, difficult land acquisition, and multi-agency coordination needs. In transportation projects, Ramu and Prasad (2020) found that most of the factors involved political interference and bureaucratic delays, whereas Jain and Garg (2020) identified the bottlenecks of procurement and coordination problems among stakeholders in developing infrastructures in health care. The situation after the pandemic has added certain new dynamics to the old problems: supply chains, labor migration, rising material prices, and increased demands on remote project monitoring. These new issues require new risk models that include more resilience, flexibility, and digital adaptability. Digital divide in the adoption of construction technology has been more evident since Indian projects are behind their global peers in the adoption of tools of advanced mitigation.

2.3 Technological interventions in risk management

High-techs come with revolutionary potential in delay mitigation yet their use is highly differing in terms of location and project nature.

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Building Information Modeling (BIM) facilitates the identification of clashes, 4D/5D simulation, and joint planning, and the research indicates that the implementation of BIM can also lead to a decrease in rework by 20-30 percent (Shirowzhan et al., 2016). AI and ML offer the opportunity of predictive analytics in delay prediction, pattern recognition in risk factors and automated monitoring systems, which will be able to detect deviations in real-time. Blockchain Technology has provided remedies in the form of smart contracts to provide automated payments, transparent documentation systems, and dispute resolution process. Internet of Things (IoT) enables real-time tracking of equipment usages, material movements, and environmental status affecting the project schedules.

Regardless of these technological developments, the adoption is still at a very low level in the developing economies because of the high implementation cost, skills imbalance, organizational resistance to change, and a lack of infrastructure to support. This brings the paradox of the situation in which the areas with the most serious delay problems are the least equipped with technological solutions that can help solve them.

2.4 Theoretical framework

The framework used in the study is the Integrated Risk Management Framework (IRMF), which is a combination of four fundamental dimensions, which are: traditional risk analysis tools (CPM, EVM, Risk Matrices), digital integration platforms (BIM, AI/ML, IoT), organizational capability building through training and process redesign, and supportive policy and process reforms. The framework acknowledges that technical, managerial and institutional aspects must be addressed concurrently and in concert instead of separately as the main means of delay mitigation. This is especially applicable to the Indian environment, where the causes of delays are usually intertwined issues, which cross several areas.

3.0 Research Methodology

3.1 Research design

This research uses a mixed-methods sequential approach that has five integrated stages that develop upon one another to guarantee in-depth knowledge and viability of application. The study process commences with Phase 1: Literature Review, which aims at building theoretical background, then moves to Phase 2: Instrument Development, where the researcher designs powerful data collection instruments, followed by Phase 3: Data Collection, where the researcher gathers data by consulting industry players, then to Phase 4: Analysis where the researcher uses quantitative and qualitative data analysis methods to transform the information to recommendations, and finally the researcher undertakes Phase 5: Framework Development to actualize the recommendations.

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3.2 Sampling and data collection

The sampling method involved a purposive approach which targeted professionals who are directly involved in the planning, execution or management of infrastructural projects. The sampling plan was based on the principles of diversity in terms of organizational roles, types of projects, and geography in order to have holistic views. The sample size finally consisted of 36 respondents who represented different organizational backgrounds as shown in Table 2.

Table 2: Respondent Demographic Profile (N=36)

Category	Sub-Category	Frequency	Percentage
Sector	Infrastructure Construction	19	52.8%
	Real Estate	11	30.6%
	Industrial Construction	4	11.1%
	Other	2	5.6%
Company Type	Contractor	15	41.7%
	Client	12	33.3%
	Consultant	9	25.0%
Experience	<5 years	31	86.1%
	5-10 years	4	11.1%
	11-15 years	1	2.8%
Project Types	Roads/Highways	11	30.6%
	Water/Dam	4	11.1%
	Metro Rail	3	8.3%
	Mixed/Other	18	50.0%

Source: Created by authors

3.3 Instrument design

The questionnaire was carefully written and had four extensive sections. Section 1 included demographic and organizational data as a background to responses. Section 2 was devoted to the evaluation of delay factors with the help of dual 5-point Likert scales with frequency (Never to Very Often) and severity (Very Low to Very High) of 13 delay factors frequently mentioned. Section 3 considered the risk mitigation practices, their adoption, and perceived effectiveness. Section 4 looked into the progress in the levels of technology adoption, barriers to the implementation and organizational preparation to digital transformation.

