

CONVERGING HORIZONS

IN CONSTRUCTION AND THE BUILT ENVIRONMENT
DIGITAL, SUSTAINABLE AND STRATEGIC PERSPECTIVES

Volume 1



Editors

Dr. Sushma S. Kulkarni
Dr. Anil Agarwal
Dr. Smitha Yadav
Dr. Tenepalli JaiSai



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About the Book

Converging Horizons in Construction and the Built Environment: Digital, Sustainable, and Strategic Perspectives

This multi-volume edited book brings together a diverse collection of postgraduate research that reflects the evolving intersections of construction, infrastructure, real estate, sustainability, digital innovation, and contemporary management practices. It offers a comprehensive view of the built environment through the lens of both technical rigor and strategic insight, making it a valuable academic and professional resource.

The chapters span critical themes such as digital construction technologies, project risk and cost management, urban mobility, green infrastructure, circular economy practices, and emerging business models in real estate and logistics. Additionally, it integrates perspectives from allied areas of management, including supply chain strategies, policy analysis, and financial planning, positioning the book at the crossroads of engineering excellence and managerial foresight.

Rooted in the academic ethos of NICMAR University, Pune, the book reflects the innovative thinking and practical orientation of its postgraduate student community. It presents not only technical solutions but also explores strategic frameworks and decision-making tools relevant to today's dynamic built environment. The volumes present a diverse range of topics organized alphabetically, offering readers a broad and accessible overview of emerging research across domains.

With contributions exclusively from postgraduate students pursuing their Master of Business Administration (MBA), this publication aims to spark critical thinking and promote research-based solutions that align with national development goals and global sustainability imperatives.

Ideal for students, educators, researchers, and professionals, this book equips readers with the knowledge to navigate, influence, and lead in the transforming world of construction and the built environment.

About the Editors

Dr. Sushma S. Kulkarni, *Vice Chancellor, NICMAR University, Pune, India*

Dr. Sushma Shekhar Kulkarni stands as a transformative force in academia, leading NICMAR University as Vice Chancellor while steering the Global Engineering Deans Council. With a distinguished academic pedigree spanning doctoral, postgraduate and undergraduate qualifications in Civil Engineering, her visionary governance has shaped higher education for nearly four decades.



An internationally recognized expert in Concrete Technology and Educational Transformation, her research legacy includes 155+ publications, two patents, and mentorship of 12 Ph.D. candidates. Global thought leadership is evidenced through 140+ keynote addresses at premier forums including IUCEE, IFEEs, and GEDC, while editorial contributions enhance academia through JEET (Scopus-indexed) and the Journal of Real Estate, Construction and Management.

Honoured with 35+ prestigious accolades including the Duncan Fraser Global Award and ISTE's Best Engineering College Principal recognition, she serves as Fellow of IEI, Promoter of IUCEE Foundation, and Lifetime Member of ISTE/ISTD - continuing to pioneer advancements in engineering education worldwide.

Dr. Anil Agarwal, *Professor and Dean of Academics, NICMAR University, Pune, India*

Dr. Anil Agarwal is a distinguished academic and leader in the field of construction management, currently serving as Professor and Dean of Academics at NICMAR University, Pune. With an illustrious career spanning over two decades at NICMAR since 1999, he has been twice honored with the prestigious 'Teaching Excellence Award' for his outstanding contributions to education. Dr. Agarwal has been instrumental in the institutional development of NICMAR, playing a pivotal role in its evolution into a university. His expertise extends to designing and delivering Management Development Programs in Construction Quality Management and Project Management for leading construction corporations. An active member of the Bureau of Indian Standards (BIS) for the Construction Management Sectional Committee (CED-29), Dr. Agarwal contributes to the framing and updating of IS codes. He also serves on the Board of Studies for several esteemed institutions. His prolific research portfolio includes numerous sponsored projects and over 50 publications in national and international conferences, seminars, journals, and magazines, cementing his reputation as a thought leader in the field.



About the Editors

Dr. Smitha Yadav, *Associate Professor and Dean, School of Construction, NICMAR University, Pune, India*

Dr. Smitha Yadav is a highly accomplished academic with a strong foundation in civil engineering, holding a BE from the Government College of Engineering, Goa, a Master's from COEP Pune, and a PhD from Savitribai Phule Pune University (SPPU). Her research and teaching interests span Estimation and Quantity Surveying, Tendering Bidding & Contracting, Contracts & Claims Management, and Geotechnical Engineering. With over 35 research papers published in national and international journals and conferences, Dr. Yadav has made significant contributions to the fields of concrete technology, construction materials, and contract management. Her work reflects a deep commitment to advancing knowledge and practice in civil engineering, earning her recognition as a leading scholar in her domain.



Dr. Tenepalli JaiSai, *Associate Professor, School of Construction, NICMAR University, Pune, India*

Dr. Tenepalli JaiSai is a dedicated educator and researcher specializing in structural engineering and construction management. He holds a B.Tech in Civil Engineering, an M.Tech in Structural Engineering, and a PhD from Vellore Institute of Technology (VIT), where his ground-breaking research focused on the effect of water quality on geo-polymer mortar characterization using Class F Fly Ash. With over a decade of teaching experience, Dr. JaiSai has designed and delivered courses for undergraduate and graduate programs, including serving as the Program Coordinator for the Advanced Construction Management program at NICMAR (2018–2020). His research spans structural engineering, construction materials, and construction management, with publications in esteemed international peer-reviewed journals and conferences.



A recipient of the Teaching Excellence Award in 2017, Dr. JaiSai is a life member of several professional organizations, including the Universal Association of Civil, Structural, and Environmental Engineers (UACSE) and the International Association of Engineers (IAENG). He also serves as a reviewer for Scopus-indexed journals such as *Innovative Infrastructure Solutions* and *Silicon*, and is an Editorial Board member for the *Journal of Civil, Construction, and Environmental Engineering (JCCEE)* since December 2021.

Preface

In a time marked by rapid urbanization, technological disruption, and growing sustainability concerns, the built environment is undergoing a profound transformation. This edited volume, *“Converging Horizons in Construction and the Built Environment: Digital, Sustainable, and Strategic Perspectives,”* emerges as a timely academic contribution that captures the essence of this evolving landscape.

Compiled as part of NLPGRS-2025, a national-level postgraduate research symposium hosted by NICMAR University, Pune, this book reflects the academic excellence, industry orientation, and innovative thinking fostered within the postgraduate community. The chapters—authored exclusively by MBA students—bridge the gap between engineering, management, and policy by addressing pressing challenges in construction, infrastructure, and real estate with strategic foresight and research-backed insights.

The diverse range of topics explored across the volumes spans digital technologies in construction, sustainable development practices, circular economy applications, risk and cost management, urban mobility, and transformative models in real estate and logistics. These are further enriched by cross-disciplinary inputs in financial planning, supply chain strategies, and policy frameworks, reflecting the interconnected nature of today’s-built environment.

This book serves as both a research compendium and a forward-looking guide, equipping students, educators, and professionals with emerging perspectives and analytical tools essential for leading in a complex and rapidly evolving sector. It not only offers technical and managerial depth but also aligns with broader national and global sustainability goals.

We express our sincere gratitude to all the student authors, reviewers, and academic mentors who made this publication possible. Their dedication, curiosity, and scholarship are vividly reflected in these pages.

We invite you to explore these converging horizons and engage with the ideas that will shape the future of construction and the built environment.

Editors

Dr. Sushma S. Kulkarni
Dr. Anil Agarwal
Dr. Smitha Yadav
Dr. Tenepalli JaiSai

Acknowledgements

We extend our heartfelt gratitude to all who contributed to the success of the National Level Post Graduate Research Symposium (NLPGRS-2025) and the subsequent publication of the multi-volume edited book, “Converging Horizons in Construction and the Built Environment: Digital, Sustainable, and Strategic Perspectives.” This achievement is the result of collaborative efforts, visionary leadership, and steadfast support from numerous individuals and organizations.

We are deeply honored to acknowledge the guidance and inspiration of Dr. Anil Kashyap, President and Chancellor of NICMAR University, whose visionary leadership continues to drive academic innovation and research excellence at NICMAR. His unwavering support has been pivotal in shaping the outcomes of both the symposium and this scholarly publication.

We are grateful to Dr. Sushma S. Kulkarni, Vice Chancellor of NICMAR University, for her constant encouragement and academic stewardship. We also extend our thanks to the Deans, faculty members, and research mentors, whose guidance was integral to the quality and diversity of contributions featured in these volumes.

Our sincere appreciation is extended to the Chief Guest, Dr. V. N. Heggade, Founder & CEO of DECon Complete Solutions, and the Guest of Honour, Mr. Mehul Ved, Vice President at EY LLP, for gracing the symposium with their presence and for delivering insightful addresses that added immense value to the academic discourse.

We acknowledge with sincere thanks the generous contribution of Saraswat Bank, which supported the successful conduct of NLPGRS-2025. We also express our appreciation to Journal Press India, our publishing partner, for their professional collaboration in producing these volumes.

A heartfelt thanks to all the postgraduate student authors whose original research and innovative thinking formed the foundation of this multi-volume publication. Their commitment to academic inquiry and problem-solving within the built environment is both commendable and inspiring.

We are equally grateful to the reviewers and academic mentors for their meticulous feedback and for upholding the scholarly rigor of the contributions.

Finally, we recognize the tireless efforts of the organizing team of NLPGRS-2025. Their dedication, coordination, and attention to detail ensured the seamless execution of the event and the successful realization of this publication.

CHAPTER 1

A Strategic Dividend Policy Framework for Real Estate and Infrastructure Firms

*Vikram Sai Pavan¹, Kurugunda Mohith Kumar²,
Nagothi Dhana Kishore², Mangala Sri Hari²*

ABSTRACT

This research focuses on the development of a strategic dividend policy framework tailored specifically for real estate and infrastructure firms. The study aims to evaluate various dividend types and policies such as cash, stock, and property dividends and their impact on firm value. The research aims to identify key factors influencing dividend policy decisions, including profitability, liquidity, and market conditions, while exploring the practical benefits of adopting structured dividend strategies. The methodology includes a comprehensive review of existing literature and data collection from real estate and infrastructure firms listed in Indian stock market. Regression analysis is employed to assess quantitative impacts, while case studies highlight real-world applications. The study will examine factors like market stability, shareholder demographics, and industry-specific challenges to offer practical insights. Findings reveal that stable and regular dividend policies significantly enhance shareholder value and financial performance, particularly in dynamic markets. While stable dividends are preferred, the study emphasizes the importance of aligning policies with organizational goals and external conditions. The analysis limited to findings from specific set of companies within the sector may not be broadly applicable to all real estate infrastructure firms. This research provides a robust framework to guide strategic decision-making in dividend policies, highlighting its potential to optimize financial outcomes and improve investor confidence in the real estate and infrastructure sectors.

Keywords: Dividend policy; Profitability; Liquidity; Market stability; Regression analysis; Shareholder value.

1.0 Introduction

The real estate and infrastructure industries are vital to economic growth, characterized by significant capital investments and long-term project timelines that can extend over several years or even decades.

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These sectors include a wide range of assets such as residential, commercial, and industrial properties, as well as infrastructure like utilities, telecommunications, and transportation networks. The financial environment of these industries requires a sophisticated approach to dividend policy, balancing the expectations of shareholders with the need for substantial reinvestment. Corporate governance is crucial in shaping dividend strategies, with elements like board composition, ownership structures, and financial transparency playing a significant role in influencing dividend decisions.

In real estate and infrastructure companies, dividend policies can be divided into three main models: a constant dividend payout ratio, a stable dividend policy, and a residual dividend policy. Each model presents unique challenges in these sectors, where it is essential to maintain investor confidence while addressing significant capital needs. Market conditions, such as interest rates, inflation, supply-demand dynamics, and geopolitical factors, add further complexity to dividend strategies. Companies must skillfully manage these challenges, developing dividend policies that offer stable returns to investors while ensuring adequate capital for ongoing and future infrastructure and real estate projects. Ultimately, the aim is to maximize shareholder value, maintain a competitive edge, and support sustainable long-term growth in these crucial economic sectors.

2.0 Literature Review

Research into dividend policy has become a vital aspect of financial management, especially for sectors like real estate and infrastructure, which involve significant capital investments and intricate financial frameworks. Studies have consistently shown that profitability is the main factor influencing dividend policy. (Singh, 2018) found that earnings per share (EPS) and net cash flow account for 67% of the variation in dividends per share, underscoring the importance of financial performance in making dividend decisions. (Sharma, 2019) expanded on this by analyzing 125 Indian real estate companies, discovering that factors such as firm risk, liquidity, previous dividends, and company growth play a significant role in shaping dividend distribution strategies.

The formulation of dividend policies in real estate and infrastructure firms is complex, as highlighted by various studies in emerging markets. (Shalini, 2020) examined Indonesian property and real estate companies, identifying a negative link between leverage and firm value, while profitability was positively correlated. (Abey, 2022) studied Indian cement and steel firms, stressing the importance of balancing dividend payouts with long-term business growth. (Labhane, 2015) offered further insights, noting that free cash flow, company size, profitability, and firm maturity positively affect dividend payments, with riskier and more leveraged companies typically providing lower dividends to shareholders.

The strategic significance of dividend policy goes beyond financial distribution, directly affecting investor confidence and market valuation. (Riya, 2017) showed the substantial impact

of dividend payments on stock prices, highlighting the crucial role of dividend policy in investor decision-making. (Islam, 2012) through research on Pakistan's cement industry, pointed out the nuanced factors influencing dividend policies, including the differing effects of profitability, debt-to-equity ratio, price-earnings ratio, and sales growth. Collectively, these studies suggest that real estate and infrastructure firms need to develop sophisticated dividend policy frameworks that carefully balance shareholder expectations, reinvestment needs, corporate governance considerations, and overall financial performance to maintain a competitive edge in dynamic market environments.

3.0 Research Methodology

3.1 Variable definition

Dividend Payout Ratio: The dividend payout ratio is the part of earnings disbursed to the stockholders in the form of dividends. Dividend Payout Ratio is calculated by dividing dividends per share by earnings per share.

Profitability: Profitability refers to the ability by which a firm can generate income in relation to its expenses and other costs.

Growth Opportunities: Growth opportunities refer to future opportunities for a firm in their industry or market in which revenues will grow.

Leverage: Leverage refers to the extent to which a firm uses debt financing in its capital structure. It is measured as the ratio of debt to equity or debt to total assets.

Market Conditions: Market conditions are those outside factors which have an impact on the financial performance and dividend policy of real estate and infrastructure firms. Interest rates, economic growth rates, and trade factors/indicators specific to an industry are some examples of what this kind of variable may contain.

3.2 Regression model specification

Dependent Variable: The dependent variable is the argument on which it is conducted, that is outcome or the variable on interest. Here, the dependent variable under study proves to be the dividend payout ratio, which tells us how much of earnings is distributed as dividends among stockholders.

Independent Variables: Independent variables are factors that are said to have an accountability source of change or explanation of such changes in the dependent variable above mentioned in the regression equation.

Regression Equation:

$$\text{Dividend Metric} = \beta_0 + \beta_1 X_1 i + \beta_2 X_2 i + \dots + \beta_k X_k i + \beta_k + 1 \text{SECTOR} i + \varepsilon i$$

where:

- Dividend Metrics represents the dependent variable (e.g., dividend yield, payout ratio, dividend growth) for firm i

- β_0 is the intercept term
- $\beta_1, \beta_2, \dots, \beta_k$ are the coefficients for the independent variables
- $X_{1i}, X_{2i}, \dots, X_{ki}$ represent firm-specific characteristics (e.g., firm size, profitability, leverage, growth opportunities)
- $SECTOR_i$ is a dummy variable (0 = Real Estate, 1 = Infrastructure) to capture sector-specific effects
- ϵ_i is the error term for firm i

3.2.1 Regression analysis methodology

Regression Equation for real estate

$$\text{Dividend} = 3.1487 + 0.0578(\text{Profitability}) + 0.1579 (\text{Return on Equity}) - 4.0296 (\text{Leverage})$$

Regression Equation for infra structure

$$\text{Dividend} = -0.08917 + 0.13(\text{Profitability}) + 0.0611(\text{Return on Equity}) - 2.7819(\text{Leverage})$$

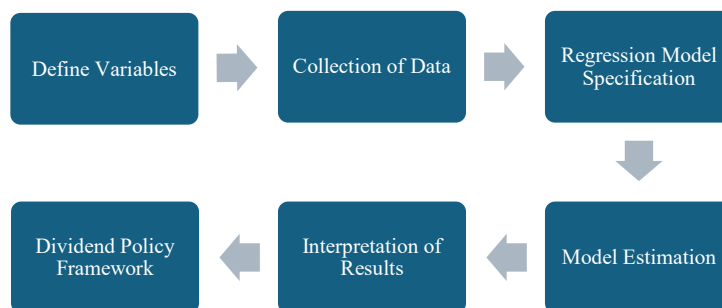
3.3 Model assumptions

Different assumptions on linearity, independence of errors, homoscedasticity, and normality of the residuals have been made for carrying out regression analyses. These assumptions must be checked so that the regression results would yield valid conclusions.

3.4 Flow chart

The Complete process represented below.

Figure 1: Flowchart of Methodology



4.0 Data Analysis

Profitability, leverage, and return on equity are some of the variables that affect the financial success of businesses in the infrastructure and real estate industries. This chapter provides a thorough data analysis utilizing statistical tools to help comprehend these

correlations. Descriptive analysis, correlation analysis, and regression analysis of thirty firms are all part of the study.

4.1 Real estate firms

4.1.1 Descriptive statistics

Real estate firms exhibit a wide range of dividend payouts, with an average of 4.92 and a standard deviation of 1.92. Profitability also shows significant variation, averaging 28.82 and ranging from 15.06 to 45.92. The average return on equity (ROE) is 9.91%, indicating moderate consistency. Leverage ratios, averaging 0.36, highlight different debt management strategies within the industry. Companies that are highly profitable and have low leverage are able to sustain regular dividend payments, whereas those with high leverage might need to retain earnings to ensure financial stability. Effective dividend strategies should align shareholder expectations with financial health metrics and the sustainability of long-term profitability.

Table 1: Descriptive Statistics Analysis for Real Estate Firms

Metrics	Dividend	Profitability	Return on Equity	Leverage
Mean	4.92	28.82	9.91	0.36
Standard Error	0.35	1.70	0.66	0.04
Median	5.31	28.91	9.99	0.32
Mode	#N/A	#N/A	#N/A	#N/A
Standard Deviation	1.92	9.31	3.60	0.20
Sample Variance	3.70	86.66	12.97	0.04
Kurtosis	-1.25	-1.17	-1.42	-1.16
Skewness	-0.05	0.16	0.15	0.35
Range	6.18	30.86	10.65	0.64
Minimum	1.87	15.06	4.98	0.08
Maximum	8.05	45.92	15.63	0.72
Sum	147.55	864.50	297.43	10.87
Count	30.00	30.00	30.00	30.00

4.1.2 Correlation analysis

There is a strong positive correlation, approximately 0.99, between dividends, profitability, and ROE, indicating that financially successful real estate firms consistently offer higher returns to shareholders and larger dividend payouts. On the other hand, leverage is significantly negatively correlated with all these metrics, around -0.98, suggesting that companies with high debt levels tend to have lower profits and smaller dividend distributions.

The negative correlation between leverage and ROE (-0.98) implies that excessive debt reduces shareholder value due to increased interest expenses. Effective dividend strategies should balance debt management with profit generation, as companies with less leverage can sustain generous payouts, whereas those with high debt focus on financial stability.

Table 2: Correlation Analysis for Real Estate Firms

	Dividend	Profitability	Return on Equity	Leverage
Dividend	1			
Profitability	0.994190087	1		
Return on Equity	0.99234943	0.994879755	1	
Leverage	-0.991518791	-0.980358552	-0.975879444	1

4.1.3 Regression analysis

The regression analysis indicates a strong model (R-squared = 0.9966) in which profitability, ROE, and leverage together account for nearly all the variation in dividend distributions among real estate firms.

Table 3: Regression Analysis for Real Estate Firms

	Coefficient	Std. Error	t-ratio	p-value
constant	3.14871	0.542754	5.801	<0.0001***
Profitability	0.0577611	0.0258623	2.233	0.0343**
Return on Equity	0.157873	0.0603989	2.614	0.0147**
Leverage	-4.02961	0.543763	-7.411	<0.0001***

Mean dependent var	4.918333	S.D. dependent var	1.924173
Sum squared resid	0.364048	S.E. of regression	0.118329
R-squared	0.996609	Adjusted R-squared	0.996218
F (3, 26)	2547.447	P-value(F)	3.27e-32
Log-likelihood	23.60686	Akaike criterion	-39.21373
Schwarz criterion	-33.60894	Hannan-Quinn	-37.42071

Profitability (coefficient = 0.0578) and ROE (coefficient = 0.1579) have significant positive effects on dividend payouts, suggesting that financially successful companies tend to reward their shareholders more generously. In contrast, leverage has a pronounced negative impact (coefficient = -4.03, $p < 0.0001$), implying that companies with high debt levels prioritize meeting debt obligations over distributing returns to shareholders. These results highlight the importance for real estate companies to strike a balance between profitability and debt management when developing dividend policies that enhance shareholder value while ensuring financial stability.

Figure 2: Real Estate Firm Dividend Performance: Regression Residual Analysis

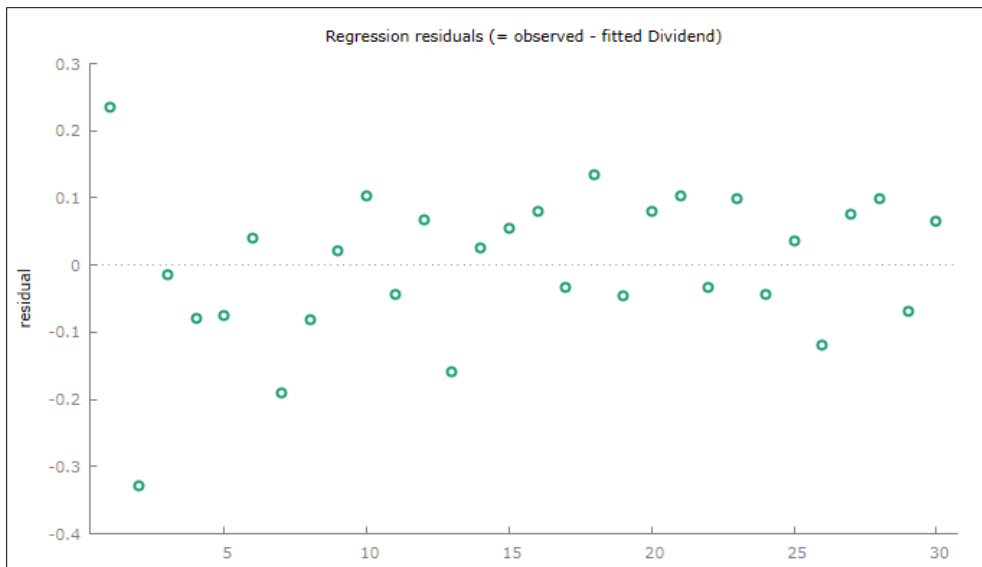
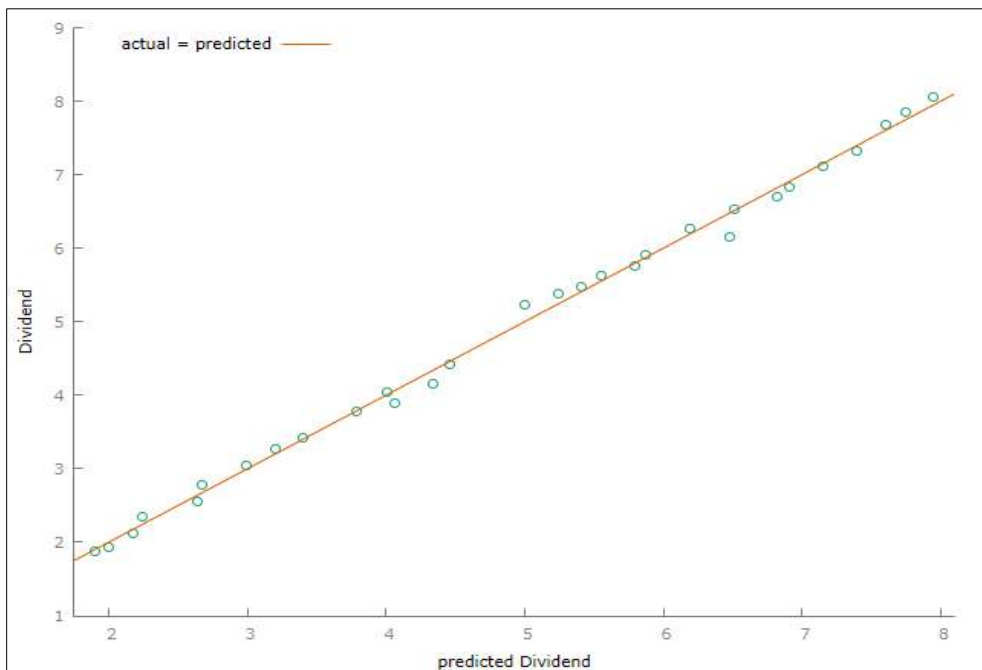


Figure 3: Real Estate Firms: Actual vs. Predicted Dividend Performance



4.2 Infrastructure firms

4.2.1 Descriptive Statistics

Infrastructure companies tend to have lower average dividend payouts compared to real estate firms (4.92), likely due to their capital-intensive nature. There is significant variation in these payouts (SD = 2.00, range = 0.09-6.64), indicating a variety of distribution strategies.

Table 4: Descriptive Statistics Analysis for Infrastructure Firms

	Dividend	Profitability	Return on Equity	Leverage
Mean	3.26	28.82	9.91	0.36
Standard Error	0.36	1.70	0.66	0.04
Median	3.41	28.91	9.99	0.32
Mode	#N/A	#N/A	#N/A	#N/A
Standard Deviation	2.00	9.31	3.60	0.20
Sample Variance	3.99	86.66	12.97	0.04
Kurtosis	-1.15	-1.17	-1.42	-1.16
Skewness	0.03	0.16	0.15	0.35
Range	6.55	30.86	10.65	0.64
Minimum	0.09	15.06	4.98	0.08
Maximum	6.64	45.92	15.63	0.72
Sum	97.88	864.50	297.43	10.87
Count	30.00	30.00	30.00	30.00

Profitability measures are similar to those of real estate companies (mean = 28.82, range = 15.06-45.92), while the average return on equity (ROE) is 9.91%, with some companies finding it challenging to achieve returns above 5%. Leverage patterns (mean = 0.36, range = 0.08-0.72) suggest a moderate reliance on debt, with a positive skewness indicating that most companies prefer conservative borrowing. A successful dividend policy framework should balance the need for ongoing capital investments by providing returns to shareholders, with firms that have higher profitability and lower debt being better equipped to sustain regular dividends.

4.2.2 Correlation analysis

In infrastructure companies, there are strong positive correlations between dividends and both profitability (0.9970) and ROE (0.9932), indicating that financial success leads to increased payouts to shareholders. On the other hand, leverage has significant negative correlations with dividends (-0.9886), profitability (-0.9804), and ROE (-0.9759), suggesting that firms with high debt levels prioritize managing their obligations over distributing dividends. This trend highlights that infrastructure companies with substantial leverage face limitations on

their ability to pay dividends due to competing financial priorities. To ensure sustainable dividend policies, these firms should aim to boost profitability while managing debt levels carefully, balancing the need for capital investment with providing consistent returns to shareholders.

Table 5: Correlation Analysis for Infrastructure Firms

	Dividend	Profitability	Return on Equity	Leverage
Dividend	1			
Profitability	0.997021681	1		
Return on Equity	0.993197982	0.99488	1	
Leverage	-0.988607061	-0.98036	-0.97588	1

4.3.3 Regression analysis

Table 6: Regression Analysis for Infrastructure Firms

	Coefficient	Std. Error	t-ratio	p-value
constant	-0.0891749	0.494764	-0.1802	0.8584
Profitability	0.130249	0.0235755	5.525	<0.0001***
Return on Equity	0.0611717	0.0550584	1.111	0.2767
Leverage	-2.78194	0.495683	-5.612	<0.0001***

Mean dependent var	3.262667	S.D. dependent var	1.996583
Sum squared resid	0.302515	S.E. of regression	0.107867
R-squared	0.997383	Adjusted R-squared	0.997081
F (3, 26)	3303.237	P-value(F)	1.13e-33
Log-likelihood	26.38416	Akaike criterion	-44.76832
Schwarz criterion	-39.16353	Hannan-Quinn	-42.97530

Regression analysis of infrastructure companies presents a strong model (R-squared = 0.9974) in which profitability is the most significant positive determinant of dividends (coefficient = 0.1302, $p < 0.0001$), reflecting that financially successful companies pay higher shareholder returns. Leverage is seen to significantly negatively impact (coefficient = -2.7819, $p < 0.0001$), affirming that companies carrying debt prefer capital-intensive projects over dividend payment owing to financial obligations. Contrary to expectations, ROE exerts no statistically significant impact on dividend policies (coefficient = 0.0612, $p = 0.2767$), reflecting that infrastructure companies are likely to reinvest returns in long-term projects rather than immediate gain. The findings reflect that dividend policies with long-term sustainability in the infrastructure industry must be directed towards profitability management while ensuring optimal debt levels for ensuring financial health and shareholder returns.

Figure 4: Infrastructure Firm Dividend Performance: Regression Residual Analysis

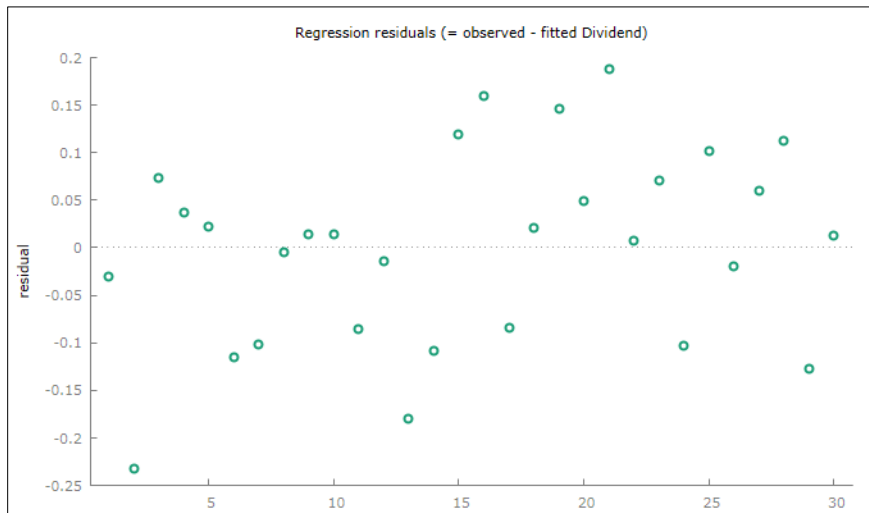
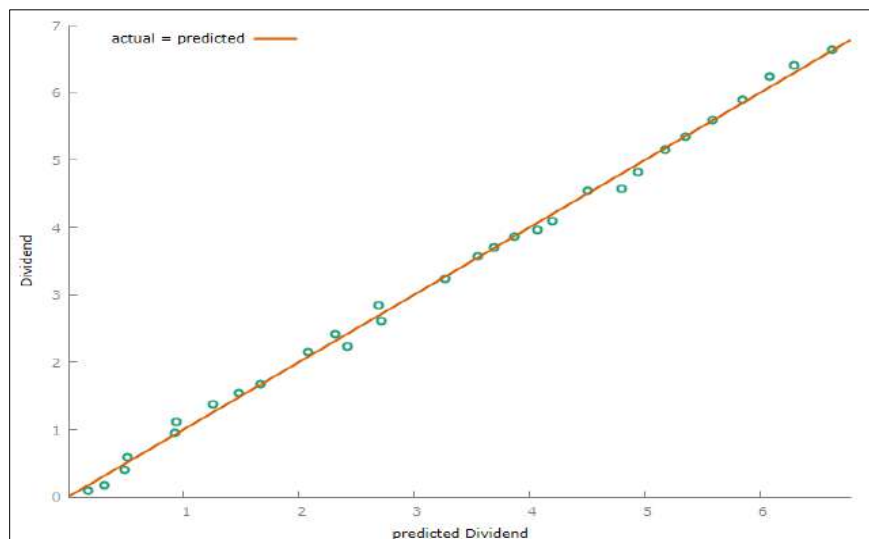


Figure 5: Infrastructure Firms: Actual vs. Predicted Dividend Performance



5.0 Conclusion

This research contributes to the development of a strategic model of dividend policy for real estate and infrastructure businesses by analyzing the effect of profitability, ROE, and

leverage on payout decisions for these capital-intensive businesses. Analysis of data reveals high positive correlations between profitability and dividends, and high leverage severely limits the ability to pay, with more stable dividend patterns in real estate businesses compared to infrastructure businesses due to more stable cash flows. This research finds that judicious dividend policies should strike a balance between shareholder reward and financial health, and hence businesses need to attempt to enhance profitability while maintaining debt at optimal levels. Despite limitations of data source and time horizon, this research provides useful insights for corporate managers to design sustainable dividend policies that can allow long-term growth objectives while meeting evolving investor sentiments.

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CHAPTER 2

A Study on Intellectual Capital in the Indian Construction Contracting Firms

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ABSTRACT

This study explores the impact of intellectual capital on the performance of Indian construction contracting firms, emphasizing its role in sustaining competitive advantage. The research examines human capital (HC), structural capital (SC), and relational capital (RC) as key independent variables influencing firm performance (FP). Control variables include firm age, size, work experience, experience within the firm, and position. Using a questionnaire survey methodology, data was collected from professionals in the Indian construction industry. Statistical data analysis was performed to evaluate the relationships between intellectual capital components and firm performance. The hypothesis testing reveals that while human capital (HC) does not significantly impact firm performance, both structural capital (SC) and relational capital (RC) have a positive influence on the overall efficiency and success of construction firms. This research provides empirical evidence on the importance of intellectual capital in organisational performance by testing the impacts of human, structural, and relational capital on total factor productivity (TFP) in the corporate market. The research offers insight into how companies can apply intangible assets to enhance productivity and competitiveness using quantitative and qualitative measurements. Findings contribute to intellectual research and practice, supporting business executives to make strategic decisions that optimize intellectual capital. Policymakers, managers, and academics concerned with knowledge economies and sustainable business development may be interested in this study very highly.

Keywords: Intellectual capital; Human capital; Structural capital; Relational capital; Firm performance.

1.0 Introduction

1.1 Intellectual capital

Intellectual Capital Intellectual Capital (IC) refers to the collective intangible assets, knowledge resources and competencies that drive organizational value creation, competitive advantage, and sustainable performance.

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It is an aggregation of human expertise, organizational knowledge infrastructure, and external stakeholder relationships that contribute to the efficiency, innovation, and long-term success of a firm. Intellectual Capital is widely recognized as a fundamental component in knowledge-driven economies, where traditional financial and tangible assets alone do not determine success. Intellectual capital is made up of three main components: 1. Human Capital: The individual knowledge, expertise, skills, and innovation of workers that aid organizational performance. (Duodu & Tsai 2020, Andreeva & Kianto 2016, Hussinki *et al.*, 2017) 3 2. Structural Capital: The company's non-human assets such as organizational processes, patents, databases, and technology that ensure operating efficiency. (Garcia-Perez & Ayres 2019, Secundo *et al.* 2017) 3. Relational Capital: The value acquired from relations with stakeholders like suppliers to clients' clients, investors, and government bodies. (Duodu & Rowlinson 2019, MacDougall & Hurst 2005) Though critical to its success, Intellectual Capital of the Indian construction industry remains untapped, with companies depending mostly on tangible and traditional financial assets. This research seeks to fill in the lacuna by investigating the contribution of Intellectual Capital towards Firm Performance and competitiveness.

1.2 Goals

The main goals of this research are:

- Identification of pertinent intellectual elements contributing to Firm Performance.
- Empirical verification of the extent to which identified intellectual impact Firm Performance of Indian Construction Contracting Organizations.

2.0 Literature Review

Based on 26 research publications, this study of the literature aims to investigate the notion of intellectual capital, its factors, and effects on the performance of construction companies. Intellectual capital, according to the body of research, is three-component: human capital, structural capital, and relational capital (Stewart, 1997; MacDougall, 2005). While structural capital relates to the organizational knowledge, procedures, and technology applied by the company, human capital is the skill acquired by employees of the company. Relational capital covers corporate private networks, stakeholders, and other corporate relationships. Effective control and integration of these intellectual resources results in higher knowledge generation, innovation, and construction companies' profitability enhancement.

2.1 Intellectual capital

Prusak defines Intellectual capital (IC) as "Intellectual material that has been formalized, captured, and leveraged to produce a higher valued asset" (Egbu 2004). Intellectual capital in the Indian construction companies can be categorized into three main components: human, structural, and relational capital (Stewart, 1997). Human capital involves the knowledge,

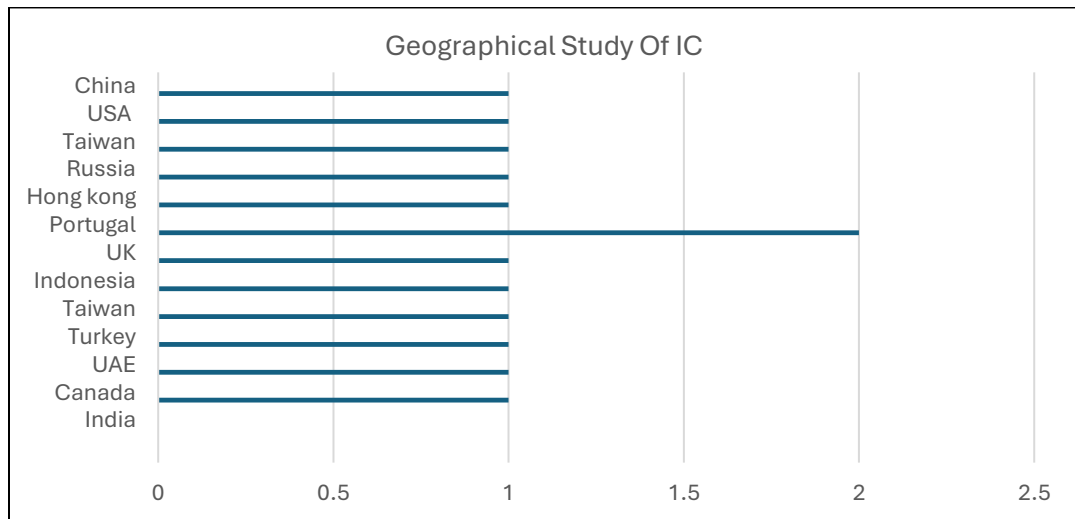
experience, and skills of engineers, architects, and project managers. Structural capital includes firm procedures, technical infrastructure, and intellectual assets, whereas relational capital is the relations with the clients, government departments, vendors, and other parties.

Table 1: Literature Review

Year	Name of Journal	Title	Geography
2001	SJM	Constructing intellectual capital statements	Denmark
2004	ECAM	Managing knowledge and intellectual capital for improved organizational innovations in the construction industry: an examination of critical success factors	Scotland, UK
2005	IC	Identifying tangible costs, benefits and risks of an investment in intellectual capital Contracting contingent knowledge workers	Wolfville, Canada
2009	JCEM	Fuzzy Intellectual Capital Index for Construction Firms	Turkey
2009	JHRCA	Construction of Intellectual Capital- the case of purchase analysis	Sweden
2010	JCEM	A study on the relationship between intellectual capital and business performance in the engineering consulting industry: A path analysis	Taiwan
2011	IC	Construction and valuation of intellectual capital: A case study	
2015	K&PM	Assessment and Management of Intellectual Capital: A Single Case Study on the Construction and Implementation of an IC Index	Italy
2016	ECKM	The Effect of Intellectual Capital and Strategic Partnerships in Construction Companies	Portugal
2016	IC	Do all elements of intellectual capital matter for organizational performance? Evidence from Russian context	Russia
2016	EPOC	Intellectual Capital and Innovation in Construction Organizations: A Conceptual Framework	USA
2016	JIC	Do all elements of intellectual capital matter for organizational performance?	St Petersburg
2016	IC	Intellectual capital, knowledge management practices and firm performance	Finland
2017	TFSC	An Intellectual Capital framework to measure universities' third mission activities	Italy
2017	IJCM	Correlation between intellectual capital and business performance of construction industry	Taiwan
2017	IC	Intellectual capital, knowledge management practices and firm performance	Finland
2017	Elsevier	An Intellectual Capital framework to measure universities' third mission activities	European countries
2019	KM	Knowledge Management and Intellectual Capital in Knowledge-based Organisations	USA
2019	KM	Knowledge Management and Intellectual Capital in Knowledge-based Organisations: A Review and Theoretical Perspectives	USA
2019	JIC	Intellectual capital for exploratory and exploitative innovation	Austria

2019	Sustainability	Intellectual Capital, Knowledge Sharing, and Innovation Performance: Evidence from the Chinese Construction Industry	China
2020	ASSEHR	The Influence of Financial Ratios and Intellectual Capital on Financial Difficulties in Construction Companies	
2020	JME	Intellectual Capital, Innovation, and Performance in Construction Contracting Firms	Hong Kong
2022	IJAFB	Examining the Role of Intellectual Capital in determining the firm's performance: A study from the construction industry of UAE	UAE
2022	ECKM	Intellectual Capital and Performance: A Case Study of Construction Companies	Portugal
2022	JMT	Impact of attracting intellectual capital on the innovative development of construction engineering enterprises	Moscow

Figure 1: Geographical Studies of IC



2.2 Industrial and geographical context

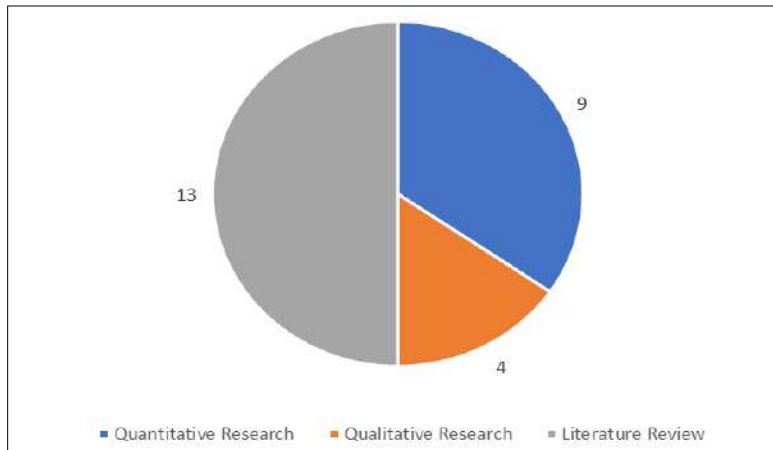
After going through the thorough review of 26 articles in IC in various industries, we learned that the study has been conducted in various regions of the world but not in India. Therefore, it is essential to study that how Indian Construction Industry is impacted by IC because Indian Construction Industry is also a complex industry and that too in the Indian Construction Contracting Firms.

2.3 Methods

This research adopts a systematic review of literature in exploring the position of Intellectual Capital (IC) among Indian construction contracting companies. The study is based

on an in-depth scrutiny of 26 academic papers consisting of diverse types of research methodology including qualitative research, quantitative analysis, and reviews of literature.

Figure 2: Methods of LR



2.4 Hypothesis Development

H1: Human Capital (HC) has a significant positive impact on firm performance.

H2: Structural Capital (SC) has a significant positive impact on firm performance.

H3: Relational Capital (RC) has a significant positive impact on firm performance.

3.0 Research Methodology

3.1 Study context, sampling criteria and data collection procedure

This study focuses on collecting data from construction managers and engineers, specifically within the contracting firms of the Indian construction industry. These professionals are chosen because their roles are critical in ensuring the successful execution of construction projects, and they hold significant accountability in project performance and organizational success. The study aims to collect approximately 200 responses from the selected strata. Given that the survey consists of fifty questions, a response size of at least 200 participants (calculated as 50×4) is required, as per Hair *et al.* (1998).

This sample size will allow for a comprehensive examination of the hypotheses related to intellectual capital and its impact on firm performance. A structured questionnaire will be developed and distributed to construction professionals through an online survey platform. The questionnaire will utilize a 5-point Likert scale to gauge respondents' opinions, ranging from "strongly disagree" to "strongly agree." Confidentiality and anonymity of all respondents will be strictly maintained, ensuring that the responses are used solely for research purposes.

3.2 Measures

3.2.1 Dependent variable

Firm Performance: Firm Performance comprises the firm's revenue growth, market share, service quality and customer satisfaction. (Henri, 2017)

3.2.2 Independent variables

Human Capital (HC): The individual knowledge, expertise, skills, and innovation of workers that aid organizational performance. (Duodu & Tsai 2020, Andreeva & Kianto 2016, Hussinki *et al.*, 2017)

Structural Capital (SC): The company's non-human assets such as organizational processes, patents, databases, and technology that ensure operating efficiency. (Garcia-Perez & Ayres 2019, Secundo *et al.* 2017)

Relational Capital (RC): The value acquired from relations with stakeholders like suppliers to clients' clients, investors, and government bodies. (Duodu & Rowlinson 2019, MacDougall & Hurst 2005)

Control Variables:

- Age of Firm
- Size of Firm
- Total Work Experience
- Experience with existing firm
- Firm position

4.0 Data Analysis and Findings

4.1 Reliability assessment (Cronbach's Alpha)

The reliability of all the scales was also tested for all the items from the questionnaire to measure the degree of consistency achieved in justifying that the findings are reliable (Nunnally & Bernstein 1994). The Cronbach's Alpha of all the scales were found to be above 0.70 (Hulin *et al.*, 2001). The Cronbach's Alpha value for all the scales has been tabulated below.

Table 2: Reliability Test

Variable	Reliability (α)
Total Human Capital (THC)	0.926
Total Structural Capital (TSC)	0.897
Total Relational Capital (TRC)	0.905

4.2 Hypothesis testing

As proposed earlier in the hypothesis chapter, where initially we concluded three hypotheses for our study and then several iterations had been conducted to find the extent of significance of those variables as well as the nature of association with outcome variables. The results generated showed us that out of three variables two variables (TSC and TRC) were significant and one (THC) was found insignificant.

4.2.1 Descriptive statistics and correlation

Each scale's mean and standard deviation were determined. To investigate the degree of correlation between the independent and dependent variables, Pearson's correlation coefficients (r) were computed. The degree of the linear relationship between two variables is shown by these correlation coefficients. The correlation between the variables as determined by SPSS is displayed in the table that is attached below.

As the study shows, Human Capital is insignificant to Firm Performance and Structural Capital and Relational Capital is significant to Firm Performance. The study also supports:

1. Structural Capital is positively related to Firm Performance.
2. Relational Capital is positively related to Firm Performance.
3. Human Capital is positively related to Firm Performance.