3.4 Analytical methods

To be certain in the analysis, the research used a variety of analytical methods. Relative Importance Index (RII) was obtained by calculation of the delay factors by the

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following formula RII = SW / (AxN), where W signifies weight provided by the respondents (1-5 scale), A is the maximum weight (5), and N signifies the total respondents (36). Severity Impact Index (SII) was calculated as follows: $SII = \Sigma (F_i \times S_i) / N$, F and S are the frequency and severity scores of respondent i. The correlation analysis was performed with the help of the Spearman rank correlation coefficient which was used to compare relations between various delay factors and relations between the frequency and severity ratings. Descriptive statistics described the sample adoption rate, effectiveness rates, and performance measures.

3.5 Validity and reliability

A number of validation processes were applied to ensure the methodological rigor. Validity of the content was ascertained by the content review of three senior construction management professionals with the aggregate experience of more than 60 years. It also pilot-tested the instrument on five practitioners and refined it based on the responses. Cronbach alpha method was used to find out the reliability and the delay factors scale gave the result of 0.87 which is high internal consistency. Coherence of response patterns was also assessed logically and outliers' response also examined to see whether there existed any data quality issues.

4.0 Results and Analysis

4.1 Ranking of delay factors

The analysis reveals a clear hierarchy of delay factors affecting Indian infrastructure projects, with administrative and regulatory challenges emerging as most significant.

Table 3: Delay Factors Ranking by Frequency, Severity, and RII

Rank	Delay Factor	Mean Frequency (1-5)	Mean Severity (1-5)	RII
1	Delay in government approvals	4.06	4.03	0.81
2	Land acquisition issues	3.42	3.86	0.77
3	Financial constraints/cash flow	3.25	3.97	0.76
4	Material supply disruptions	3.83	3.61	0.75
5	Design changes during execution	3.61	3.58	0.72
6	Contractor inefficiencies	3.47	3.53	0.70
7	Lack of skilled labor	3.36	3.47	0.68
8	Environmental/weather conditions	3.33	3.33	0.67
9	Inadequate project planning	3.31	3.31	0.66
10	Ineffective communication	3.28	3.25	0.65
11	Equipment breakdowns	3.08	3.17	0.63
12	Community/stakeholder opposition	2.94	3.06	0.60
13	Legal disputes and arbitration	2.89	3.03	0.59

Source: Created by authors

The evidence shows that delay in government approvals (RII=0.81) is the most influential factor closely followed by land acquisition issues (RII=0.77) and financial constraints (RII=0.76). The three items are a group of administrative-financial issues that cumulatively explain the greatest delays effects (Table 3). More importantly, all of the three leading factors have an RII value greater than 0.75, which means that they are common and severe in effect. The close association of frequency and severity ranking ($r=0.89$, $p<0.01$) confirms that frequently recurrent delays are also rated as the most severe ones by the practitioners.

4.2 Risk mitigation practices analysis

Current risk mitigation practices show a strong preference for traditional, established methods over innovative or technology-driven approaches.

Table 4: Adoption and Effectiveness of Risk Mitigation Practices

Practice	Adoption Rate	Perceived Effectiveness (1-5)	Primary Users
Critical Path Method (CPM)	69.4%	3.6	Contractors, Planners
Risk Assessment Matrix	63.9%	3.8	All sectors
Contingency Planning	58.3%	3.5	Clients, Consultants
Early Stakeholder Consultation	52.8%	3.9	Consultants, Clients
Digital Project Management Tools	47.2%	3.7	Contractors, Planners
Regular Risk Audits	44.4%	3.4	Clients, Large Contractors
Earned Value Management (EVM)	33.3%	3.3	Large Organizations
Performance-based Contractor Selection	25.0%	3.8	Clients
AI/ML-based Predictive Tools	8.3%	4.2*	Early Adopters
Blockchain Applications	2.8%	4.5*	None in sample

Source: Created by authors

4.3 Potential effectiveness based on literature

Analysis indicates that there is a strict dichotomy between the conventional ones (which prevail in the rates of adoption but have moderate ratings of potential effectiveness (mean 3.6/5) (Table 4) and the progressive digital tools (with low adoption rates but much higher potential effectiveness based on the literature and experience of early adopters). The highest percentage of 27.8% of the respondents rated their current mitigation methods as being rated as Highly Effective with the majority (52.8) indicating that they were rated as being modestly Effective. This is also an indication of the effectiveness gap in which the traditional tools have the necessary baseline control but cannot systematically control the delay factors which are complex and interconnected issues in the Indian infrastructure projects.