Table 3: Correlation

Variable	TFP	THC	TSC	TRC
TFP	1			
THC	.778**	1		
TSC	.837**	.851**	1	
TRC	.879**	.826**	.883**	1
**p< 0.01				
*p< 0.05				

TFP= Total Firm Performance; THC= Total Human Capital; TSC= Total Structural Capital; TRC= Total Relational Capital

4.2.2 Multiple regression analyses

- Total Human Capital (THC) ($\beta = 0.032$, $p = 0.659$)
- Total Structural Capital (TSC) ($\beta = 0.22$, $p = 0.01$)
- Total Relational Capital (TRC) ($\beta = 0.22$, $p < 0.001$)
- Control Variables (Age, Size, Work Experience, Position, and Current Experience): None of these variables were found to be significant

The detailed regression performed in SPSS software is attached below.

MODEL SUMMARY				
Model	R	R Square	Adjusted R Square	Std. Error
1	.274	.075	.048	6.301
2	.852	.726	.713	3.458

Table 4: Multiple Regression Model of Firm Performance and its Independent Variables

Model	Variable	Standardized Coefficients	Sig.
		Beta	
2	(Constant)	-	<.001
2	AGE	0.051	0.331
2	SIZE	0.005	0.928
2	WEX	-0.01	0.889
2	CEX	0.025	0.718
2	PSN	0.028	0.522
2	THC	0.032	0.659
2	TSC	0.22	0.01
2	TRC	0.22	<.001

AGE = Age of firm; SIZE = Size of company; WEX= Total Work Experience; CEX = Current Company Experience; PSN= Position in firm; THC = Total Human Capital; TSC= Total Structural Capital; TRC= Total Relational Capital

Key Findings

- TSC (p = 0.010) and TRC (p < 0.001) significantly impact TFP.
- THC (p = 0.659) does not show a significant direct effect.

Summary of Results: The summary of the results are as follows:

Table 5: Summary of Results

Sl. No.	Variables	Results
1	THC	Not Supported
2	TSC	Supported
3	TRC	Supported

5.0 Discussion, Implications and Conclusion

5.1 Implications for practice

5.1.1 Human capital

A lack of correlation between Human Capital and Firm Performance suggests that employee turnover may not be a determinant factor as previously thought.

5.1.2 Structural capital

- *Technology Integration:* Firms should invest in advanced digital tools, automation, and data management systems to streamline operations and improve efficiency.
- *Process Standardization:* Developing well-documented SOPs (Standard Operating Procedures) ensures knowledge continuity and reduces dependency on individuals.
- *Innovation & R&D:* To promote innovation and keep a competitive edge, businesses should invest in research and development.

5.1.3 Relational capital

- *Customer Relationship Management:* Companies should strengthen their CRM systems to maintain long-term client relationships and enhance customer loyalty.
- *Strategic Partnerships:* Building alliances with industry leaders, suppliers, and government bodies can open new growth opportunities.
- *Brand Reputation & Trust:* Firms should invest in corporate social responsibility (CSR) initiatives and transparent business practices to enhance their market credibility.

5.2 Limitations and conclusion

This study was to find effect of Intellectual Capital on Indian Construction Contracting Firms. The thesis was done in keeping with the prescribed methodology and analysis by previous studies. We recognize that our study has some limits. We chose 3 components of Intellectual Capital but there are various components of Intellectual Capital such as spiritual capital, social capital, etc. Further, analysis of moderation and mediation is possible among components of IC. Our sample size is as per prescribed survey formulation still we think it could have been more diverse as we restricted ourselves to Indian Construction Contracting Firms. As the study shows, Human Capital is insignificant to Firm Performance and Structural Capital and Relational Capital is significant to Firm Performance.

The study also supports:

- Structural Capital is positively related to Firm Performance.
- Relational Capital is positively related to Firm Performance.
- Human Capital is positively related to Firm Performance.

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CHAPTER 3

A Study on Quality and Safety Aspects in Tunneling

*Shardul Shamrao Patil¹, Aditya Deepak Bhadule¹,
Sharvari Bhaskar Desai², Rutvik Tanaji Patil¹*

ABSTRACT

Tunneling projects play a crucial role in modern infrastructure but pose significant safety and quality challenges. This study examines quality standards, risk management, and emergency response in tunnel construction, analyzing case studies such as the Atal Tunnel, Silkyara Bend-Barkot Tunnel, and Channel Tunnel. Key aspects include material selection, structural integrity, and compliance with international safety standards. Various tunneling methods, including NATM, TBM, and Drill & Blast, are assessed for seismic and geological suitability. The research highlights fire safety, ventilation, and real-time monitoring systems to mitigate hazards. The Uttarkashi Tunnel Accident (2023) is reviewed to identify lapses in geotechnical assessment and support structures. Recommendations include advanced risk evaluation, real-time monitoring, and emergency preparedness. By integrating technological advancements and best practices, this study aims to enhance tunneling safety, efficiency, and long-term operational reliability, ensuring adherence to stringent quality and safety protocols in underground construction.

Keywords: Quality aspects; Safety protocols; Evacuation plan; Risk management; Tunneling.

1.0 Introduction

Urbanization and infrastructure development have led to a growing reliance on tunneling projects for transportation, utilities, and other essential services. These underground structures provide solutions to space constraints in densely populated areas while enhancing connectivity and efficiency. However, tunneling presents significant engineering challenges, particularly regarding safety, quality control, and risk management. From geological uncertainties to fire hazards, construction failures, and environmental concerns, tunneling demands rigorous planning, advanced methodologies, and strict adherence to safety protocols. This study, “A Study on Quality and Safety Protocols in Tunneling,” aims to explore the critical quality and safety measures that govern modern tunneling projects. It investigates various design methodologies, risk evaluation techniques, and emergency response strategies to ensure the structural integrity and long-term sustainability of tunnels.

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A key focus is placed on the importance of geological assessments, material selection, reinforcement techniques, and anti-collision systems. Additionally, the study examines tunnel support design using Rock Mass Rating (RMR) and Tunneling Quality Index (Q) systems, evaluating their applicability across different geological conditions. Through case studies such as the Atal Tunnel, Silkyara Bend-Barkot Tunnel, and Channel Tunnel, the research identifies best practices in safety and quality management. These real-world examples provide insights into critical factors such as fire safety, ventilation, evacuation planning, and risk mitigation techniques. The study also explores technological advancements, including real-time monitoring systems and AI-based predictive models, to enhance tunnel safety. By synthesizing engineering principles, case study analyses, and best practices, this research aims to contribute to safer and more efficient tunneling projects. The findings will serve as a valuable resource for engineers, policymakers, and construction managers in developing robust safety frameworks and quality assurance strategies for future underground infrastructure projects.

1.2 Objectives

- To comprehend tunnelling safety procedures and quality requirements.
- To understand the effects of site conditions, seismic activities, and other conditions on the tunnel during and after construction
- To develop a robust emergency response plan to handle any unforeseen events during or after construction.
- To prepare evacuation plans in case of emergency.

1.3 Need for study and scope of work

Tunneling projects often face significant challenges related to accidents, structural collapses, and safety issues, leading to severe project delays, fatalities, and property damage. Despite the existence of international guidelines from organizations like the British Tunnelling Society (BTS) and the International Tunnelling and Underground Space Association (ITA), safety and quality standards vary across regions. These inconsistencies arise due to differing legal frameworks, limited resources, and the unique complexities of each project. As a result, evaluating current quality and safety measures is crucial to identifying gaps and opportunities for improvement in tunneling operations.

Previous research has explored aspects such as risk assessment, accident prevention, and the use of advanced technologies in tunneling. However, a comprehensive study that examines the entire project lifecycle from a quality and safety standpoint is still lacking. This study aims to bridge that gap by analyzing existing protocols, highlighting best practices, and recommending improvements. A deeper understanding of these challenges will contribute to the development of more effective safety measures, leading to safer, more efficient, and sustainable tunneling projects worldwide.

2.0 Literature Review

City tunnel projects pose engineering safety and quality challenges, especially in earthing system design. With growing urban congestion, underground infrastructure demands careful management of soil resistivity, operational safety, corrosion, and utility commissioning. A systems approach integrating tunnel components and risk assessment of circulating currents and induction risks is crucial for long-term safety. Emphasizing testing, commissioning, and multidisciplinary coordination ensures underground systems remain secure and functional (McKerrow *et al.*, 2020).

Tunnel safety is crucial for mitigating fire hazards, explosions, and emergency evacuations. Studies emphasize fixed firefighting systems, passive fire protection, and fire safety engineering to enhance response and minimize casualties. Ventilation and fire dynamics research provide insights for better tunnel designs (Lönnermark & Ingason, 2014). Additionally, rock mass quality evaluation is essential for tunnel stability. The Rock Mass Rating (RMR) and Tunneling Quality Index (Q) systems aid in rock classification and stress analysis, with the Q system preferred for high-stress environments due to its stress reduction factor (Rehman *et al.*, 2020). Effective tunnel risk management ensures quality and safety by integrating design verification, contractual procedures, and quality control. Advanced risk evaluation methods, like TOPSIS and fuzzy logic, enhance accuracy and decision-making by identifying high-risk scenarios and mitigation strategies. The inclusion of new assessment criteria such as detectability, vulnerability, and reaction to events further improves uncertainty management in tunnel construction (Fouladgara *et al.*, 2020). Another critical aspect of safety in tunneling operations is the use of anti-collision systems to prevent accidents in underground construction sites. Various technologies such as radar, RFID, ultrasonic sensors, Lidar, and infrared imaging are employed to enhance visibility, detect potential hazards, and improve safety protocols. These systems are designed to address blind spots, monitor worker proximity to machinery, and prevent collisions, thereby improving overall safety in tunneling environments (Patrucco *et al.*, 2021).

3.0 Methodology

The methodology for this study involves comprehensive analysis of quality and safety protocols in tunneling through literature reviews, case studies, and expert interviews. The research examines various tunneling methods, construction safety measures, and risk mitigation strategies. Key aspects include geotechnical analysis, material quality assessment, and the implementation of safety protocols. Case studies of the Atal Tunnel and Silkyara Bend-Barkot Tunnel provide real-world insights into best practices and challenges. The study employs qualitative and quantitative analysis, incorporating site condition evaluations, seismic impact assessments, and emergency response planning. Data collection includes expert consultations,

project documentation reviews, and comparative analysis of tunnel construction methodologies. The study aims to develop recommendations for improving tunneling safety, enhancing structural integrity, and optimizing emergency preparedness. Findings will contribute to refining the best practices for safer, more efficient tunnel construction projects.

4.0 Data Analysis

In regions with seismic activity, choosing the right tunneling method is crucial to ensure both safety during construction and the long-term stability of the tunnel. Different seismic zones present varying levels of risk, such as ground shaking, fault movements, liquefaction, and landslides. The selection of the tunneling method depends on several factors, including the seismicity of the region, geological conditions, and depth of the tunnel. Below explain the main tunneling methods and their suitability for different seismic zones, as well as modifications that can be applied to enhance safety in seismically active areas.

Table 1: Tunneling Methods in Seismic Zones

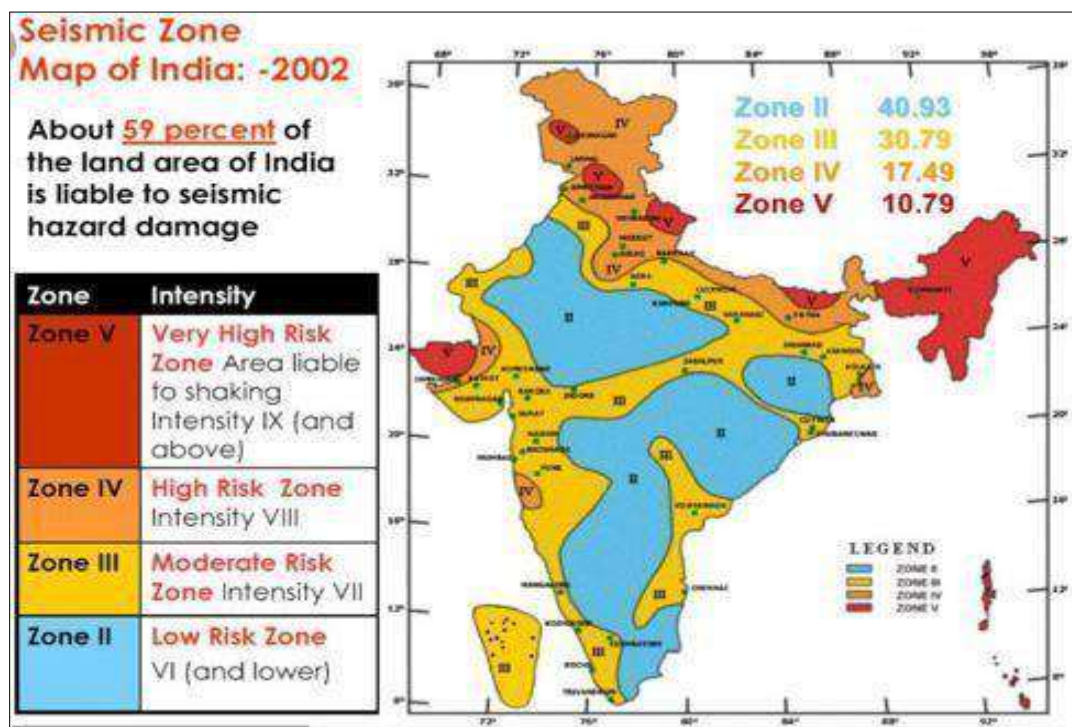
Tunneling Methods	Best used in	Seismic Zone Suitability
Cut and cover	Shallo Urban Tunnel	Low to Moderate
NATM	Variable rock conditions, mixed ground	Moderate to High
TBM	Deep, stable rock foundation	Moderate to High
Sequential Excavation (SEM)	Soft Ground	High
Immersed Tube	Underwater Crossing	Low to Moderate
Drill and blast	Hard Rock Tunnel	Moderate to High
Horizontal Directional Drilling	Utility Crossing	Low to Moderate

4.1 Uttarkashi tunnel accident analysis

The Uttarkashi tunnel collapse was a tragic incident that occurred on November 12, 2023, as part of the Char Dham Highway project, a major infrastructure initiative aimed at improving access to Uttarakhand's holy shrines. The tunnel, under construction to connect Uttarkashi with Gangotri, collapsed, trapping around 40 workers inside. This raised serious concerns about safety protocols and construction practices. The collapse was caused by the failure of a section of the tunnel roof, followed by water ingress from an underground source, which further destabilized the structure. Rescue efforts were delayed due to debris blocking access, prolonging the workers' entrapment and complicating emergency response measures. Investigations into the incident highlighted major irregularities in construction methods and material use. One of the key issues was inadequate geotechnical surveys, which failed to fully analyze the region's sedimentary rock formations and water-bearing layers. The construction plan also lacked sufficient seismic safety measures despite the region's high vulnerability to

earthquakes. Additionally, the tunnel did not have adequate structural support such as rock bolts, steel ribs, or shotcrete—elements essential for maintaining stability in weak rock conditions. Concerns were also raised regarding the quality of materials used, with reports suggesting that low-grade concrete with insufficient compressive strength may have compromised the tunnel’s integrity.

Figure 1: Seismic Maps of India



Another major contributing factor was poor water management and drainage systems. The construction team did not install adequate waterproofing membranes or drainage channels to handle groundwater ingress, which became a significant issue when the collapse occurred. Proper water detection techniques, such as pre-drilling and waterproofing layers, could have prevented the sudden flooding that further weakened the tunnel structure. The lack of these crucial measures highlights significant gaps in project planning and execution.

To prevent similar accidents in the future, several safety measures should be implemented. Comprehensive geotechnical and risk assessments, including the use of ground-penetrating radar and borehole logging, should be conducted before tunnel construction begins. Reinforcement systems like rock bolts and steel ribs must be installed in unstable geological zones. Additionally, real-time monitoring systems, including sensors for ground movement and

water levels, can provide early warnings of potential structural failures. Improved drainage infrastructure, waterproof membranes, and pre-drilling techniques to detect water pockets should also be mandatory in tunnel projects.

Finally, regulatory oversight and worker safety training must be strengthened. Independent third-party audits should be conducted regularly to ensure compliance with national and international construction standards. Material testing should be enforced to maintain quality control. Furthermore, workers should be trained in emergency response protocols, and regular safety drills should be conducted to improve preparedness. By implementing these measures, tunneling projects can enhance safety, reduce risks, and ensure better protection for workers and infrastructure in the future.

5.0 Analysis and Result

5.1 Quality aspects in tunneling

Ensuring quality in tunnel construction is vital for structural integrity, safety, and longevity. High-quality materials, including high-strength concrete (30-50 MPa) with waterproofing additives, durable steel reinforcements (minimum 500 MPa), and waterproofing membranes like HDPE or PVC, help prevent structural failures and water loss. Rigorous quality assurance methods, such as non-destructive testing (NDT) and sample testing, ensure compliance with industry standards like ISO 9001.

Workmanship also plays a crucial role, as skilled labor and precise excavation techniques are necessary to prevent defects. Tunnel Boring Machines (TBMs) require expert handling to maintain alignment, and continuous supervision helps detect and address issues like cracks or misalignments early. Regular inspections by quality control engineers further enhance construction quality. A strong structural design is essential to withstand internal and external forces, including seismic activity and traffic loads. Proper geotechnical analysis informs reinforcement strategies like shotcrete and rock bolts, while fire-resistant materials and advanced ventilation systems improve tunnel safety. Adhering to global standards such as Eurocode 7 and AASHTO ensure tunnels meet high safety benchmarks.

Post-construction monitoring and maintenance are equally important. Sensors like strain gauges and accelerometers help detect shifts, cracks, or water infiltration, allowing for timely interventions. Regular maintenance of drainage, ventilation, and fire suppression systems ensures the tunnel remains safe and functional throughout its lifespan. By implementing these quality measures, tunnel projects can achieve durability, safety, and long-term sustainability.

5.2 Safety aspects in tunneling

Ensuring safety in tunnel construction requires a multi-phase approach, starting from pre-construction planning to emergency response. Before excavation begins, thorough geological surveys and risk assessments help identify potential hazards like fault lines, gas

pockets, and water pressure. For instance, challenges faced during the Atal Tunnel project demonstrated the need for adaptive construction strategies when unexpected conditions arise. Proper planning allows engineers to implement mitigation measures, reducing risks before tunneling starts. During construction, worker safety depends on effective excavation techniques, ventilation, and fire prevention systems. The use of Tunnel Boring Machines (TBMs) minimizes direct human exposure to hazardous conditions, while traditional drilling and blasting require strict vibration and dust control. Adequate ventilation is necessary to prevent dangerous gas buildup, as seen in large-scale projects like the Channel Tunnel, which incorporates complex air quality management systems. Additionally, fire-resistant materials and suppression systems, combined with regular fire drills, ensure preparedness in case of an emergency.

Operational safety relies on real-time monitoring and communication systems. Advanced surveillance, gas detection sensors, and emergency broadcast networks, such as those installed in the Atal Tunnel, help detect risks early and enable quick responses. Reliable communication, through radios and PA systems, ensures that emergency coordination is swift and effective, reducing potential casualties in critical situations. Lastly, emergency response planning plays a crucial role in tunnel safety. Escape routes, such as cross passages and emergency exits, are essential in long tunnels like the Channel Tunnel, providing quick evacuation paths. Specialized rescue teams trained in confined-space operations are vital for effective crisis management. The Uttarkashi Tunnel accident highlighted the need for rapid rescue mobilization and improved preparedness. By integrating these safety measures, tunnel projects can enhance worker protection and ensure long-term infrastructure stability.

6.0 Practical Implementation

6.1 Igloo tunnels

IGLOO Tunnels are compact, oval-shaped structures made of SCS Steel Concrete Steel lining, designed as emergency escape routes in tunnel construction. Running parallel to the main tunnel, they extend their entire length until the structure is fully stabilized. Positioned 100-200 meters before the main tunnel opening, these tunnels allow workers to pass through with essential equipment and feature strategically placed entry and exit points for quick access.

In emergencies like tunnel mouth cave-ins or internal collapses (such as the Uttarkashi accident), IGLOO Tunnels provide a crucial escape route. If the main entrance is blocked, workers can safely exit through an alternate opening 50-100 meters away. Even if the IGLOO Tunnel sustains damage, only minimal excavation is required to reopen it, significantly reducing evacuation time and effort. This system ensures a safer work environment and enhances emergency preparedness in tunnel construction.

6.2 Steel concrete steel – SCS sandwich tunnels

The Steel-Concrete-Steel (SCS) sandwich tunnel lining system is an advanced structural design that enhances tunnel durability and resilience by integrating steel's tensile

strength with concrete's compressive capabilities. This composite structure consists of an inner steel plate, a concrete core, and an outer steel plate, forming a robust tunnel lining that withstands extreme conditions. Unlike traditional concrete-only linings, the SCS system is particularly beneficial in high seismic zones, underwater tunnels, and unstable ground conditions, where additional strength and flexibility are crucial for structural integrity. The inner steel plate resists abrasion and internal forces, while the concrete core acts as the primary load-bearing element. The outer steel plate provides resistance against external pressures, corrosion, and impacts, making the system more durable in aggressive environments.

One of the primary advantages of the SCS system is its superior structural strength and seismic resilience. The steel layers prevent buckling and provide enhanced load-bearing capacity, which is essential for tunnels subjected to intense pressures and ground movements. In earthquake-prone areas, the flexibility of steel helps dissipate seismic energy, reducing structural damage.

Additionally, the outer steel layer acts as a protective barrier against water ingress, making the SCS system ideal for underwater tunnels. The improved water and gas tightness prevents seepage, safeguarding the concrete core from chemical attacks and ensuring the tunnel's longevity. These characteristics make the SCS system particularly suitable for high-pressure tunnels, hydroelectric projects, and urban subway systems where maintaining tunnel integrity is critical.

Beyond its structural benefits, the SCS system also improves space efficiency and cost-effectiveness over time. The high strength of the composite layers allows for thinner tunnel walls compared to conventional concrete linings, reducing excavation needs and optimizing available space—an essential factor in densely populated urban areas. Furthermore, the corrosion-resistant steel and protective coatings extend the tunnel's lifespan, lowering long-term maintenance costs. While the initial construction expenses may be higher due to material selection, joint design complexities, and precise installation techniques, the durability and reduced upkeep costs ultimately outweigh these challenges. The use of automated welding, expansion joints, and careful concrete pouring techniques ensures high-quality construction, minimizing future risks.

Real-world applications of the SCS system demonstrate its effectiveness in challenging environments. The Tokyo Bay Aqua-Line Tunnel in Japan, built under intense water pressure and seismic risks, relies on SCS lining for durability and water tightness. Similarly, the Gotthard Base Tunnel in Switzerland, one of the world's longest railway tunnels, implemented SCS in sections facing high rock pressure and groundwater ingress. The Qinling Tunnel in China, passing through seismically active zones, utilized the SCS system to enhance safety against potential earthquakes and rockfalls. As infrastructure projects continue to push engineering limits, the SCS sandwich system is proving to be a critical advancement, ensuring safer, more resilient tunnels worldwide.

7.0 Conclusion

Tunneling projects are essential for modern infrastructure, but they come with significant challenges, including geological unpredictability, fire hazards, water ingress, and seismic risks. Ensuring safety and quality requires meticulous planning, advanced construction techniques, and continuous monitoring. Key factors for success include robust material selection, geotechnical analysis, fire safety, and emergency response preparedness.