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4.4 Technology adoption analysis

The adoption of digital technologies for delay mitigation reveals significant disparities between awareness and implementation.

Table 5: Technology Adoption Rates and Barriers

Technology	Adoption Rate	Primary Barriers (Frequency)
BIM	41.7%	High cost (47.2%)
IoT	11.1%	Lack of skilled personnel (38.9%)
AI/ML	8.3%	Resistance to change (30.6%)
Blockchain	2.8%	Limited organizational policy (22.2%)

Source: Created by authors

Building Information Modeling (BIM) is the least utilized system with a rate of 41.7 and is mainly to facilitate coordination of designs and detect clashes as opposed to combined schedule and risk management (Table 5). The adoption of Internet of Things (IoT) applications is still at 11.1% and is primarily applied in large-scale or high-value endeavors to monitor equipment. The adoption of Artificial Intelligence and Machine Learning (AI/ML) tools is the lowest with an 8.3 percent adoption which is usually pilot implementations in technologically advanced organizations. The adoption of blockchain technology is non-existent with the lowest adoption being 2.8 and none of them reported to have implemented the technology at any of their projects.

High implementation costs (mentioned by 47.2 percent of the respondents) are the barrier to adoption that is dominated by the high costs of construction, which are capital-intensive, and by the lack of profit margins to invest in the technology. The shortage of competent staff (38.9%) cites a human resource critical aspect in digital construction management requirements. The fact that resistance to change is the highest (30.6%) shows cultural and organizational inertia in an industry that is approached slowly to innovations. Inadequate organizational policy (22.2%) implies inadequate institutional and legal structures that may contribute to and enforce technology integration.

4.5 Project performance metrics

Actual project outcomes confirm the severity of delay challenges identified through factor analysis (Table 6). The performance data shows an ugly truth 77.8% of projects are overrun by more than 10 percent and almost half (47.2) of the projects are overrun by 10-30 percent of the schedule. On the same note, the percentage of cost overruns experienced in 72.2 is above 15% and 41.7 in the 15-30% bracket. The numbers are in line with the national reports by MoSPI and they it proves that delays and cost escalations is not a one-off phenomenon, but a systemic problem. The fact that schedule delays, and cost overruns are strongly linked (83.3% of respondents reported these problems) highlights the interdependence of the two issues - delays are bound to cause more costs due to the inflations, lengthy overheads, and penalties.

Table 6: Project Performance Analysis (N=36)

Performance Indicator	Range	Frequency	Percentage
Schedule Delay	10-30%	17	47.2%
	>30%	11	30.6%
	<10%	8	22.2%
Cost Overrun	15-30%	15	41.7%
	>30%	11	30.6%
	<15%	10	27.8%

Source: Created by authors

4.6 Interrelationships among delay factors

Correlation analysis reveals important patterns in how different delay factors interact and compound each other. The correlation table shows some significant patterns. The highest correlation is found between the government approvals and land acquisition (r= 0.82) and the two are related as one because of the administrative- regulatory issues (Table 7). There are moderate to strong correlations between financial constraints with all the top factors indicating that they are the cause as well as the effects of other delays. Changes in design are highly correlated with disruptions in material supply (r=0.73), which means that late design modifications tend to interfere with procurement and logistic planning. Those interrelationships are the reasons why solutions to individual delay factors are often not sufficient when they are considered in isolation--the factors are not independent challenges due to their interrelation.