Case studies highlight valuable lessons in tunneling safety. The Atal Tunnel demonstrated the importance of adapting to extreme weather and geological conditions with advanced reinforcement techniques. The Channel Tunnel showcased fire suppression systems and emergency planning in high-risk environments. In contrast, the Uttarkashi Tunnel Accident underscored the consequences of poor risk management and inadequate geological assessments, emphasizing the need for strict safety protocols. Choosing the right tunneling method—such as TBM, NATM, Cut-and-Cover, or SEM—is crucial based on geological conditions. Additionally, innovations like Steel-Concrete-Steel (SCS) sandwich linings and Igloo Tunnels enhance structural resilience and evacuation options. Smart monitoring systems with sensors for ground movement, fire detection, and gas leaks further improve safety.

In conclusion, tunneling projects must balance engineering expertise, safety compliance, and sustainability. Learning from past experiences, implementing advanced technologies, and maintaining strict quality control will ensure safer and more efficient tunnel construction worldwide.

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CHAPTER 4

Acquisition's Synergy Evaluation - Indian Cement Industry

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ABSTRACT

This paper aims to conduct a comprehensive analysis of the financial performance characteristics of the firms involved in acquisitions, especially those within the construction sector, focusing on the acquisition of ACC and Ambuja Cement by Adani Enterprises. This case example represents a unique scenario wherein the acquired and the acquiring firm, both are available for pre- and post-acquisition analysis. The paper also gives an insight of how it has affected the cement industry within the construction sector. It seeks to evaluate the synergy between these entities pre- and post-acquisition and understand the underlying motives driving the acquisition activities. The research leverages widely accepted financial variables and models, alongside market evidence, to evaluate the pre- and post-acquisition financial synergy as well as assess the value-adding potential of the transaction that is crucial for a company's development. Our study shows a mixed market emotions of the said acquisition. Despite the negative Cumulative Abnormal Returns for Adani Enterprise and ACC, Ambuja Cement managed to show a long-term positive return. In early stages, immediately after the acquisition announcement, the financial performance failed, however in 2023, both the acquired companies made a considerable comeback showing higher Return on Equity, better asset efficiency, and liquidity ratios. Between the two, Ambuja Cement shows more resilience through the changes. Despite difficulties in formulating a joint functioning unit initially, the acquisition has had a positive effect on the financial position of the two companies, along with the emergence of tangible signs of sustainable synergies. This acquisition established Adani Group as India's second largest cement manufacturer, enhancing its position through operational synergies and cost optimization.

Keywords: Acquisition synergies; Infrastructure sector; Financial performance; Adani Enterprise; Market dominance.

1.0 Introduction

Mergers and Acquisitions (M&A) are strategies used by organisations to enter new potential markets or to enter a new business sector (Malik, 2014).

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These two terms M&A are often used interchangeably but are different terminologies. In a merger, two or more organizations combine to form a single legal entity while when one organization takes over another organization and keeps itself as the owner, it is known as acquisition (Moskovicz, 2018). Business landscapes are, most often than not, characterized by ever evolving landscapes that are marked by strategic decisions that not only redefine industry trajectories but also amplify market influence. Mergers and acquisitions are one such strategic decision that significantly affects and shapes the nature of any corporate function (Mehta, 2007). The accelerated mergers and acquisition trend in India have resulted in the companies opting for this route to secure higher rates of growth. The greater deal momentum is a result of Foreign Direct Investment available with the corporate sector and other favourable conditions (Sahoo, 2006). The introduction of conducive incentive schemes makes India an attractive destination for Foreign Direct Investments, causing the foreign player to transform their business and investment structure, giving rise to potential surge in cross border merger and acquisition opportunities. The study was hindered by the time limit which moved it towards a case-based approach. Also, the nearness of the event period to COVID-19 pandemic impacted the t-test results to be insignificant under the event study methodology despite significant synergies being seen today. The study also focuses only on short term financial impacts due to the acquisition event, failing to fully address the possible long term synergy effects that surface after several years. This study restricts the use of quantitative data analysis only, and it does not consider the qualitative variables like cultural changes, management choices, and strategic realignments.

1.1 Justification for M&A in construction field

Mergers and acquisitions (M&A) in the construction industry are critical strategies that offer a variety of benefits that contribute to the long-term success of the companies involved. By leveraging mergers and acquisitions, construction companies can capture economies of scale and scope and consolidate resources and expertise to efficiently tackle larger, more diverse projects. Access to new markets becomes possible, allowing companies to expand their reach, take advantage of new opportunities and reduce dependence on specific regions or sectors (Carrillo, 2010). This expansion not only drives growth but also improves competitiveness as mergers and acquisitions allow companies to strengthen their market position, negotiate favourable terms with stakeholders and strategically align with industry trends and customer preferences. Additionally, mergers and acquisitions enable efficiencies to be gained by optimizing processes, resource allocation and overall costs, thereby promoting innovation and long-term profitability within the combined company. Fundamentally, mergers and acquisitions serve as a risk mitigation tool, allowing companies to diversify revenue sources, project portfolios and geographic footprint, thereby improving resilience and financial stability in the face of economic fluctuations and market uncertainties (Rottke, Schiereck, & Pauser, 2011). Overall, mergers and acquisitions in the construction sector represent a strategic imperative for

companies seeking sustainable growth, market leadership and resilience in an ever-evolving industry landscape.

1.2 Aim & Objectives

To analyse and compare the valuation of acquisitions in the case of Adani's acquisition of Abuja & ACC cement, focusing on key challenges and emerging opportunities within the industry.

Objectives of the study are as follows:

- To identify the quantitative factors influencing acquisitions in the construction sector.
- To conduct a case-based analysis to examine specific acquisitions.
- To evaluate the accuracy and relevance of various valuation models used in M&A transactions.
- To compare the comprehensive performance of both the acquired and acquiring companies, assessing pre- and post-merger periods.

2.0 Review of Literature

There are several factors that influence the merger and acquisition decision of any company. An investigation into the financial and performance characteristics of merging companies is important. It is observed that firms with higher technological and financial productivity are more likely to go for acquisitions, while firms that have potential to grow in the future but are struggling at present owing to low profits or losses are more likely to be acquired and the management of firms that are not actively involved in research activities are also likely to be replaced (S., 2023).

Another important factor is the relationship between the size of acquisition deals and their outcomes for acquiring companies. A study by Journal of Corporate Finance contributes by documenting a robust negative relationship between the size of acquisition targets and premiums paid (Alexandridis *et al.*, 2013). The study presents various measures of acquisition premiums, showing that acquirers tend to pay lower premiums for large targets compared to small ones due to value destruction. The reasons for value destruction being that managers of acquiring firms may overestimate their ability to extract benefits from large acquisitions, leading to overpayment, top executives may pay higher premiums for large firms due to the perception of high private benefits and concerns such as strategic potential or deal complexity (Alexandridis *et al.*, 2013). The analysis includes statistics on deal and firm characteristics, such as target and acquirer market capitalization, transaction value, acquirer market-to-book ratio, competition levels, and payment methods. Large targets tend to have higher transactions and market values, are less likely to be financially distressed, and are acquired with stock more often. Regression analysis confirms the negative association between target size and acquirer returns, even after controlling various factors like offer premiums and market conditions.

In another research, the study found that the acquirers failed to gain financial synergy even after three years of the deal with the results suggesting that the manufacturing industry in India performed better in the post-acquisition scenario as compared to the service industry and the study found that the stock returns are well-explained by the long-term financial variables, and the acquisitions resulted in a decline in performance (Mehrotra & Sahay, 2023).

The study on corporate mergers and acquisitions in India identified discriminating variables that help delineate bidder and target firms which indicated that targets have higher liquidity, growth, and size, and lower risk, leverage, profitability, and operating efficiency (Aggarwal & Garg, 2010). These results support the theory that takeovers are a market share enhancing mechanism and may be driven by synergy gains through economies of scale or scope, reducing the cost of capital, or increasing debt capacity (Basu *et al.*, 2008).

Case Review of Adani's Ambuja-ACC Acquisition: The Adani Group acquired major stakes in Ambuja Cements and ACC for \$6.50 billion, marking one of India's largest cement sector transactions. This acquisition followed Holcim's strategic exit, which was driven by sustainability goals and environmental compliance pressures. Through this deal, Adani secured 63.15% ownership in Ambuja Cements and 56.69% in ACC (with 50.05% held through Ambuja), positioning itself as India's second-largest cement manufacturer with a 67.5 MTPA capacity and a combined market capitalization of \$19 billion. The acquisition served multiple strategic objectives for Adani, including backward integration to ensure reliable cement supply for its infrastructure projects, vertical integration to control costs and improve operational efficiency, and portfolio diversification across energy, logistics, and real estate sectors. This move strengthened Adani's market position while allowing Holcim to divest from carbon-intensive operations in emerging markets, aligning with global ESG trends and environmental regulations that increasingly scrutinize carbon emissions in industrial processes.

3.0 Research Methodology

The study integrates quantitative measures such as market measures, accounting measures, mixed metrics and stock price impacts to evaluate the company's performance pre- and post-acquisition. Both short-term and long-term impacts of M&A events are analysed and provide insights into the immediate market perceptions and sustained performance over the period. This research study is significant in understanding the gap between the valuation process and the performance outcomes of M&A in the construction sector. The study aims to integrate financial, operational and strategic perspectives to provide substantial actionable insights for stakeholders, policymakers and academicians alike.

4.0 Analysis, Observations and Implications

After Adani's takeover, ACC and Ambuja Cements went through a financial transformation characterized by revenue highs in 2022 followed by declines in 2023, with net

profit margins initially falling in the year of acquisition before rebounding in 2023, indicating cost of adjustment followed by operational gains.

Table 1: Financial Performance of ACC Limited

	2017	2018	2019	2020	2021	2022	2023
Book to Market Value	498	560	613	674	757	747	852
Operating Income over Sales	10.54%	10.69%	13.52%	13.93%	16.14%	6.39%	13.39%
Return on Assets	6.40%	9.40%	7.95%	7.80%	8.70%	4.26%	9.27%
Return on Equity	9.77%	14.31%	11.80%	11.18%	12.79%	6.30%	14.59%
Acid Ratio (Quick Ratio)	0.87	1.04	1.34	1.55	1.5	1.16	1.27
Asset Turnover	89.22%	92.36%	91.65%	0.78%	0.83%	1.07%	0.92%
Debt-to-Equity Ratio	0.01	0	0	0	0	0	0
Interest Coverage Ratio	ND	ND	ND	ND	ND	ND	ND
Net Revenues	13,416	14,940	15,968	13,989	16,356	22,547	20,444
Earnings per Share	48	80	72	75	96	46	113
Sales Growth	19.03%	11.36%	6.88%	-12.40%	16.93%	37.85%	-9.33%
Profit Margin Ratio	6.89%	10.18%	13.52%	13.93%	16.14%	6.39%	13.39%
EV	30,411	25,483	22,764	24,642	34,362	31,046	45,152
EV/EBDITA	14.9	11.58	8.31	9.6	10.7	13.76	12.72

Source: Compiled by authors, Data: BSE Website

Table 2: Financial Performance of Ambuja Cement Ltd

	2017	2018	2019	2020	2021	2022	2023
Book to Market Value	100.59	105.82	111.83	102.31	111.84	143.56	168.39
Operating Income over Sales	16.50%	15.13%	17.41%	21.96%	21.06%	16.71%	18.33%
Return on Assets	5.07%	5.90%	5.66%	7.02%	7.38%	7.11%	5.29%
Return on Equity	6.25%	6.88%	8.79%	9.35%	7.31%	8.94%	6.31%
Acid Ratio (Quick Ratio)	1.08	1.33	0.81	0.99	1.71	1.50	2.08
Asset Turnover	0.44%	45.09%	43.22%	0.43%	0.52%	0.62%	0.45%
Debt-to-Equity Ratio	0.00%	0.16%	0.21%	0.19%	0.12%	0.16%	0.10%
Interest Coverage Ratio	18.13	22.78	25.88	30.07	32.35	26.10	20.25
Net Revenues	10,457	12,047	11,622	14,546	16,510	20,711	18,762
Earnings per Share	6	7	9	10	10	12	11
Sales Growth	13.71%	15.21%	-3.53%	25.16%	13.50%	25.45%	-9.41%
Profit Margin Ratio	11.94%	13.10%	15.74%	14.89%	13.04%	12.77%	13.02%
EV	50,378	34,314	46,532	70,848	97,275	70,080	125,768
EV/EBDITA	21.91	18.21	13.32	15.42	20.28	16.79	29.78

Source: Compiled by authors, Data: BSE Website

Liquidity metrics demonstrated conflicting trends with Ambuja's fast ratio becoming stronger considerably after acquisition while ACC retained stability as both firms held low debt and managed leverage levels during the transition. Performance ratios illustrated this transition period, where both firms witnessed ROA and ROE declining in 2022 before staging a partial recovery in 2023, evidencing incremental efficiency gains and recovered shareholder value. The market welcomed the acquisition positively, especially for Ambuja, whose market capitalization increased significantly in 2022, while ACC's recovered EPS in 2023 showed signs of regaining profitability, both implying that although there was short-term financial uncertainty, the acquisition showed promising signs of stabilization and operational recovery by 2023.

Stock Price Reaction (ACC Limited): ACC Limited's share price showed remarkable volatility throughout the Adani Group takeover process. When the takeover news broke out on May 15, 2022, the stock rallied from ₹2,099.95 (May 13) to an intra-day high of ₹2,398.10 (May 16) 14.2% higher, demonstrating initial investor optimism—before tapering off gradually to about ₹2,100 by mid-June as market players re-balanced expectations. So, too, with ACC's stock price advancing 8.9% to ₹2,786.85 from ₹2,558.65 (August 16) as of September 16, 2022, acquisition completion, only to lose 4.96% right away to ₹2,611.50 and then go down further to about ₹2,390 in mid-October, indicating short-term investors' profit-taking after the pre-acquisition run-up and perhaps integration results uncertainty.

Figure 1: ACC's Stock Price Reaction-time of Announcement



Source: Brokerage application

Figure 2: ACC's Stock Price Reaction at Time of Acquisition



Source: Brokerage application

Figure 3: Ambuja's Stock Price Reaction at Time of Announcement



Source: Brokerage application

Figure 4: Ambuja's Stock Price Reaction at Time of Acquisition

Source: Brokerage application

Stock Price Reaction (Ambuja Cements Ltd): Ambuja Cements' share showed high volatility around the Adani Group takeover. After the May 15, 2022, announcement, shares rose from ₹358 (May 13) to ₹377.75 (May 16)—a 5.53% rise—with volumes spiking to 50.46 million shares, before correcting to ₹349.55 by June 16, indicating investor rethinking after initial euphoria. The trend gained momentum in the course of acquisition completion, with the stock surging spectacularly from ₹380 in early August to ₹586.35 by mid-September—a whopping 54.82% increase in six weeks—before ending at ₹516.70 on the day of completion (September 16), showing a 4.09% intraday fall amidst increased trading volume of 42.87 million shares. The stock then went into a consolidation phase at ₹511.25 in October 2022, with strong gains from pre-announcement levels still in place despite the correction, as the overall price trend and high trading volumes on major dates suggest favourable market perception balanced with normal post-event profit-taking and overall implication evaluation.

5.0 Conclusion

The assessment of ACC and Ambuja Cements' financial Performance pre & post-acquisition by the Adani Group reveals important patterns in achieving synergies. Before the acquisition, both firms showed consistent growth in critical financial areas such as book to market value, return on assets, and return on equity, which indicated solid investor trust and efficient operations. However, shortly after the acquisition, there was a noticeable drop in profitability measures like operating income relative to sales and profit margin, pointing to difficulties in integration and necessary cost adjustments. Nevertheless, by 2023, signs of

financial recovery became clear, with both companies improving their ROE, asset use efficiency, and management of liquidity. Notably, Ambuja showed more strength in keeping its financial stability after the acquisition, which is evident in its higher quick ratio and enterprise value. Moreover, the fluctuations in stock prices also reflect the optimistic market views on the acquisition, with notable price increases during the announcement and completion stages. While immediate revenue synergies were achieved, ensuring long-term profitability will depend on ongoing improvements in operations and cost effectiveness. This concludes, the acquisition has enhanced the financial health of both companies, with clear long-term synergies despite initial integration hurdles.

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CHAPTER 5

Advanced Technologies and Sustainability Practices for High-rise Building Construction

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ABSTRACT

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

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

1.0 Introduction

As urban populations grow, cities must optimize land use while managing environmental and social costs. High-rise buildings offer a solution but contribute to high energy consumption, carbon emissions, and inefficient resource use. According to the United Nations Environment Programme (UNEP, 2023). The construction sector accounts for 37% of global emissions and has the potential to reduce 5-7 billion tons of CO₂ by 2030 (Xiong *et al.*, 2024). Sustainable construction practices address these challenges through advanced technologies like Building Information Modeling (BIM), precast construction, and automation, alongside green materials and energy-efficient systems. The construction industry is shifting toward low-carbon buildings, integrating new methodologies and evolving technologies to enhance sustainability (Akadiri *et al.*, 2012).

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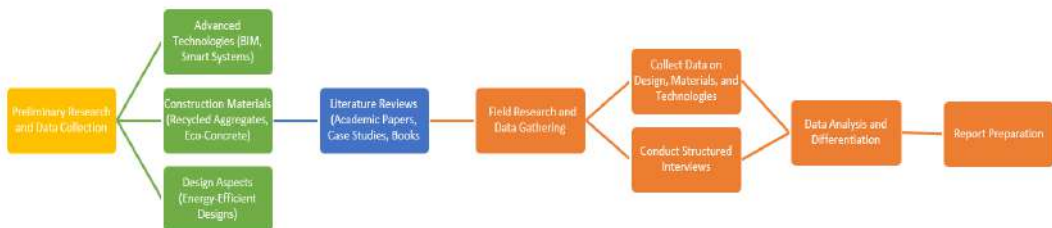
Global standards such as LEED (Leadership in Energy and Environmental Design), BREEAM, and CASBEE evaluate sustainability performance. LEED, developed by the U.S. Green Building Council (USGBC), provides a framework for eco-friendly construction, reducing environmental impact, lowering costs, and improving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

2.0 Literature Review

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

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

A circular economy approach to prefabricated buildings can cut carbon emissions by 30-50%. However, challenges such as high transportation emissions and inconsistent carbon accounting methods persist (Li *et al.*, 2024). Green buildings help reduce emissions and promote energy efficiency, but adoption barriers include high costs, lack of financial incentives, and regulatory gaps. Government support, financial incentives, and policy standardization are essential for large-scale adoption (Liu *et al.*, 2022). Sustainable materials such as Recycled Aggregate Concrete (RAC) and Eco-Concrete can significantly reduce the carbon footprint of buildings. Cross-Laminated Timber (CLT) has a negative CO₂ footprint, though challenges like fire resistance and market acceptance remain. Addressing these barriers through policy incentives, industry collaboration, and material standardization is crucial (Arnesson, 2019).



3.0 Methodology

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

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

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

Figure 1: NICMAR Precast Building



4.0 Advanced Technology

4.1 precast construction

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

Table 1: General Info. of Ore-cast Building

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

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

Product-process predictability

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

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

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

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

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

Reduction of material waste:

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

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

Speed of construction:

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

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

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

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

4.1.1 Limitation of Pre-cast technology:

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

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

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

Table 2: Traditional vs Pre-cast Building

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

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

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

4.1.2 Difference between traditional and pre-cast building

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

Table 3: Traditional Solar vs BIPV

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

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

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

Figure 2: AL – Rehan Building Mumbai



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

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

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

Figure 3: Smart Building Techniques



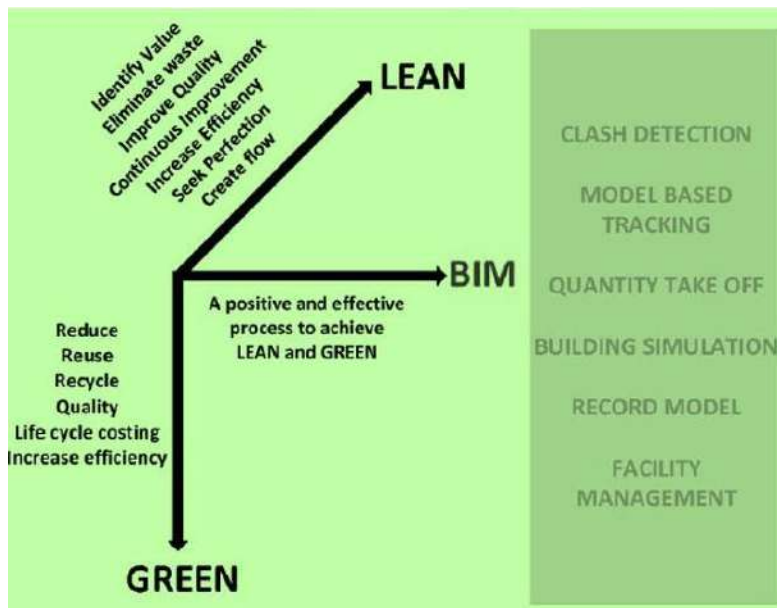
Source: Alhassan et al., 2024

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

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

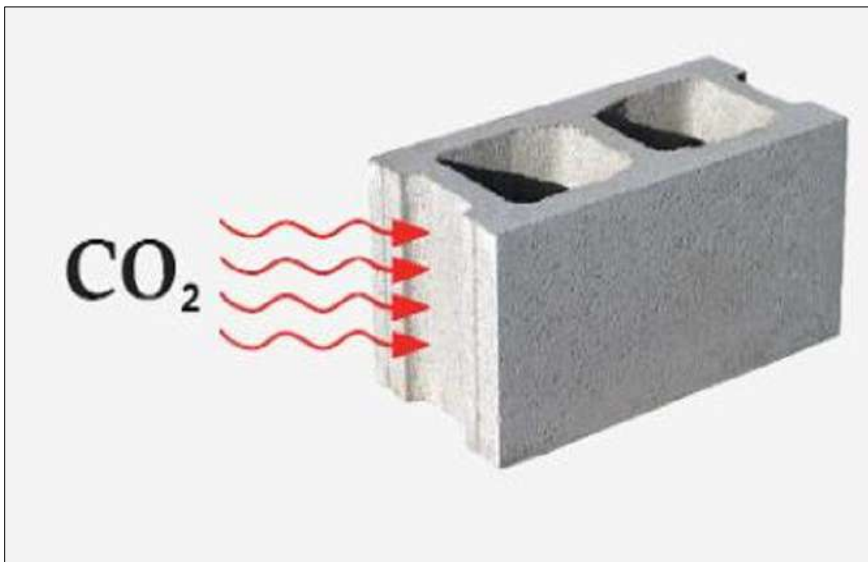
BIM Technology: BIM software allows architects and engineers to simulate various design scenarios to determine the most energy-efficient options. This includes analysing the building's orientation, natural lighting, and ventilation strategies. Energy analysis tools in BIM software help in assessing the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

Figure 4: Integration of LEAN, BIM & GREEN



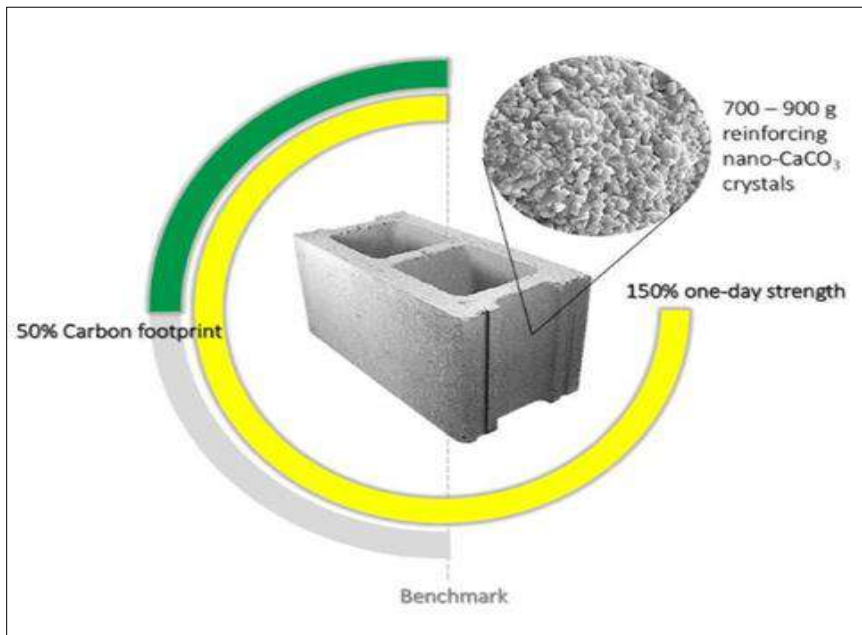
Source: www.google.com, n.d.

Figure 5: Carboclave Block



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

Figure 6: Carboclave block



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

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

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

Improved performance relative to conventional block, including:

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

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

5.1 Recycle aggregate concrete

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

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

Table 4: Carboclave Block Contribution to LEED Credit

LEED® Credit	Credit Points	Carboclave Block Contribution
EAp2: Minimum Energy Performance (option 1) & EAc1: Optimize Energy (option 1)	BD + C ² : up to 19 ID + C ³ : n/a	Thermal mass from exposed exterior and interior masonry walls absorbs and releases heat slowly, which moderates temperatures to reduce heating and cooling loads, energy consumption, and equipment size
MRc2: Construction Waste Management	BD + C: up to 2 ID + C: up to 2	- Modularity of masonry minimizes waste - Demolition & construction concrete masonry unit waste can be crushed & recycled
MRc4: Recycled Content	BD + C: up to 2 ID + C: up to 2	- Carboclave normal-weight blocks contain ±4% pre-consumer recycled content (slag cement, CO₂) - Carboclave light-weight blocks contain ±69% pre-consumer recycled content (expanded slag aggregate, slag cement, CO₂)
MRc5: Regional Materials	BD + C: up to 2 ID + C: up to 2	Carboclave blocks are produced in Cambridge, Ontario, and are typically shipped by truck within 800 km radius
RPc1: Durable Building	BD + C: 1 ID + C: n/a	Concrete masonry units are a proven material for the durability credit based on demonstrated effectiveness.
Innovation in Design - Building Product Innovation	BD + C: 1 ID + C: 1	- Concrete Carboclave block may be considered for an Innovation and Design point - Boehmers will provide the documentation required for credit submission
Innovation in Design - MRpc63: Building life-cycle impact reporting	BD + C: 1 ID + C: n/a	- Pilot credit is based on LEED v4 MR credit <i>Building life-cycle impact reduction (option 4)</i> - Data from the CCMPA EPD may be used in whole-building LCA assessments
Alternative Compliance Path (ACP) - MRpc84: v4 MR credit category for v2009 projects <i>This pilot credit permits pursuing the entire LEED v4 Materials and Resources category in place of the MR credits from LEED v2009. Carboclave block qualifies for the following MR credits:</i>	BD + C: 3 ID + C: n/a	<u>Building life-cycle impact reduction (option 4)</u> - Data from the CCMPA EPD may be used in whole-building LCA assessments - CCMPA EPD data included in the <i>Impact Estimator for Buildings</i> LCA software <u>Building product disclosure and optimization - environmental product declarations (option 1)</u> - Boehmers was a participant in the Canadian Concrete Masonry Producer Association (CCMPA) industry-wide environmental product declaration EPD⁴. - EPD valued as one half (1/2) of a product for credit calculation <u>Construction and demolition waste management</u> - Modularity of masonry minimizes waste - Demolition & construction masonry waste can be crushed & recycled

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

5.2 Eco concrete

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

5.3 Difference between LEED and IGBC

Table 5: Key Difference between IGBC and LEED

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

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

6.0 Government Incentives for Green Building

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

6.1 Who pays who gain

Table 6: Beneficiaries of Sustainable Practices

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

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

7.0 Conclusion

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

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CHAPTER 6

Agile Methodology in Construction Management

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ABSTRACT

This research examines the application of agile concepts in construction management that typically entail rigorous planning procedures. The study is motivated by the complexity of contemporary construction projects, where unplanned alterations, increasing material prices, fluctuating regulations, and varying stakeholder expectations frequently lead to delays, increased costs, and reduced client satisfaction. To mitigate this, this research examines how agile concepts, originally developed for software development, can be applied to enhance the performance of projects in construction contexts. Agile practices are all about planning in stages, teamwork, and ongoing improvement as well as flexible management of risk. These aspects make good alternatives to traditional practices in the sense that they help groups to react to changes all at once and avoid problems from arising before they become full-scale problems. The web questionnaire was administered for two months and used a five-point Likert scale to quantify opinions regarding the advantages and disadvantages of using agile. The findings of the survey indicated that the majority of the respondents believed that agile practices are good. Some of the primary advantages highlighted include improved communication and coordination among project teams, improved response to unexpected problems, and the capability to deliver project pieces step by step, enabling early demonstration of value. This study is both theoretically and practically significant. Theoretically, the research contributes to the literature on agile project management by way of application in the construction sector, which has not been widely researched previously. Practically, the study provides sound recommendations to practitioners who are interested in enhancing the quality of projects. The recommendations include investment in good agile training programs, altering firm procedures to foster collaboration, and applying online platforms that provide open improvement and stakeholder participation. In brief, agile practices have numerous advantages for construction management, such as improved communication, increased flexibility, and proactive risk management. Nevertheless, there are real challenges to applying these practices. To overcome these challenges, organizations must transform their cultures, enhance training programs, and revise rules and regulations. This research demonstrates the potential of a hybrid project management method that integrates agile principles and conventional construction practices, resulting in improved, accelerated, and more efficient project outcomes.

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Future research should investigate long-term studies and pilot tests to enhance this hybrid model and determine the best ways of implementing agile practices in complex construction projects.

Keywords: Agile methodologies; Construction management; Iterative planning; Cross-functional collaboration; Risk mitigation; Hybrid project management.

1.0 Introduction

The construction industry is marked by inherent uncertainty, stakeholder complexity, and varying operating conditions. Traditional project management models—usually based on linear, waterfall constructs—cannot react to unforeseen changes, leading to delays, cost overruns, and reduced client satisfaction. In contrast, agile approaches, originally conceived for software construction, promote iterative planning, continuous feedback, and more collaboration. This research explores the use of agile principles applied to construction management practice to improve project performance.

Driven by demands for more flexibility and responsiveness, this research synthesizes the existing literature, proposes a mixed-method approach to research methodology, and provides empirical results that assess the advantages and challenges of adopting agility. The structure of the paper is as follows: Section 2 provides a literature review; Section 3 formulates the research methodology; Section 4 explains the data analysis; Section 5 interprets the results and makes recommendations; and Section 6 concludes with theoretical and practical implications.

1.1 Research objectives

Analysing the Concept and its need in the Construction industry, following are the objectives that can be inferred from the study:

- To understand Agile Project management in construction.
- To compare traditional project management with agile project management.
- To understand the impact of agile methodology in construction from real data.

1.2 Gap analysis

The study landscape in the topic of Agile methodology shows a significant imbalance, with greater emphasis on its application in software development contexts than on its use in construction management. Agile principles have gained widespread recognition and implementation in software projects, their adaptation and application in construction management remain relatively underexplored. This gap suggests a significant opportunity for further research and compatibility into how Agile principles can be effectively translated and integrated into the unique dynamics and requirements of construction projects.

2.0 Literature Review

Agile practices have transformed software development project management through a concentration on iterative stages, team self-direction, and client involvement (Highsmith). Early research (John, 2018); (Kashikar, 2016) pointed out the viability of agile sprint planning application in a bid to reduce delays and improve cost control in construction. Current research has highlighted the importance of agile practices in achieving maximal communication, risk management, and overall project performance ((OWAIS, 2022); (Reid, 2019)).

Adaptation to Construction Management: The construction sector has traditionally employed linear methods such as the Waterfall method, Critical Path Planning (CPM), and Earned Value Method (EVM). Conventional models inevitably lead to rigidity owing to their lack of flexibility when there are scope changes in the project, fluctuating materials availability, or changing regulatory requirements. Studies by (OWAIS, 2022) and (Reid, 2019) have indicated the ways in which agile practice can overcome these by promoting iterative planning and ongoing interaction with stakeholders. The iterative model not only facilitates communication within project teams but also makes it easy to identify and solve problems quickly.

Empirical Evidence and Case Studies: Several empirical studies have supported the benefits of agile practices in non-conventional industries. (Oja, 2017) reported a case study of adopting agile project management in engineering, procurement, and construction projects and recorded considerable improvement in project flexibility and efficiency. Similarly, Padalkar *et al.* (2011) and subsequent studies highlighted that agile methods lead to shorter project cycle times and cost reduction. Such findings are also supported by comparative studies (Kaur, 2015); (Paul, Study on Agile Management in construction project using Scrumban methodology., 2018)) establishing how agile methods are superior to traditional management methods in changing project environments.

Adoption Barriers and Organizational Issues: Despite its great potential, construction uptake of agile practices is not without challenges. Cultural resistance, absence of formal training in agile, and hierarchical organizational designs are listed as significant hindrances by most studies (Hassan, 2019; OWAIS, 2022). Coupled with that, regulatory compliance and rigid contractual frameworks naturally work against agile's adaptive, iterative processes. Researchers argue that agile practices must be preceded by cultural change—embracing cross-functional collaboration and investing in training their personnel in agile for them to be successful in construction.

Emerging Trends and Future Directions: New technologies emerging from digital technology, such as Building Information Modeling (BIM) and collaborative project management software, offer new opportunities for agile deployment. Digital technology allows for real-time data exchange and shared decision-making, bridging some of the gaps between the conventional approaches to construction and agile principles (Ing. Radan Tomek, 2015)). In the

future, the literature suggests that a hybrid model combining agile and conventional approaches will be the most important factor to achieve the balance right—applying agile flexibility without losing the structure required in large-scale construction projects. Comparative studies show that agile practices not only speed up the delivery of projects but also promote a preemptive culture towards problem-solving. Nevertheless, impediments like cultural resistance, inadequate agile training, and regulatory hurdles have been realized (Oja, 2017); (Hassan, 2019). Theoretical studies indicate that a hybrid approach—combining agile principles with conventional practices—may solve these impediments while taking advantage of iterative development and adaptive project management. Finally, the literature indicates that while agile methods hold tremendous promises for improving construction management, successful implementation is contingent upon overcoming entrenched organizational, cultural, and regulatory barriers. The evolving research environment highlights the need for additional empirical research with a focus on developing standardized frameworks and training modules that can integrate agile principles into the construction sector seamlessly.

3.0 Research Methodology

This study adopts a mixed-method research design that combines quantitative surveys with qualitative interviews to gain a comprehensive understanding of agile implementation in construction.

3.1 Research design

A self-administered online questionnaire was distributed among construction professionals to capture their perceptions regarding agile benefits and obstacles. The questionnaire utilized a five-point Likert scale to assess various parameters. Qualitative interviews were also conducted to further explore the contextual challenges and advantages of agile practices.

3.2 Participants and sampling

- *Target Population:* Construction professionals, including project managers, engineers, and field supervisors.
- *Sampling Technique:* Convenience sampling was employed through digital channels (LinkedIn, Email, WhatsApp).
- *Sample Size:* Over 50 responses were collected, ensuring adequate representation for statistical analysis.

3.3 Data collection procedures

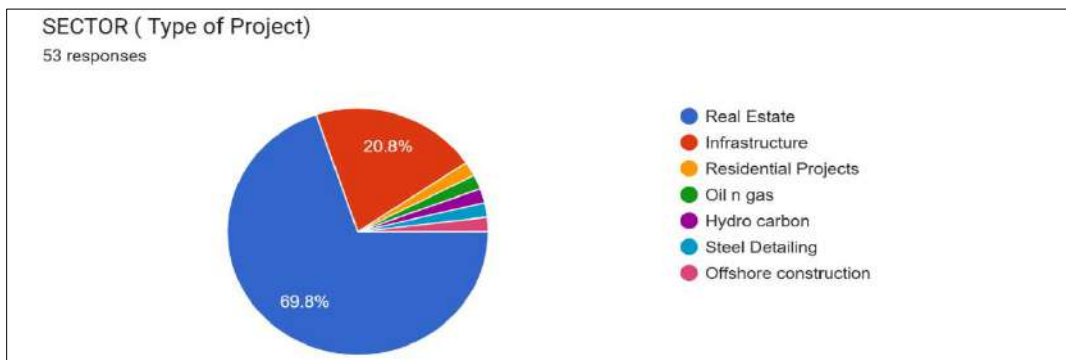
Data was collected over a two-month period using Google Forms. Responses were securely stored and later analyzed using spreadsheet software to generate descriptive statistics and thematic insights.

3.4 Data analysis

Quantitative data were analyzed to determine the percentage of respondents indicating positive benefits and significant obstacles. Qualitative data from interviews were thematically coded to complement the survey findings.

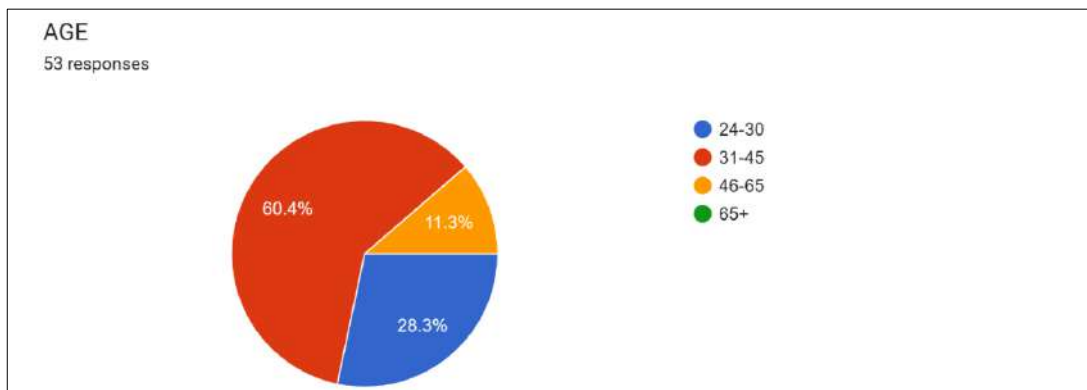
4.0 Data Analysis

Figure 1: The Sector in Which Participants are Working



Data were gathered using a mixed approach of survey and interview type questions from various construction experts. This allowed a broad-based perspective of current practices and attitudes towards agile management on construction projects to be gathered. Pie-Charts 1 & 2 show the details regarding the sector in which participants are working at and the age demography of participants.

Figure 2 : The Age Demography of Participants



The survey data were analyzed to determine the consensus on the benefits and obstacles of agile practices in construction. Two tables were developed to summarize key parameters, using both the percentage of positive agreement (indicating perceived benefits) and the percentage of respondents who identified a given obstacle.

Table 1: Benefits of using Agile Methodologies

Benefit Parameter	% Agreement (Positive Benefit)	% Disagreement (Negative/Not Perceived Benefit)
Improved Communication & Collaboration	85 %	15 %
Enhanced Flexibility & Adaptability	80 %	20 %
Incremental Delivery & Early Value	75 %	25 %
Continuous Improvement Culture	70 %	30 %
Proactive Issue Resolution	65 %	35 %
Cost Efficiency & Savings	60 %	40 %
Timely Project Completion	68 %	32 %
Increased Client Satisfaction	72 %	28 %
Effective Risk Mitigation	66 %	34 %

Agile practices improve communication, flexibility, and project efficiency. The benefits allow for enhanced collaboration among the stakeholders and result in faster project completion.

Table 2: Obstacles in Implementing Agile Methodologies

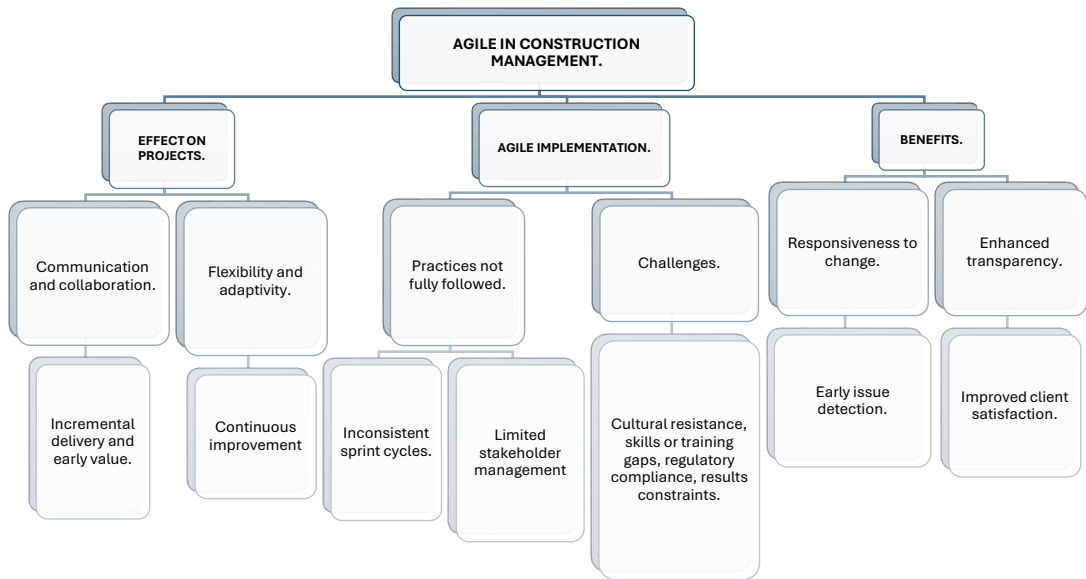
Obstacles Parameter	% Indicating Obstacle (Positive)	% Not Indicating Obstacle (Negative)
Lack of Formal Agile Practices	90 %	10 %
Inadequate Training & Skill Gaps	85 %	15 %
Inconsistent Meeting Frequency	80 %	20 %
Resistance from Traditional Hierarchical Systems	88 %	12 %
Limited Integration with Regulatory Frameworks	75 %	25 %
Poor Digital Tool Utilization	70 %	30 %
Cultural Resistance to Change	78 %	22 %
Resource & Time Constraints	82 %	18 %
Communication Barriers with Stakeholders	80 %	20 %

These tables summarize both the positive impacts and challenges associated with agile adoption in construction, reflecting the survey's quantitative outcomes as well as qualitative insights from interviews.

Mapping the Agile Transformation; A tree Diagram Overview: Below is the tree diagram showing our data analysis hierarchical structure. Its key theme is the main research

question—assessing the impact of agile project management on construction practices. Descendants from this centre, the diagram branches into different main themes according to our findings. For example, one of the key branches shows “Communication and Collaboration,” while other branches show “Flexibility and Adaptability,” “Incremental Delivery and Early Value,” and “Continuous Improvement.”

Figure 3: Interpretation



Structured visualization breaks down top-level branches into specific sub-themes or nodes. For instance, under “Communication and Collaboration,” sub-nodes include stakeholder engagement, meeting frequency, and decision transparency. Similarly, “Flexibility and Adaptability” refers to how agile practices enable teams to react to change and manage risks. This structure explains the interrelation between the different elements, guiding readers from broad themes to specific information. It highlights notable contributions to understanding agile methodologies in the construction industry and suggests potential directions for further research or improvement.

5.0 Result, Discussion and Recommendations

The findings underscore that agile methodologies can effectively enhance project outcomes through iterative feedback and adaptive planning. For instance, improved communication was linked to the regular stand-up meetings and collaborative decision-making processes. Similarly, benefits such as cost savings and risk mitigation emerged as critical factors, particularly in projects with dynamic scopes. However, the obstacles table reveals that challenges—such as resistance to change and regulatory constraints—remain formidable. These

issues suggest that while the potential benefits are substantial, overcoming the cultural and procedural inertia in traditional construction environments is essential for the successful adoption of agile practices.

5.1 Recommendations

Based on the survey and interview insights, the following recommendations are proposed:

1. Adopt Iterative Planning: Implement shorter planning cycles (sprints) to facilitate frequent reassessment.
2. Enhance Training Programs: Develop comprehensive agile training for construction teams to bridge skill gaps.
3. Restructure Teams: Form cross-functional, self-organizing teams to break down hierarchical barriers.
4. Invest in Digital Tools: Integrate digital collaboration platforms (e.g., BIM with agile project management software) for real-time updates.
5. Revise Contractual Frameworks: Work with regulators to create flexible contracts that allow iterative changes.
6. Promote a Culture of Continuous Improvement: Institutionalize regular retrospectives and process reviews to foster ongoing enhancements.

6.0 Conclusion

This paper provides empirical evidence supporting the integration of agile methodologies in construction management. The research highlights significant benefits—including enhanced communication, flexibility, and cost efficiency—while also pinpointing critical obstacles such as training deficiencies and cultural resistance. A hybrid model that combines agile practices with conventional project management may offer a viable solution to bridge these gaps. The findings have important implications for both theory and practice. Theoretically, this study extends the agile discourse into the construction domain, suggesting new avenues for research. Practically, the recommendations outlined provide actionable steps for industry practitioners aiming to enhance project performance and stakeholder satisfaction. Future studies should explore longitudinal effects and develop standardized frameworks to facilitate agile adoption in complex construction environments.

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CHAPTER 7

AI-Powered Construction Dispute Resolution: Overcoming Challenges and Enhancing Efficiency in the Indian Context

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ABSTRACT

This paper explores the integration of Artificial Intelligence (AI) in resolving construction disputes within India's industry, addressing issues of inefficiency, cost overruns, and inconsistent outcomes. By utilizing natural language processing and machine learning algorithms, the proposed AI-powered system streamlines the dispute resolution process, automating dispute analysis and offering data-driven recommendations to minimize time and costs. Drawing on case studies from the Bombay High Court on delay disputes, the system provides a user-friendly interface for stakeholders to input case details and receive guided resolutions. The system aims to overcome challenges such as resource shortages, complexity, and inconsistency in legal outcomes, improving decision-making fairness, efficiency, and cost-effectiveness. The paper also discusses challenges such as data quality, resistance to technology adoption, and ethical considerations, emphasizing the potential for sustainable growth and the broader adoption of AI in the legal industry.

Keywords: AI-powered dispute resolution; Construction dispute resolution; Machine learning algorithms; Indian construction industry; Legal automation.

1.0 Introduction

To address inefficiencies, lessen conflicts, and improve project performance, this paper investigates the application of artificial intelligence (AI) to dispute resolution in the construction industry. Although the construction sector is essential to economic growth, disagreements within the sector frequently result in project delays, cost overruns, and strained stakeholder relations. Conventional dispute resolution procedures, such as arbitration and litigation, are expensive and time-consuming, and they frequently make disputes worse. Conversely, artificial intelligence (AI)-powered solutions like machine learning, natural language processing, and applied legal analytics have the potential to revolutionize dispute resolution by offering sophisticated Online Dispute Resolution (ODR) platforms that enhance mediation, negotiation, and decision-making.

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The paper discusses the potential of AI platforms, drawing on successful international models like Rechtswijzer in the Netherlands and the British Columbia Civil Resolution Tribunal in Canada, which have streamlined legal processes using AI. It suggests that India can benefit from these examples, adapting AI solutions to its legal framework. However, challenges such as data quality, transparency, and resistance to digitalization need to be overcome to ensure successful AI adoption. The research adopts a three-phase methodology: planning, analysis, and synthesis. It aims to identify gaps in current dispute resolution practices, highlight the benefits of AI, and suggest strategies for overcoming barriers to implementation. The paper concludes with actionable recommendations for integrating AI into the construction sector to enhance dispute resolution efficiency, improve project success rates, and foster a more collaborative environment. Key to this transformation is the involvement of policymakers, industry stakeholders, and technology developers to navigate the challenges and facilitate smooth AI adoption in construction dispute resolution.