Table 7: Correlation Matrix of Top Delay Factors (Spearman's ρ)

Factor	1	2	3	4	5
1. Government Approvals	1.00				
2. Land Acquisition	**0.82**	1.00			
3. Financial Constraints	**0.76**	**0.71**	1.00		
4. Material Supply	**0.68**	0.64	**0.69**	1.00	
5. Design Changes	0.62	0.59	**0.65**	**0.73**	1.00

Bold indicates statistically significant correlations ($p < 0.05$)
Source: Created by authors

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5.0 Discussion

5.1 Systemic nature of delay challenges

The fact that the administrative factors are the primary causes of delays suggests that the challenges are systemic and project-specific. The RII of government approvals (0.81) and land acquisition (0.77) are very high and hence imply that they are institutional constraints that lie within the regulations and governance structures of India. Such outcomes are related to the literature that hints on the complexities of the Indian federal system, where the infrastructure projects are more likely to require corroborations of a large number of organizations at the central, state, and local levels. The sequence of time-consuming nature in such processes is further compounded by the fact that the rules and documents requirements keep changing thus extending the time further making it impossible to eradicate the delays that even the management of the individual project team would be unable to eradicate.

The interdependence between delay factors presented in Table 7 gives valuable information on mitigation strategy creation. The close correlation between administrative delays and financial constraint (r=0.76) indicates that the delayed approvals tend to create cash flow issues since spending is made and revenue targets are delayed. On the same note, the relationship between material supply and design modifications (r=0.73) suggests that the process of procurement planning is more often than not interrupted by design alterations at the late design stages and this leads to the creation of the vicious cycle of delays. The implication of these interrelationships is that mitigation should be effective at reducing clusters of related factors and no single issues.

5.2 Weaknesses of traditional risk management: Striking the performance ceiling

The analysis has found that there is a severe weakness in the contemporary industry practice as the traditional risk management tools have reached a major plateau in terms of performance. The current rating of 3.6 out of 5 in the average effectiveness of such methods as the Critical Path Method (CPM) and Risk Assessment Matrices is no longer enough when it comes to the dynamic complexities of the modern Indian infrastructure projects. The issue is their very way in which they are built. CPM however good in establishing a baseline schedule, is based on the deterministic assumptions. It is not enough to capture the profound ambiguities and instabilities, of hysterical regulatory power and unbalanced material chain, within the reality on the ground. Similarly, the risk matrices are beneficial in the initial identification, but they are basically fixed documents. They fail to offer the dynamism and updating aspect required in responding risk management as the project takes a shape and new issues emerge.

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It is this reactive nature that focuses on detection of deviation after they occur, rather than prevention that renders them having a narrow impact.

This creates a colossal industry paradox; strong adoption levels and average outcomes. The fact that one or another organization continues to use the tools does not imply that they are more effective, it is merely the familiarity, standardization, or that fact that the tools are part of the organizational culture. Such reliance puts the industry in a state of competency trap where complacency with any tools that are below the best is a literal stumbling block to searching any that are even better. These data show that additional optimization of these traditional methods can only have a diminishing marginal return. This performance ceiling would entail a paradigm shift to reach this performance ceiling as opposed to incremental changes to an aging and traditional method of doing things.

5.3 Technology adoption paradox: Closing the gulf between potential and practice

Indian construction is marked by the extreme and vivid distinction between the projected potential and minimal realisation. It is a manifestation of this so-called readiness-adoption paradox that the gap between the 88.9 percent of the interviewed people who stated having positive attitudes toward digital tools and the only 8.3 and 2.8 percent adoption rates of AI/ML and blockchain, respectively. This contradiction is perpetuated by a self-maintaining cycle of obstacles. High upfront cost (47.2%), a significant barrier in an industry that is well-known with low profit margins and significant budget constraints, is the most mentioned barrier. Although it is evident that strategic technology investments can pay off 3-5x with efficiency benefits, the industry has a poor track record of working with short-term financial horizons because long-term value is lost.

To worsen the cost challenge, there is an acute skills shortage (38.9%). The construction labour force, which has been highly labour-intensive, is not digitally savvy to support and operate hi-tech tools such as predictive analytics platforms. Additionally, the cultural barriers related to organizational inertia and change resistance (30.6) in established firms represent the cultural barriers as well as the lack of supportive policy (22.2) in supporting the wide adoption. The combination of all these factors has formed an environment of stagnation in which the knowledge of technological potential is not being acted upon resulting in a vast array of tools of delay mitigation remaining largely untapped.