2.0 Literature Review

The literature currently in publication emphasizes how AI can improve legal decision-making by using precedent-based reasoning and data-driven analysis. Research has examined the ways in which Large Language Models (LLMs), including domain-specific models like LLaMA-2 and GPT-based architectures, enhance legal text comprehension, case summarization, and argument extraction. Furthermore, contract analysis, arbitration support, and litigation prediction have all made extensive use of AI-powered tools. But for complicated legal fields like construction law, the majority of research is still broad and lacks specific applications. Few studies concentrate on construction dispute resolution within the Indian legal system, even though AI applications in legal analytics are well-documented. Particular AI models that can comprehend the legal, technical, and financial facets of construction disputes are necessary because these cases frequently involve multi-party negotiations, arbitration procedures, and contractual delays. The lack of a structured AI framework in the literature that is adapted for Indian court decisions restricts the usefulness of AI in settling legal disputes pertaining to construction. Building on these discoveries, this study creates a unique AI framework that combines ML and NLP methods to examine court rulings pertaining to construction disputes. The study aims to close the gap between hypothetical AI applications and actual legal issues by utilizing extensive legal datasets and AI-driven text processing. By providing a methodical approach to gathering, evaluating, and interpreting legal case data, the study presents an organized methodology for AI-assisted dispute resolution.

3.0 Methodology

The research follows a two-stage normative legal research approach, aiming to explore the integration of Artificial Intelligence (AI) in construction dispute resolution within the Indian

legal framework. The study is structured to first analyze existing challenges in construction disputes and then propose AI-driven solutions to enhance the efficiency and effectiveness of the resolution process.

3.1 Research framework and design

The research is exploratory, examining the intersection of AI technology and construction dispute resolution. The study assesses the current adoption of AI in legal conflict resolution and identifies barriers that hinder its effective implementation.

To achieve this, the research follows a three-phase methodology:

- *Planning*: Establishing the scope and objectives, defining key legal and technological aspects of AI integration in dispute resolution.
- *Analysis*: Examining real-world legal cases, AI applications, and industry challenges.
- *Synthesis*: Proposing AI-based solutions, considering legal, ethical, and regulatory implications.

3.2 Data collection and preprocessing

The study relies on a combination of primary and secondary data sources:

- *Literature review*: Extensive review of academic journals, legal reports, books, and case studies on AI in dispute resolution and construction law.
- *Case study analysis*: The research focuses on 100 Bombay High Court cases related to construction delay disputes, sourced from <https://indiankanoon.org/>. The selection criteria included cases involving contract delays, arbitration proceedings, and AI references in legal resolutions.
- *Data validation*: Case details, judicial judgments, and legal precedents were verified for authenticity and relevance, ensuring accuracy and reliability.

3.3 AI model development and application

The research investigates AI applications such as Large Language Models (LLMs) like LLaMA 2 and Python-based frameworks for legal data analysis. However, the study further explores:

- *Model Training*: Understanding how AI models were trained, fine-tuned, and adapted for legal case analysis.
- *Performance Metrics*: Evaluating AI effectiveness using parameters such as accuracy in case prediction, processing time, and consistency in legal reasoning.
- *AI's Role in Decision-Making*: Assessing how AI assists in automating legal research, analyzing precedents, and improving arbitration processes.

3.4 Legal and ethical considerations

Given the sensitive nature of legal disputes and AI interventions, ethical concerns were a priority:

- *Data Privacy & Compliance:* Ensuring adherence to Indian legal standards on data confidentiality.
- *Regulatory Challenges:* Evaluating existing laws governing AI in dispute resolution and identifying gaps for potential policy reforms.
- *Stakeholder Impact:* Addressing concerns of lawyers, arbitrators, and policymakers regarding AI-assisted legal judgments.

4.0 Model Development

By examining previous court rulings and producing possible legal outcomes, the AI model was created to improve legal case prediction. The model sought to support legal reasoning and dispute resolution with a high level of accuracy and efficiency by utilizing machine learning and natural language processing (NLP) techniques. The AI model was designed and developed with the valuable assistance of Atharva Yadav (B.Tech, Computer Engineering), whose expertise in system architecture and AI implementation significantly enhanced the framework's performance.

4.1 Model training and fine-tuning

To optimize AI performance for legal case analysis, the study utilized LLaMA-2, fine-tuned using QLoRA (Quantized Low-Rank Adaptation) on a specialized legal dataset. Training was conducted through Hugging Face's TRL (Transformer Reinforcement Learning) library, employing Supervised Fine-Tuning (SFT) techniques. The model was optimized using:

- Adam optimizer to enhance parameter updates for more efficient learning.
- Warmup ratio scheduling, ensuring stable convergence during training.
- Weight decay, reducing overfitting and improving model generalization.

4.2 Performance evaluation metrics

To assess the reliability and credibility of AI-generated legal outcomes, the model's performance was evaluated using industry-standard metrics, including:

- *Precision, Recall, and F1-score:* These metrics measured the AI's ability to generate accurate, relevant, and well-structured legal arguments, comparing AI-generated case assessments with human legal expert evaluations.
- *Time Efficiency Analysis:* A comparative study was conducted between AI-driven legal analysis and traditional manual legal research, demonstrating AI's ability to significantly reduce processing time while maintaining legal accuracy.

4.3 Validation and contextual accuracy

The AI model's validation process was centred on making sure that legal outputs were reliable and contextually accurate, especially in construction delay disputes where time and cost

overruns are frequent problems. We verified the AI's logic by contrasting its produced results with actual case outcomes rather than seeking legal advice. We started by collecting real-world instances of construction delays, carefully examining the data, and then using it to train the model. After training, we put the AI to the test by presenting various scenarios and examining whether the results matched those of earlier cases. The outcomes demonstrated the model's efficiency in resolving such disputes with a high degree of accuracy, roughly 100%. Nonetheless, expert legal opinions would still be required to further refine more complicated or important cases.

5.0 Model Design

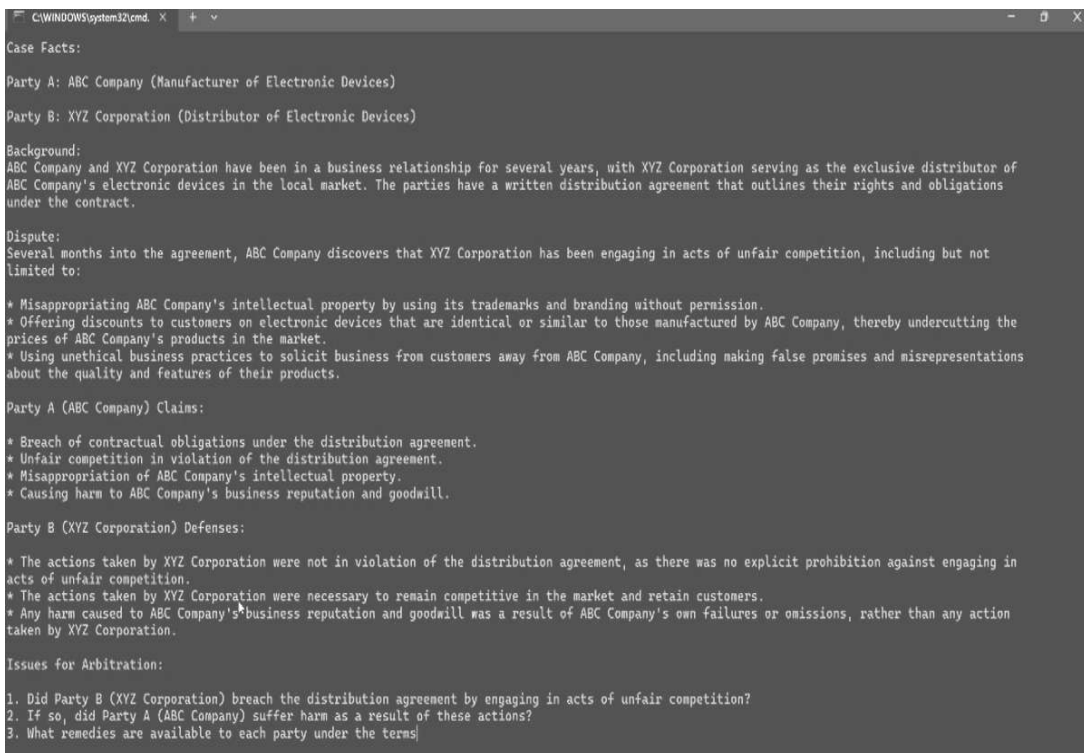
Figure 1: Framework for AI-Integrated Dispute Resolution



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Microsoft Windows [Version 10.0.26100.3476]
(c) Microsoft Corporation. All rights reserved.

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>>> give me case facts where a Party A goes against Party B for an Arbitration case. Make sure to keep them detailed
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Figure 2: AI-Powered Extraction of Legal Arguments



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Case Facts:
Party A: ABC Company (Manufacturer of Electronic Devices)
Party B: XYZ Corporation (Distributor of Electronic Devices)

Background:
ABC Company and XYZ Corporation have been in a business relationship for several years, with XYZ Corporation serving as the exclusive distributor of ABC Company's electronic devices in the local market. The parties have a written distribution agreement that outlines their rights and obligations under the contract.

Dispute:
Several months into the agreement, ABC Company discovers that XYZ Corporation has been engaging in acts of unfair competition, including but not limited to:
* Misappropriating ABC Company's intellectual property by using its trademarks and branding without permission.
* Offering discounts to customers on electronic devices that are identical or similar to those manufactured by ABC Company, thereby undercutting the prices of ABC Company's products in the market.
* Using unethical business practices to solicit business from customers away from ABC Company, including making false promises and misrepresentations about the quality and features of their products.

Party A (ABC Company) Claims:
* Breach of contractual obligations under the distribution agreement.
* Unfair competition in violation of the distribution agreement.
* Misappropriation of ABC Company's intellectual property.
* Causing harm to ABC Company's business reputation and goodwill.

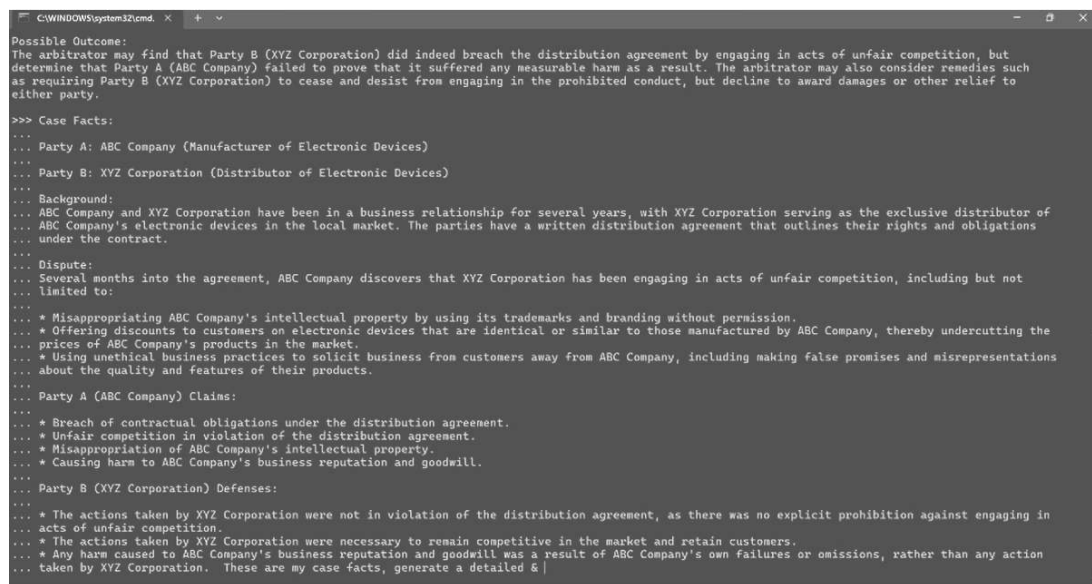
Party B (XYZ Corporation) Defenses:
* The actions taken by XYZ Corporation were not in violation of the distribution agreement, as there was no explicit prohibition against engaging in acts of unfair competition.
* The actions taken by XYZ Corporation were necessary to remain competitive in the market and retain customers.
* Any harm caused to ABC Company's business reputation and goodwill was a result of ABC Company's own failures or omissions, rather than any action taken by XYZ Corporation.

Issues for Arbitration:
1. Did Party B (XYZ Corporation) breach the distribution agreement by engaging in acts of unfair competition?
2. If so, did Party A (ABC Company) suffer harm as a result of these actions?
3. What remedies are available to each party under the terms
```

The general framework of the dispute resolution procedure is shown in Figure 1, which also demonstrates how AI is used to examine previous court decisions. It highlights efficiency gains in dispute assessment and resolution by illuminating the shift from conventional legal research techniques to an AI-assisted framework. Figure 2 illustrates how AI can recognize and extract important legal arguments from court documents using Natural Language Processing (NLP) techniques. After processing case law data, the model finds precedents, legal principles, and crucial dispute elements that are pertinent to the case. The structured extraction guarantees the contextual accuracy and legal soundness of the AI-generated evaluations.

Figure 3 demonstrates how AI methodically arranges and assesses claims and defences, representing one of the fundamental functions of AI in legal reasoning. The AI model helps to provide a clearer understanding of legal positions in a dispute by organizing respondent arguments, plaintiff claims, and judicial interpretations. Legal decision-making is improved, and case prediction accuracy is increased by this structured format.

Figure 3: Analysis of Structured Claims and Defences



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Possible Outcome:
The arbitrator may find that Party B (XYZ Corporation) did indeed breach the distribution agreement by engaging in acts of unfair competition, but
determine that Party A (ABC Company) failed to prove that it suffered any measurable harm as a result. The arbitrator may also consider remedies such
as requiring Party B (XYZ Corporation) to cease and desist from engaging in the prohibited conduct, but decline to award damages or other relief to
either party.

>>> Case Facts:
...
... Party A: ABC Company (Manufacturer of Electronic Devices)
...
... Party B: XYZ Corporation (Distributor of Electronic Devices)
...
... Background:
... ABC Company and XYZ Corporation have been in a business relationship for several years, with XYZ Corporation serving as the exclusive distributor of
... ABC Company's electronic devices in the local market. The parties have a written distribution agreement that outlines their rights and obligations
... under the contract.
...
... Dispute:
... Several months into the agreement, ABC Company discovers that XYZ Corporation has been engaging in acts of unfair competition, including but not
... limited to:
...
... * Misappropriating ABC Company's intellectual property by using its trademarks and branding without permission.
... * Offering discounts to customers on electronic devices that are identical or similar to those manufactured by ABC Company, thereby undercutting the
... prices of ABC Company's products in the market.
... * Using unethical business practices to solicit business from customers away from ABC Company, including making false promises and misrepresentations
... about the quality and features of their products.
...
... Party A (ABC Company) Claims:
...
... * Breach of contractual obligations under the distribution agreement.
... * Unfair competition in violation of the distribution agreement.
... * Misappropriation of ABC Company's intellectual property.
... * Causing harm to ABC Company's business reputation and goodwill.
...
... Party B (XYZ Corporation) Defenses:
...
... * The actions taken by XYZ Corporation were not in violation of the distribution agreement, as there was no explicit prohibition against engaging in
... acts of unfair competition.
... * The actions taken by XYZ Corporation were necessary to remain competitive in the market and retain customers.
... * Any harm caused to ABC Company's business reputation and goodwill was a result of ABC Company's own failures or omissions, rather than any action
... taken by XYZ Corporation. These are my case facts, generate a detailed &
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Figure 4 illustrates the creation of a legal judgment based on prior case law and legal principles, which is the last stage of AI-assisted legal analysis. In order to make sure that its forecasts concur with past decisions and judicial interpretations, the model maps patterns of legal reasoning. This step illustrates how artificial intelligence (AI) can assist lawyers and arbitrators in resolving disputes by proposing possible case outcomes based on precedent-based reasoning.

Figure 4: Case Judgment Process Generated by AI

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Judgment:

Based on the case facts provided, it is clear that Party B (XYZ Corporation) has engaged in acts of unfair competition in violation of the distribution agreement with Party A (ABC Company). Specifically, XYZ Corporation has misappropriated ABC Company's intellectual property by using its trademarks and branding without permission, offered discounts to customers on identical or similar products in an attempt to undercut ABC Company's prices, and used unethical business practices to solicit business away from ABC Company.

In light of these findings, the arbitrator must determine an appropriate remedy for Party A (ABC Company). While Party B (XYZ Corporation) may argue that their actions were necessary to remain competitive in the market and retain customers, such arguments are insufficient to justify their unfair competition. The arbitrator must prioritize the protection of Party A's rights under the distribution agreement and applicable law.

Based on the evidence presented, the following remedies are available to the arbitrator:

1. Injunctive Relief: The arbitrator may issue an injunction against Party B (XYZ Corporation) to cease and desist from engaging in any further acts of unfair competition. This will help prevent any further harm to ABC Company's business reputation and goodwill.
2. Monetary Damages: The arbitrator may award monetary damages to ABC Company for the harm caused by Party B's (XYZ Corporation) unfair competition. The amount of damages will depend on the severity of the harm and the extent to which Party B's actions caused a loss to ABC Company.
3. Specific Performance: In addition to injunctive relief, the arbitrator may order specific performance by Party B (XYZ Corporation) to fulfill their contractual obligations under the distribution agreement. This may include requiring Party B to pay damages or make restitution for any harm caused to ABC Company.
4. Termination of Agreement: If the unfair competition is found to be severe and persistent, the arbitrator may termination of the distribution agreement between Party A (ABC Company) and Party B (XYZ Corporation). This will provide ABC Company with the opportunity to seek new distribution partners or pursue other legal remedies.

In conclusion, based on the case facts presented, it is clear that Party B (XYZ Corporation) has engaged in acts of unfair competition in violation of the distribution agreement with Party A (ABC Company). The arbitrator must prioritize the protection of ABC Company's rights and consider appropriate remedies to address the harm caused by Party B's actions.

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6.0 Conclusion

This study emphasizes how AI has the potential to revolutionize the evaluation of legal cases, especially in construction dispute resolution. Legal analysis can be carried out more quickly by utilizing AI-driven technologies, which will improve accuracy and transparency while cutting down on case processing time. AI-driven legal analytics is now more accessible thanks to the QLoRA-assisted fine-tuning of LLaMA-2, which showed that AI adoption is feasible even for small and medium-sized businesses. Notwithstanding these benefits, issues still exist, such as worries about data integrity, adherence to regulations, and opposition from stakeholders. The study emphasizes the necessity of strong legal frameworks to guarantee impartial, equitable, and morally sound AI applications in the legal field. AI's successful integration into dispute resolution still depends on addressing algorithmic biases and making sure it complies with current legal frameworks. Future studies should concentrate on growing AI training datasets, adding legal expertise specific to a given domain, and improving AI models for enhanced contextual comprehension. Legal professionals also need to be AI literate in order to properly interpret insights produced by AI. AI's potential can be maximized while maintaining fairness and dependability in legal decision-making through a hybrid approach that combines human expertise with AI-driven legal analytics.

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CHAPTER 8

Analysing the Implications of Integration of Electric Bus Service in Urban Transit Systems

Priyanka Bendigiri¹ and Sukruti Magar²

ABSTRACT

Revolutionizing urban mobility by incorporating electric bus services is an essential advancement needed in city transit systems. Pune has become a key player in the shift towards electric mobility within its urban transportation framework. This research explores the various impacts of this integration, emphasizing sustainability, efficiency, public acceptance, infrastructure, and economic feasibility. The integration is also in terms of metro transit systems and autoicures that are there as a part of electric mobility. It is therefore essential to incorporate other aspects in terms of policies which will integrate other transportation systems with electric buses. The study identifies significant obstacles, such as technological, financial, and institutional issues, that impede the widespread adoption of electric vehicles (EVs) in urban areas. Furthermore, it examines policy structures, collaboration among stakeholders, and public attitudes. By analysing case studies from cities worldwide and utilizing simulation models, this study emphasizes the best practices and possible challenges, offering practical recommendations for policymakers and transit officials. Ultimately, a detailed framework is suggested to integrate electric mobility into Pune's urban planning and decision-making processes. This framework aims to promote collaboration among stakeholders, enhance infrastructure development, and ensure policies align with long-term sustainability goals. The findings aim to provide actionable insights for policymakers, urban planners, and stakeholders to accelerate Pune's transition toward an eco-friendly and socially equitable mobility ecosystem.

Keywords: Electric Mobility; Public Transit; Integration; Sustainability Goals; Public acceptance

1.0 Introduction

The need for transportation services to accommodate commuters has grown as cities attempt to grow due to urbanization. Integration of public transportation systems has arisen as a method to aid in navigating the challenges of urban transportation. Integration of public transportation facilitates commuters' transitions between modes, which eventually encourages a switch from personal vehicles to public transportation (ESCAP, 2024).

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By lowering overall costs through less overlap and redundancy and raising revenue through attracting more consumers, an efficient integration of the public transportation system can improve the financial sustainability of public transportation (Zimmerman & Fang, 2015). Cities need public transit, which poses a number of issues going forward. Transportation is thought to account for about 24% of the global energy demand (L. Bravo-Moncayo *et al.*, 2017). According to Woo *et al.* (2017), while the growth in the automobile fleet has benefited the economy, it has also had a negative impact on human health and natural ecosystems. A sufficient transit system that ensures user comfort is necessary to stop the indiscriminate proliferation and individual usage of private vehicles. However, internal combustion engines (ICEs), which power public buses, are generally associated with high noise levels and emissions of greenhouse gases (GHGs) (Dong *et al.*, 2014 and Lucas *et al.*, 2015). To lessen global warming, GHG emissions in particular are a crucial issue that needs to be resolved. In addition, other pollutants including NO₂, SO₂, and PM_{2.5} may cause serious health problems and lead to conditions like cancer and asthma. Particularly, areas with traffic stoppages and high-altitude cities have higher pollution levels because of the reduced motor efficiency brought on by the lower oxygen levels (Onar *et al.*, 2015).

Public transportation is undergoing a global shift to electric propulsion. In order to preserve a sustainable economic environment, cities have included battery-powered electric buses into their current fleets of buses. To preserve a sustainable economic environment, urban regions have been adding more battery-powered electric buses (EBs) to their fleets of buses in recent years (Wenz *et al.*, 2021). A key component of sustainable development is sustainable transportation. It is essential to accomplish both the Paris Climate Agreement and the 2030 Agenda for Sustainable Development, as it has implications for several Sustainable Development Goals (SDGs). “The provision of services and infrastructure for the mobility of people and goods—advancing economic and social development to benefit today’s and future generations—in a manner that is safe, affordable, accessible, efficient, and resilient, while minimizing carbon and other emissions and environmental impacts” is the definition of sustainable transport given in the organization’s 2016 report. Therefore, sustainable transportation is a tool to accomplish sustainable development rather than an aim in and of itself (United Nations Transportation report, 2021). With an ambitious plan to modernize its urban transportation networks by implementing electric buses on a big scale, India is moving forward. This revolutionary step, which aims to reduce carbon emissions and improve air quality, is supported by strong central government policy. India’s public transportation system is making a significant effort to transition to electric vehicles with the launch of the “PM-e-Bus Sewa” programme in addition to the current Faster Adoption and Manufacturing of Electric Vehicles (FAME) frameworks (ET Energy World, 2024).

The Ministry of Urban Development (MOUD), Government of India, aims to equip every city with first- and last-mile connectivity as well as a smooth transportation system including all modes (MOUD, 2013). The future of mobility in India could be redefined by the

merging of public and private transportation systems in the quickly changing current landscape. For commuters across the nation, this convergence heralds a profound paradigm shift that promises increased convenience, accessibility, and inclusivity. There are numerous advantages to integrating transportation networks. A new era of mobility can be unlocked with this integrated strategy, which offers more cost-effective and efficient travel options as well as smooth transitions between different means of transportation. Through interconnecting buses, trains, taxis, bike rentals, and other transportation options, commuters may experience hassle-free travel that is customized to meet their individual requirements and tastes. The amalgamation of public and private transportation networks has immense promises for transforming our modes of transportation and providing copious advantages to both commuters and the community at large. The future of mobility in India depends on the convergence of factors such as economic growth, technological innovation, improved accessibility, cost-effective travel, sustainable mobility, and cultural shift. According to Express Mobility (2024), a paradigm shift would facilitate countries' efforts toward integration and sustainability.

The goal and road map for the nation's rapid adoption of electric vehicles and their manufacture are provided under the National Electric Mobility Mission Plan (NEMMP) 2020. This plan was created to improve fuel security at the national level, offer reasonably priced, eco-friendly transportation, and help the Indian car sector become a global leader in manufacturing.

Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) Scheme was developed in 2015 by the Department of Heavy Industry as part of the NEMMP 2020 with the goal of fostering the production of electric and hybrid vehicle technology and ensuring its sustainable growth. Buyers of electric vehicles (EVs) may take advantage of a demand incentive in the first phase of FAME, which offered a lower upfront purchase price to encourage EV adoption.

The second phase of FAME is mostly concerned with promoting the electrification of shared and public transportation. It seeks to finance the purchase of 7000 e-Buses, 5 lakh e-3 Wheelers, 55000 e-4 Wheeler Passenger Cars, and 10 lakh e-2 Wheelers through subsidies. The program will primarily apply to vehicles registered for commercial use in the e-3W, e-4W, and e-bus segments, or vehicles used for public transportation, with a focus on providing accessible and environmentally friendly public transportation options for the general public (National Electric Mobility Mission Plan, 2020, Ministry of heavy industries). With no tailpipe emissions, electric buses hold the potential to provide public transportation that is quieter, greener, and more energy efficient. However, a complex interplay of technological, financial, and logistical factors must be taken into account for their incorporation into the current urban transit frameworks. This research examines the possible advantages, difficulties, and wider effects on municipal infrastructure, environmental sustainability, and public policy of integrating electric bus services into urban public transportation networks. Stakeholders can more adeptly manage the shift to a more environmentally friendly and resilient urban transportation system by comprehending these dynamics.

1.1 Research questions

RQ: How can an integrated urban transit system be proposed in Pune with a focus on electric buses in the transit system?

1.2 Research objectives

The following research objectives are listed below:

RO1: To assess the current state of electric buses in urban transit systems in Pune.

RO2: To identify barriers and challenges in integration of electric buses in the urban transit systems in Pune.

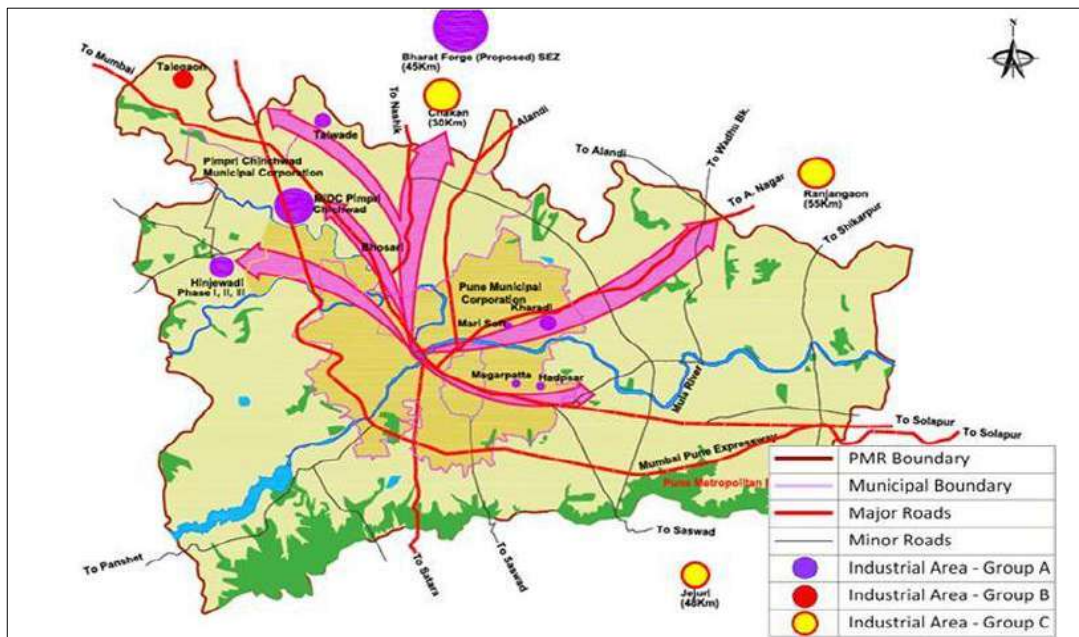
RO3: To assess the environmental and social impacts of integrating electric buses into the urban transit systems in Pune.

RO4: To develop a framework for integrating electric buses into urban transit systems in Pune.

1.3 Study area

Pune, with a 600-year history, is one of India's most culturally advanced cities. With the exception of 2009 and 2010, the number of units and jobs in the large-scale industries in the Pune region have increased throughout time. Different industrial segments are the main drivers of PMC's growth.

Figure 1: Pune Metropolitan Region Industries



Source: Comprehensive mobility plan, 2008.

With the exception of Kharadi Knowledge Park, which is situated inside PMC boundaries, all other industries are now found outside PMC in PMR or in close proximity to PMR in the directions of North, West, and North-East. The bulk of the industrial developments are located within Pimpri Chinchwad Municipal Corporation (Pune Development Plan (DP), 2041). The traffic in and around Pune is growing quickly as a result of the city's industrial and other social expansion. Pune is crossed by a number of major thoroughfares. Both important State Highways and National Highways pass through Pune. On the other hand, traffic congestion was brought on by vehicles passing through Pune City on their way in one direction. The bus and BRT service provider in Pune and Pimpri & Chinchwad has had difficulty keeping up with the transportation needs of the city. The city's transportation system has been under pressure recently due to urban sprawl. The growth in small, medium, and heavy sectors is driving up traffic in the city at unsustainable rates. Despite their narrowness, the city's roads accommodate a range of vehicles at once.

In Pune, there are various types of public transportation available: buses, metro, and vehicles, which are used for paratransit. Urban transport policy's primary objective is to provide people with mobility; public transportation is the most efficient way to achieve this, as opposed to private automobiles. When compared to other public transportation options like the metro, tram, and monorail, the bus rapid transit system (BRTS) is the most affordable and convenient, making it the most chosen choice (Pune DP, 2041).

The Metro Rail Project made a point of highlighting the area's poor support for public transportation and rising use of private vehicles. A home interview survey result shows that 13% of people use public transportation, but at least 50% of people think this should be the case. This may have been accomplished by creating a high-carrying-capacity, effective mass transit system based on transportation technologies (Pune DP, 2041). There are now two operational metro routes built by Maha Metro under Phases I and II. Purneri Metro is in charge of the building of Phase III. In order to improve last-mile connection, the city's paratransit system should be expanded to include non-motorized transportation infrastructure, including as bike lanes, sidewalks, and parking spaces close to bus stops and metro stations, which are in high demand by riders. The integration of the bus and metro is depicted on the map below, along with the locations that are and are not served by public transit. Therefore, it will assist in analyzing the city's public transportation infrastructure, feeder routes, demand and ridership factors, and overall mobility.

Pune has started offering electric bus services in order to meet the goal of sustainable transportation. PMPML Electric Bus. To reduce pollution and save money on diesel, PMPML (Pune Mahanagar Parivahan Mahamandal Limited) has added 25 electric buses, or e-buses, to its fleet. In the first phase of the smart city program, 150 new e-buses will be added, and in the second, 350 more. On the other hand, the cost of maintaining these buses is growing. Each month, the cost of recharging the current 25 buses is 9 lakhs. Consequently, 400 more CNG buses will be added to the transportation agency's fleet, sources claim. Pune faces challenges in

the first and last miles, especially as the population on the outskirts of the city increases, and there is a lack of coordination between many groups and projects.

Figure 2: Integrated BRT and Metro Routes

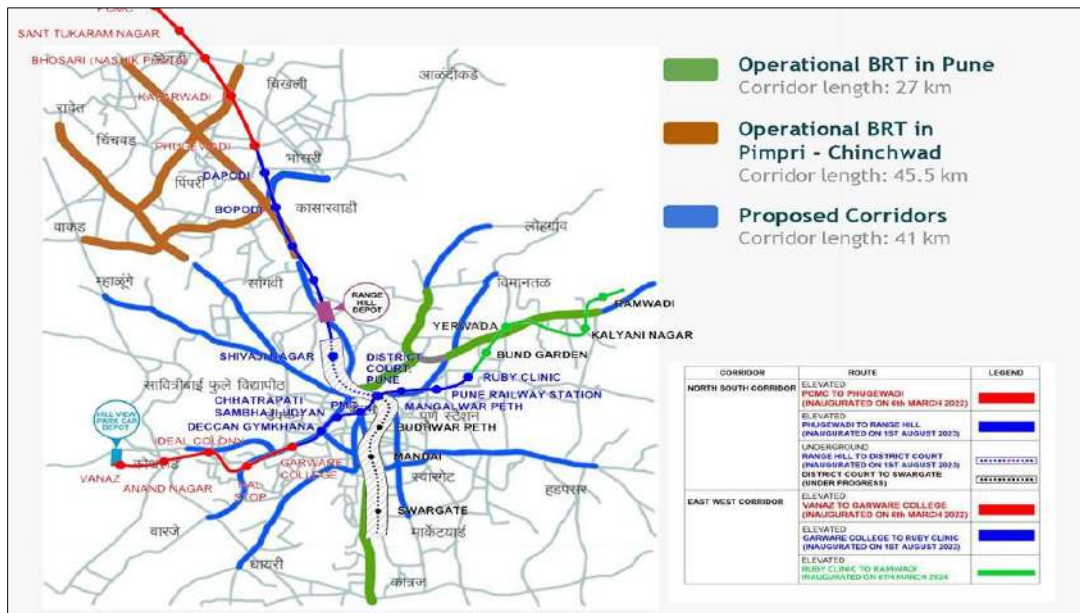
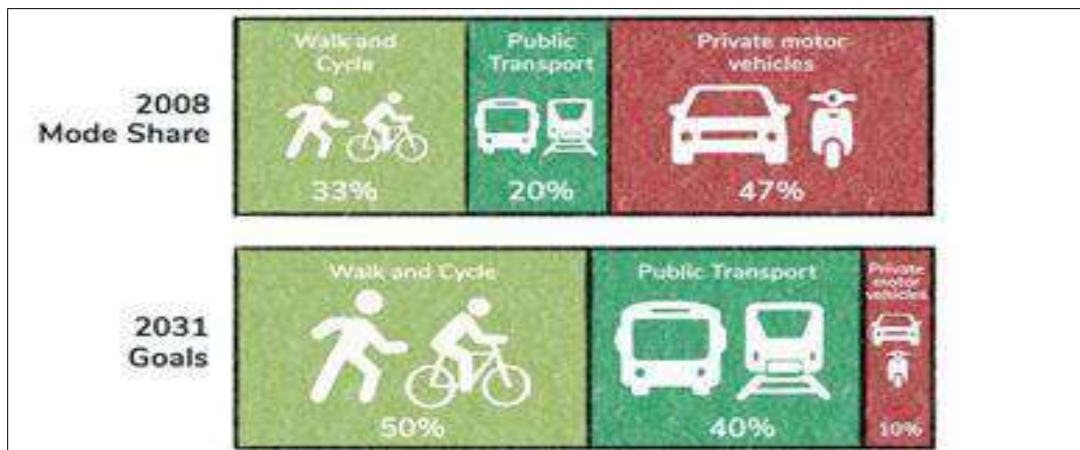


Figure 3: Sustainable Transport Policy by ITDP



Additionally, it has been noted that there is more traffic congestion. The Pune Metropolitan Region's public transportation situation is unsatisfactory (Gaikwad, 2021). This is

evident from the fact that, in 2013, average traffic speeds were 18 mph, and projections for 2031 predict that this will drop to nine mph. (RMI & PMC, 2018). Additionally, it is said in the Comprehensive Mobility Plan for Pune Metropolitan Region (PMR) that 8% of motorized travel trips are made by bus, 12% by intermediate public transportation (IPT), and 4% by suburban railway (PMRDA, 2018).

Establishing a Sturdy and Integrated Public Transportation System in PMR is the answer to resolving this issue (Gaikwad, 2021). In order to assure a complete approach to constructing functioning and habitable streets, the ITDP (Institute for Transportation and Development Policy) report states that the city has implemented various progressive policies and programs driving the change on the ground. The purpose of Pune's Walk Smart Policy is to increase pedestrian safety in the city. It offers recommendations for narrowing traffic lanes, slowing down driving speeds, and establishing pedestrian-only areas, safe crossings, and walkways. The city of Pune established the Integrated Bicycle Plan as the main framework for distributing funds, carrying out initiatives, and assessing the outcomes in order to achieve its objectives for raising the number of people who ride bicycles.

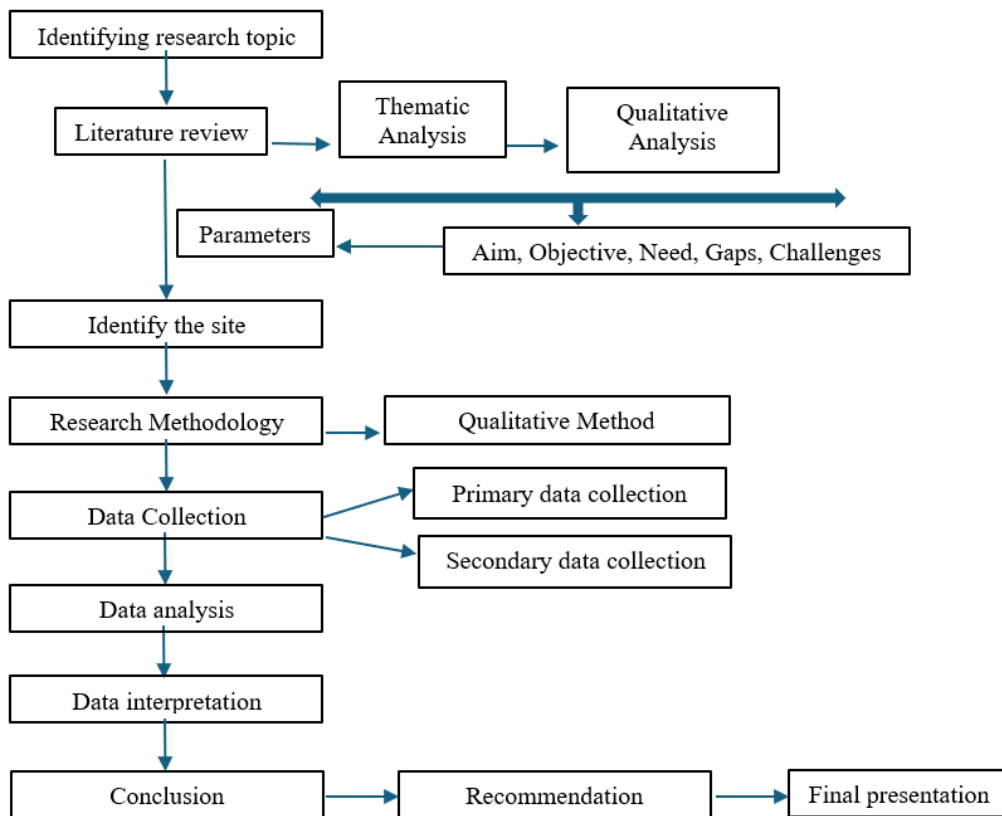
The primary means of transportation between Pune and Pimpri Chinchwad is the regular bus service. For all Pune-kars, it is the most dependable form of transportation, carrying 10 to 11 lakh passengers every day. On the busiest routes between 05.30 and 12.00 am, Pune Mahanagar Parivahan Mahamandal Ltd (PMPML) buses are renowned for their punctuality and excellent service. Currently, 389 routes encompassing a 40-kilometer radius offer services that reach the PMRDA boundaries in the Pune and Pimpri-Chinchwad area. Additionally, growth plans are created, and new ones are implemented based on the recommendations that are regularly made and by researching the city's population. Today, there are roughly 1660 schedules with 21916 trips planned for daily bus travel; 96% of these operations efficiently serve customers. The World Bank, UNDP, and GEF are supporting Pune and Pimpri Chinchwad Municipal Corporation's Sustainable Urban Transport Project (SUTP), which is an initiative of the Indian Ministry of Urban Development. The PMPML E-Bus Implementation Plan called for the provision of 650 electric buses in 2022, an extra 300 electric minibuses in 2023, three operating e-bus depots, an increased number of 250 charging points, 75 charging points that are now in service, and three opportunity charging sites that are suggested (PMPML).

Table 1: Statistics of PMPML, 2023-24

Statistic	Value
Total Fleet	2066
Bus on Road per day	1658
Total Bus Depots	15
Total Bus Stops	3974
Total Routes	387
No. of trips per day (Planned)	20706

3400 buses in Pune and Pimpri-Chinchwad's fleet to guarantee public transportation for everyone. Buses near Everyone: Using the People Near Transit Analysis, increase frequency to one bus every five minutes and extend service coverage to every area of the city. Greener Buses: Include electric buses in the city to help transition to cleaner fuels. The estimated population for 2021 is used to compute the number of additional fleet units needed.

3.0 Research methodology



3.0 Literature Review

3.1 Introduction

Due to growing concerns about sustainability, air pollution, and the global shift towards renewable energy sources, the integration of electric bus services into metropolitan public transit networks has received a lot of attention. The shift to electric vehicles is a crucial part of sustainable development since urban transportation networks are important for environmental policy and municipal planning. Even though electric buses are being used extensively in many

cities, little is known about how these changes will affect the environment and operating efficiency over the long run, especially in growing cities. Furthermore, a thorough examination of the regulations controlling the incorporation of electric buses into the current public transportation networks is still lacking. This review of the literature aims to summarize the current research on the integration of electric buses, pinpoint the main technological, financial, and policy obstacles, and emphasize the essential success elements for urban transportation networks. Important topics covered in this review include the advantages of electric buses for the environment, the difficulties in building infrastructure, user happiness, and the legislative frameworks that encourage the use of electric buses in metropolitan areas. It covers key themes such as Energy and Sustainability, BEB Technology and Infrastructure, Mobility and Transit Integration, Policy and Governance and Technology and Innovation.

3.2 Scopus search

The Scopus search was conducted to get broad number of papers that are related to the topic to have maximum number of research which can be used for review. The keywords used were integrated transit, public transit, electric bus and transport. The review is organized as follows: First, it examines the environmental and economic impacts of electric buses. Next, it explores the technological advancements and infrastructure requirements. Finally, it reviews policy initiatives and user perceptions surrounding electric bus services. The papers identified were around 1000 considering the range between the year 2000-2024. The present literature review was done for 100 papers following the thematic analysis. Considering the areas as social science, Environmental science, Decision science, Energy, Material science, Business management, Urban planning, Transportation engineering, Electric buses, Urban public transport, Sustainable transportation, Electric vehicle infrastructure, public transit policy, Bus electrification, Environmental impact of electric buses. Analysis of the literature according to the trends and patterns by filtering the data. The articles helped to analyse the integrating the integrated system and electric buses in the context of urban transit, focusing on sustainability, infrastructure.