5.4 A future-moving strategy: Technology-Integrated Risk Management (TIRM) framework

In order to address the two-fold problem of ineffective conventional means and lack of digital implementation, this paper introduces the Technology-Integrated Risk Management (TIRM) Framework. It is not just an isolated tool, but a five-layer ecosystem covering all

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layers of holistic changes aimed at encouraging a paradigm shift in project governance, which is not reactive but proactive.

Data Foundation Layer: This bottom layer forms an integrated information ecosystem through the compilation of IoT sensor data of sites, rich Building Information Modeling (BIM) model and historical project databases into one source of truth.

Analytical Engine Layer: Raw data in the bottom layer are analyzed by machine learning algorithms and AI in this layer. This allows the predictive analysis of delays, the recognition of trends in aspects of risks and the simulation complexities of situations.

Decision Support Layer: Here, the complicated analytics are transformed into actionable intelligence to the project teams in a form of user-friendly dashboards, automated early-warning messages and AI generated mitigation recommendations to enable them to make timely, informed decisions.

Organizational Integration Layer: This is a highly crucial layer because it entails making sure that the technology is effectively integrated through the development of digital proficiencies through the training, process redesigning and nurturing an organizational culture of data-driven decision making.

Policy Environment Layer: The outermost layer facilitates the conditions of success: a good governmental regulation, the standard of data within the industry, and financial or procedural incentive driving the technology adoption.

TIRM model is a paradigm shift: to make predictions but not diagnoses, to make decisions using data and not gut feeling and to open datastores and not closed datastores.

5.5 Policy and implementation requirements: Multi-stakeholder mandate

The effective change that is evident in the context of the TIRM demands the concerted action of all participants of the infrastructure ecosystem.

On the policymakers' side: The task here is to be enablers. This includes the adoption of digital single window clearance systems with legally required timelines to address the primary cause of delay. It is essential to develop technology adoption incentives i.e. tax benefits, bid preferences or accelerated approvals of tech-forward projects.

The creation of the national digital construction standards will guarantee the interoperability, but the sectoral innovation funds could be used to de-risk early adoption.

In the case of Industry Associations: They are involved in the facilitation of collaboration and capability building. It also involves the creation of standardized digital competency frameworks, industry-academia collaboration in modernizing the curriculum, development of technology demonstration centres to facilitate hands-on education and peer learning networks to share knowledge.

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In the case of Educational Institutions: Academia has to overcome the increasing gap of skills. This involves incorporating digital construction modules in mainstream engineering and management degrees, provision of specialized certification degrees, creating applied research centres with local issues, and developing strong industry immersion degrees.

In the case of Project Organizations: It is up to the leadership to instigated internal change. Firms need to develop phased technology adoption roadmaps, allocate dedicated technology budgets (2-3% of project cost), establish cross-functional digital teams, and implement performance-linked incentives that reward proactive risk management and successful tech integration.

6.0 Conclusions

The results of this research provide a definite and compelling argument of change. The continual pre-eminence of administrative delays, systemic quality of cost and time overruns, low efficiency of conventional tools, and the evident technology adoption paradox all point to the fact that the status quo is unsustainable.

The development of infrastructure in India is at a crossroad. The way of gradual change towards old ways has been exhausted. It is only through the alternative option that is the adoption of an overall transformational change that will be digitally enhanced in terms of its offerings under the TIRM framework that there is a solution to the attainment of the efficiency, predictability and excellence that the ambitious development agenda of the country requires. It is not a trip that can be completed by just buying new software, but rather it is a systemic change of processes, reskilling of the labor force, change of organizational culture and supportive policy development.

The policymakers, industry leaders, educators, and practitioners should work together to create an ecosystem where digital innovation becomes the driving force that makes the project deliver timely.

The more disruptive technological space that India faces today, the more it poses a threat to the infrastructure industry in India, not the adoption of new tools, but such a risk of failing to modernize. Taking the decisive step in the direction of the complete digital transformation, the industry will be able to recreate its future, make the constant delays its history.

7.0 Limitations and Future Research

The limitations of this study include a small sample (N=36), subjectivity to early-career professionals, self-reported data, and lack of representation of the sector, which have

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influence on generalizability. Further studies need to be conducted longitudinally on the effect of technology, sector analyses (e.g., renewable energy), India analyses on ROI, and behavioural studies on how organisations may be encouraged to adopt technology in the building industry.

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