3.3 Themes

3.3.1 Battery Electric Bus (BEB) technology and Infrastructure

The shift to Battery Electric Buses (BEBs) and their incorporation into metropolitan public transportation networks have attracted noteworthy attention owing to the technological, economic, and environmental difficulties associated with decarbonization. Numerous aspects of BEB adoption, such as their total cost of ownership (TCO), infrastructure for charging, energy management, and environmental effects, have been examined in recent research. The results of multiple important research investigations are summarized in this overview of the literature, with an emphasis on the operational difficulties, technological developments, policy implications, and economic viability of BEB implementation.

Managing the limitations of the limited charging infrastructure and optimizing charging schedules are frequent challenges in the adoption of BEBs. A nonlinear optimization approach was put forth in Nanjing with the goal of simultaneously minimizing system costs through vehicle scheduling and charging times. System-wide and billing expenses were significantly reduced as a result of the application of this methodology (Zhang *et al.*, (2024)). To further guarantee system efficiency and lower operating costs, a number of research have concentrated on optimizing nighttime and en route charging schedules. To optimize en-route charging plans, for example, a study built a mixed-integer linear programming model and used robust optimization algorithms to address energy consumption uncertainties (Avenali *et al.*, (2024)). Research on technological advancements in energy storage and battery systems has also been quite popular. The importance of choosing the right energy storage technologies is highlighted by a study that compared Lithium Iron Phosphate (LFP) batteries and Electrochemical Recuperators (ECR) for electric buses in Finland. The study found that although the manufacturing of ECR has a higher potential to cause global warming, it performed better environmentally in bus applications (Zeng *et al.*, (2024)).

Furthermore, the next generation of BEBs is being shaped by modular trends in electric vehicle manufacturing, such as scalable units for charging and propulsion systems, which guarantee supply chain security and streamline the manufacturing process (Gnap *et al.*, (2024)). Infrastructure for Charging Electric Buses: One important area of effort for cutting carbon emissions is electrifying public transportation. When strategically placing electric bus (e-bus) charging stations, a multi-objective optimization model that makes use of the Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) successfully minimizes planning costs while optimizing traffic flow capture (Optimizing E-Bus Charging Infrastructure). Battery swapping was found to be the most effective charging technique in a comparative study of Guangzhou's Bus Rapid Transit (BRT) system, while dynamic wireless charging demonstrated higher efficiency for long routes with high service frequencies (Comparative Analysis of Charging Methods in BRT Systems). Large-scale use of BEB systems requires ensuring their operational stability. In order to make recommendations for enhancing vehicle reliability, particularly in challenging operating situations, a fatigue life evaluation of BEB bodywork was carried out (Teasdale *et al.* (2024)). Furthermore, utilizing their huge battery capacity for Vehicle-to-Grid (V2G) services, one study suggested employing BEBs to improve the resilience of urban power systems during high-impact, low-probability (HILP) disruptive events (Belloni *et al.*, (2024)).

3.3.2 Energy and sustainability

Studies reveal that electric buses (EBs) are more vulnerable to seasonal variations than diesel buses, especially when it comes to lifecycle carbon emissions. The bus body, chassis, and batteries are the main sources of emissions. When coal-based power generation is replaced with sustainable energy sources, emissions can be significantly reduced. The promotion of EBs as a practical means of lowering carbon footprints draws attention to their potential for use in

environmentally friendly transportation systems (Zhang *et al.*, 2024). Research has shown that battery electric buses (BEBs) have certain difficulties in areas with harsh weather, like Qatar.

In comparison to gentler climes, BEBs are less efficient in high temperatures due to increased energy consumption, especially for subsystems like air conditioning (Alarrouqi *et al.*, 2024). Increased research is being called for in order to determine the possible health consequences of electromagnetic fields (EMFs) produced by electric bus batteries on both drivers and passengers. (Mazurek *et al.*, 2024). Effectively controlling energy usage is essential for BEB systems, particularly in hostile environments or for large-scale installations. One study studied energy management solutions for extended-range electric buses (EREVs), focused on improving both engine systems and air conditioning energy usage (Zhang *et al.*, (2024)).

Using a supercapacitor and battery combination, which considerably increased battery endurance, the usage of regenerative braking systems was also emphasized as an essential technology to recover energy and prolong battery life (Kepka & Minich (2024)).: Curitiba, Brazil, is a prime example of how integrated transit systems may support urban sustainability objectives. The need of switching to electric buses for attaining urban sustainability is further supported by New Energy Vehicle (NEV) programs in Chinese cities, which have demonstrated notable reductions in urban CO₂ emissions. New Energy Vehicles (NEVs), such as electric buses, can dramatically cut urban CO₂ emissions, according to pilot programs in Chinese cities. These reductions illustrate how NEVs might help decarbonize urban transportation, especially in developing nations, and benefit not just the cities themselves but also the surrounding areas (Cheng & Xiong, 2024). Advanced Energy Management Systems: By employing Deep Transfer Reinforcement Learning (DRL), among other novel techniques, energy management systems have increased the fuel efficiency of electric vehicles by as much as 6.78%. These solutions are particularly helpful for hydrogen-powered vehicles in urban transportation and also reduce development cycles (Huang, 2024). Deep Transfer Reinforcement Learning (DRL)-based energy management system (EMS) for electric vehicles was found to increase fuel efficiency by 6.78%, which is especially advantageous for hydrogen-powered vehicles in the urban transportation sector (Deep Reinforcement Learning for Electric Vehicle Energy Management).

Furthermore, reserve provision was shown to be more profitable than energy arbitrage in a bi-level optimization framework for managing the charging strategies of electric bus fleets, though battery degradation costs remained a concern. that high temperatures have a significant impact on energy consumption, particularly in the subsystems responsible for heating, ventilation, and air conditioning (Alarrouqi, 2024). This indicates that electric buses face particular challenges in extreme climates. BEBs have been shown to have positive environmental effects, especially when it comes to lowering greenhouse gas (GHG) emissions. The effects of widespread E-bus charging on the grid and emphasized the necessity of careful planning to guarantee grid stability and sufficient hosting capacity. An effective means of increasing electric public transportation without stressing the grid was also investigated: the implementation of In-Motion-Charging (IMC) trolleybuses (Zheng *et al.* (2024)).

3.3.3 Policy and governance

Policies are a major factor in encouraging the use of ecologically efficient buses. A Slovakian study assessed how the EU Directive 2019/1161 affected the promotion of clean cars and found that legislative changes were necessary to promote BEB uptake in suburban regions (Alamoodi *et al.*, (2024)). Furthermore, the adoption of eco-friendly buses is strongly correlated with higher GDP per capita, with Nordic countries setting the standard due to their financial capacity to invest in environmentally friendly public transit systems.

3.3.4 Mobility and transit integration

The conversion of dispersed bus systems into integrated transit networks relies heavily on community involvement. For instance, research conducted in Bogotá reveals a “vision dissonance” between planners’ objectives and user demands that might be lessened by early user engagements to match transportation improvements with community expectations (Kash, 2014).

Similarly, the effective integration of buses, ferries, and fast transit in Vancouver is a testament to the value of strategic planning and community engagement, as seen by the system’s growth that overcome geographical obstacles (Glover, 1988). Innovative transit options with substantial energy savings and increased computational efficiency, such as the Modular Electrified Transit System for Urban Corridor Areas (Zou *et al.*, 2024), provide effective, flexible public transportation. MET-CA outperforms conventional Bus Rapid Transit (BRT) models by reducing energy use by 24.4% and minimizing operating expenses for the transit system (Zou *et al.*, 2024). On the other hand, poor transit accessibility outside of the city centre is revealed by an analysis of Surat’s Bus Rapid Transit (BRT) system, which may account for the low ridership and mode share. The integration promotes more equitable resource distribution to close accessibility gaps in transit (Rathod, 2024). The temporal variation of accessibility, policymakers could improve service provision in underserved regions. In a similar vein, time-sensitive factors influence intermodal transfers between metro and bus services in Shanghai, highlighting the necessity for improved intermodal connection to enhance the user experience (Shi, 2023). Enhanced accessibility due to smartcard-based bus-subway integration, but unequal benefit distribution highlights equity issues and calls for more equitable public transportation regulations (Kim, 2024).

A number of studies recommend combining public transportation systems with ride sourcing services, such as those offered by Transportation Network Companies (TNCs). According to study, TNCs in the Twin Cities can enhance access and improve the quality of services provided by public transit, complementing it (Zhang, 2021). According to a University of Michigan study, ride sourcing might enhance last-mile connection, decrease wait times and possibly boost transit ridership if low-ridership bus lines are replaced. This is according to a suggested system called MTransit. Transit usage is greatly impacted by the quality and accessibility of real-time information, particularly when traveling outside of regular routes. Better information search quality and real-time availability boost transit use by enhancing

perceived service levels and familiarity, according to a study comparing Copenhagen with Recife and Natal (Kaplan, 2017).

A model used in Florence, Italy, which separated the optimization of fare structures into two sub-problems—minimizing the costs to transit agencies and configuring zones to improve affordability—shows that optimizing transit systems requires striking a balance between operational efficiency and passenger convenience (Pratelli, 2004). Similar difficulties with network adaptation and schedule design arise when integrating autonomous and electric bus systems. The necessity of incorporating the unique needs of electric buses into future transit systems is highlighted by a study that employs adaptive large neighbourhood search optimization (Electrification and Autonomous Buses: Challenges for Sustainable Transport Networks). At signalized crossings, eco-driving tactics that make use of Vehicle-to-Everything (V2X) communication have demonstrated notable gains in both travel time and energy efficiency. By cutting energy use by more than 21%, these methods improve the overall sustainability of electric bus operations (Rodrigues *et al.*, 2024). Urban Planning and Sustainable Transit: Curitiba, Brazil, offers a well-accepted example of how to combine urban planning and public transportation. Curitiba serves as an example of the long-term advantages of coordinated urban transit planning for cities looking to establish eco-friendly transport networks by emphasizing sustainability and lowering dependency on automobiles (Zhang *et al.*, 2024).

3.3.5 Financial Viability

Numerous studies have placed a strong emphasis on the economic viability of BEBs, particularly when considering the total cost of ownership (TCO) framework. According to a study that examined actual data from Shanghai, fast-charging BEBs are typically more costly than slow-charging ones because quick charging shortens battery life and raises the cost of charging equipment (Xiao *et al.*, (2024)). Sensitivity analysis also showed that operational subsidies play a crucial role in the economic viability of BEB systems, as they have a considerable impact on the TCO, especially for slow-charging BEBs. The high upfront costs of electric buses, particularly in poor nations, continue to be a major obstacle to their broad adoption, notwithstanding the advantages they have for the environment. Around the world, many electric bus charging techniques have been compared.

While dynamic wireless charging is advantageous on long routes, particularly when infrastructure is shared with other modes of transportation, battery swapping is thought to be the most efficient method for regular services (Pei *et al.*, 2024). Furthermore, by giving reserve services priority over energy arbitrage, aggregator-supported charging schemes can lower fleet management costs even while battery degradation is still a financial concern (Miraftabzadeh, 2024). While dynamic wireless charging is advantageous on long routes, particularly when infrastructure is shared with other modes of transportation, battery swapping is thought to be the most efficient method for regular services (Pei *et al.*, 2024). Furthermore, by giving reserve services priority over energy arbitrage, aggregator-supported charging schemes can lower fleet

management costs even while battery degradation is still a financial concern (Miraftabzadeh, 2024). The high initial prices of electric buses, however, continue to be a significant obstacle despite their positive environmental effects, particularly in developing nations where diesel buses can still be more cost-effective (Sistig *et al.*, 2024).

4.0 Conclusion

Country	City	Electric Bus Integration	Mode of Integration	Key Data/Highlights
China	Shenzhen	Full conversion of its public bus fleet to electric buses.	Integrated with metro systems and bike-sharing schemes.	Over 16,000 electric buses; 48% reduction in CO2 emissions from the transport sector.
Netherlands	Amsterdam	Electric buses operate on key routes, including airport connections and urban areas.	Integrated with trams and metro systems for seamless transfers.	258 electric buses, targeting zero-emission public transport by 2030.
India	Pune	Deployed electric buses under the FAME-II scheme, improving urban transit connectivity.	Integrated with Pune Metro and feeder services.	Over 150 electric buses, plans to expand fleet size to 1,000.
Germany	Hamburg	Electric buses used in urban routes with charging stations powered by renewable energy sources.	Integrated with metro, suburban trains, and car-sharing systems.	100+ electric buses; city targets a zero-emission bus fleet by 2030.
United States	Los Angeles	The metro bus system will be transitioning to fully electric by 2030, targeting dense urban corridors.	Integrated with light rail and subway systems.	225+ electric buses in operation; reduced GHG emissions by 36% since integration began.
United Kingdom	London	Electric double-decker buses serve major routes across the city, alongside hybrid buses.	Integrated with Underground (Tube), overground rail services, and bike-sharing schemes.	Over 850 electric buses aim to achieve a fully zero-emission bus fleet by 2034.
Chile	Santiago	Operates one of the largest electric bus fleets in Latin America, deployed in urban areas.	Integrated with the Metro system for multimodal connectivity.	Over 800 electric buses are in operation, supported by renewable energy for charging.
Norway	Oslo	Electric buses used in urban and suburban routes; charging supported by clean energy sources.	Integrated with trams, ferries, and metro systems.	Over 100 electric buses; the city aims for a fossil-free public transport fleet by 2028.
Sweden	Gothenburg	Operates electric buses in urban areas with opportunity charging at select bus stops.	Integrated with trams, suburban rail, and bike-sharing.	200+ electric buses; city has reduced transit-related emissions by 30% in recent years.
South Korea	Seoul	Electric buses deployed on high-demand urban routes; plans for large-scale deployment.	Integrated with subway systems and local taxis as part of smart mobility initiatives.	Over 100 electric buses; plans to expand to 3,000 by 2025, with significant investment in charging infrastructure.

BEB integration offers opportunities and problems for urban public transportation systems. The research that are discussed here stress how crucial it is to improve energy management, optimize charging infrastructure, and put supportive policies in place in order to guarantee the effective deployment of BEBs. The long-term viability of BEB systems will be greatly influenced by developments in energy storage and battery technology as well as financial incentives like subsidies. In order to strengthen BEB's position in decarbonizing urban transportation, more research should be done on how their widespread use affects grid stability and environmental performance. To put it briefly, these studies highlight the significance of ride sourcing integration, real-time information, optimization strategies, user engagement, and spatial-temporal accessibility in enhancing the performance of integrated transit systems. They also highlight the complex challenges and solutions that these systems present. For those in charge of transit planning and policy, this research offers vital information.

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CHAPTER 9

Analysis of Interaction among the Critical Success Factor Affecting a Successful Claims Management

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Athul Thomas¹ and Abhishek Shrivastava²*

ABSTRACT

The intricacy of projects, stakeholder disputes, and disparate legal systems present claims management difficulties for the construction sector in emerging countries like India. To handle contract modifications or compensation demands resulting from circumstances affecting schedule, scope, and time, effective claims management is crucial. Critical success factors (CSFs) for efficient claims management in construction contracts are identified and examined in this study, with a focus on methodical approaches to dispute resolution and lawsuit avoidance. Using systematic screening and Scopus database searches, the study examines literature to uncover trends, gaps, and areas for improvement. An exhaustive review of 187 research articles, filtered into 32 relevant publications, forms the basis of this research. Key themes were identified, and surveys of industry professionals, academics, and legal experts were conducted to refine the CSFs, focusing on organisational, technical, and legal dimensions. The study identified 10 CSFs, including adaptability, role clarity, communication effectiveness, conflict resolution skills, and strong leadership. Further ISM analysis is used to explore hierarchies and interdependencies among these elements, with categorising factors into autonomous, dependent and driving categories, resulting in a network chart. This investigation highlights the importance of proactive claims handling through systematic and collaborative methods. By leveraging identified CSFs, construction projects can achieve improved execution, reduced disputes, and successful outcomes.

Keywords: Claims Management; Construction Industry; Critical Success Factors; ISM

1.0 Introduction

The intricacy of projects, contractual ambiguities, and competing stakeholder interests present major claims management difficulties for the construction sector, especially in developing countries like India. To avoid disagreements, reduce financial risks, and guarantee efficient project execution, effective claims management is crucial.

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Contract misinterpretations, scope revisions, cost escalation, and delays frequently result in disputes that end up in arbitration or litigation. Decision Support Systems (DSS) and Alternative Dispute Resolution (ADR) techniques have become more popular in response to these problems. Compared to traditional litigation, alternative dispute resolution (ADR) methods like mediation and negotiation provide speedier, more affordable resolutions. Furthermore, risk assessment procedures and contractual adherence are essential for averting disputes before they become more serious. In order to examine the critical success factors (CSFs) in claims management, this study uses Interpretive Structural Modeling (ISM). The report highlights important components such stakeholder collaboration, communication, leadership, and flexibility, offering guidance on how professionals in the field can improve claims resolution techniques for more efficient construction project execution.

2.0 Need and Objective of the Study

The construction sector in India employs the second most number of people nationwide and contributes to 8-10 % annually to the country's GDP. Economic development depends heavily on the construction sector, and poor claims management can result in disputes, cost overruns, and project delays. Improving project efficiency and lowering legal conflicts require an understanding of the major elements impacting claims in the construction industry. The objectives of this study are twofold. First, the study aims to identify the critical factors influencing claims management in construction projects through a comprehensive literature review and expert opinion.

The majority of previous studies focused on the causes of claims, while our study is focused on CSF for claims management. Previous studies have focused on ranking these factors using conventional methods such as frequency index and relative importance index (RII), limited research has explored the interrelationship among these factors. To bridge this gap, this study employs the Interpretive Structural Modeling (ISM) approach along with network analysis to determine both the driving and dependent factors influencing claims management. This structured approach can help project stakeholders identify root causes and develop strategic solutions to improve claims handling and dispute resolution in construction projects.

3.0 Literature Review

Claims management is an essential component of project success in the construction sector because of the high level of uncertainty, multi-stakeholder collaboration, and intricate contractual agreements. Numerous studies emphasize how crucial it is to identify claims proactively, use structured dispute resolution procedures, and document effectively in order to avoid delays and financial losses.

3.1 Importance of effective claims management

Prasad *et al.* (2019) and Aibinu & Jagboro (2002) stress that improperly handled claims can result in major cost overruns and project delays. Unexpected site conditions, poor contract interpretation, design modifications, and insufficient risk assessment are the main causes of construction disputes. Researchers like Dao & Chen (2021) contend that in order to increase the effectiveness of claims resolution, crucial success factors (CSFs) should be found rather than just concentrating on the reasons for claims.

3.2 Key elements of claims management

Stokes & Potts (2006) highlight that early claim identification, transparent notification, and proper documentation are critical for successful resolution. According to Hillebrandt (2000), incomplete or postponed paperwork reduces the veracity of claims and frequently leads to disagreements turning into legal challenges. According to Hossam *et al.* (2014), disputes are greatly decreased by creating a cooperative contractual environment, clearly outlining stakeholder roles, and making sure claim notifications are sent on time.

3.3 Modern approaches in claims management

Building information modeling (BIM) for real-time documentation, artificial intelligence (AI) for predictive claims analysis, and blockchain-based smart contracts to provide tamper-proof claim records are some recent innovations (Pishdad-Bozorgi & Beliveau, 2016). Machine-learning-powered adjudication models are suggested by Chen *et al.* (2023) as a substitute for conventional conflict settlement frameworks.

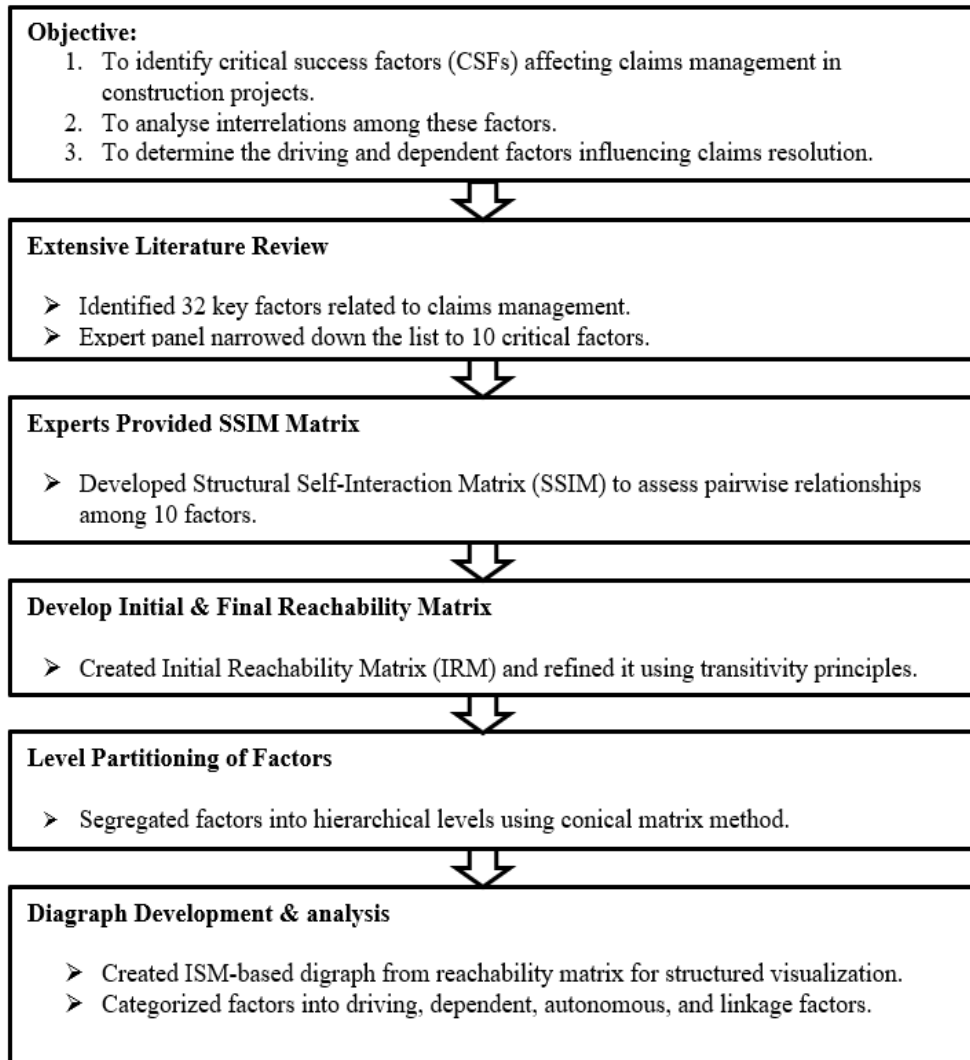
3.4 Literature review trends

- Claims Management in Construction Contracts
- Key Aspects of Claims Management
- Strategies for Effective Claim Management
- Dispute Resolution Techniques
- Legal Considerations in Construction Projects

4.0 Research Methodology

The authors identified 32 critical success factors (CSFs) based on an extensive literature review on claims management in construction contracts. A panel of experts critically examined each of these 32 factors to determine their relevance and significance. After detailed evaluation, the experts narrowed the list down to 10 key factors, identified as the most critical for effective claims management. The methodology followed is similar to the one used by El-Razek *et al.* (2008).

Figure 1: Flow Diagram for Preparing ISM Model



Source: Self made

The panel of experts was interviewed using semi-structured questions. Some of the key questions framed for experts included: “From your expert opinion, do you think this factor plays a significant role in claims management?” “Are there any additional factors you believe should be considered?” “Are there any factors that have similar meanings and should be grouped together?” The panel of experts included academic experts, legal professionals, and industry experts in the construction sector.

The final list of 10 critical success factors affecting claims management is given below:

- Adaptability to changes
- Clarity of roles and responsibilities
- Communication and feedback mechanisms
- Conflict resolution capability
- Management support and leadership
- Mutual trust and confidence among stakeholders
- Problem-solving and decision-making efficiency
- Project team experience and technical expertise
- Teamwork and collaboration among stakeholders
- Transparent tendering and procurement methods

5.0 Interpretive Structural Modeling (ISM)

5.1 ISM framework for claims management

ISM is a structured approach used to analyze interdependence among factors influencing claims management. It is used when there is not much information available regarding the subject matter but there are experts available which help in research development. It enables the development of a hierarchical model representing relationships among CSFs.

5.2 ISM model development steps

- VAXO Table Development: Establishes interdependence between CSFs.
- Direct Relation Matrix Formation: Converts relationships into a structured binary format.
- Reachability Matrix: Identifies direct and indirect relationships among CSFs.
- Level Partitioning: Categorizes CSFs based on their hierarchical influence.
- Canonical Matrix Refinement: Arranges factors logically, eliminating redundant dependencies.
- Final Structuring & Analysis: Classifies factors into autonomous, dependent, linkage, and driving categories.

6.0 Table Analysis and Interpretation

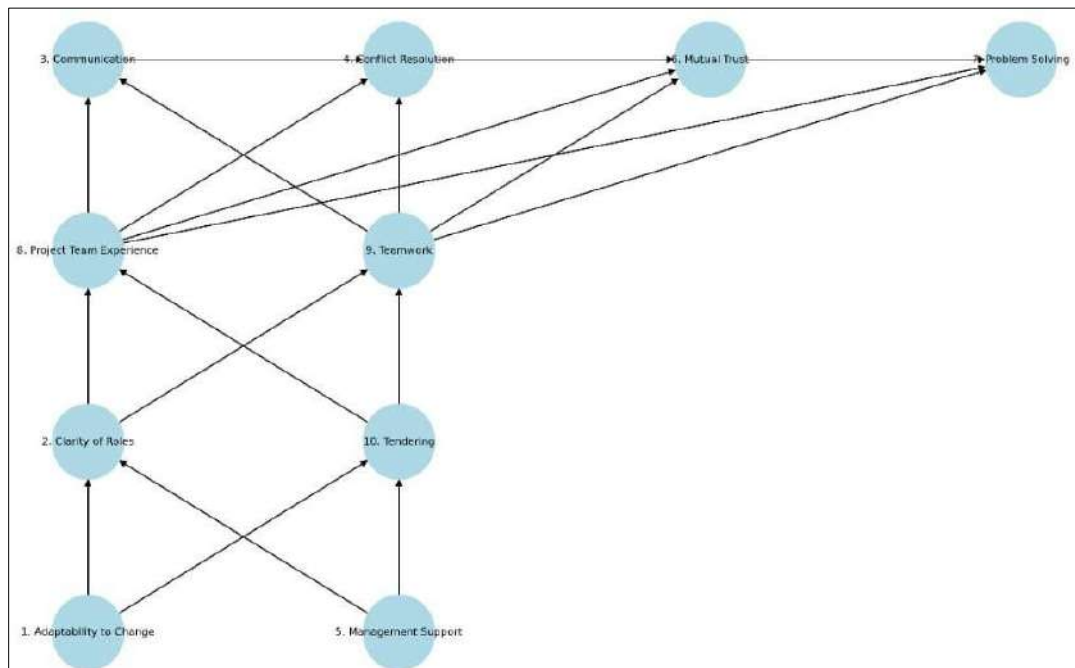
VAXO Interdependency Matrix: The VAXO matrix captures relationships among CSFs using the following classifications:

- V (Driving Factor) – The row factor influences the column factor.
- A (Dependent Factor) – The column factor influences the row factor.
- X (Bidirectional Relationship) – Both factors influence each other.
- (No Relationship) – No direct impact.

Network Analysis Results

- Driving Factors: Management Support, Adaptability to Change
- Linkage Factors: Tendering & Procurement, Clarity of Roles
- Dependent Factors: Teamwork, Project Team Experience, Problem-Solving
- Autonomous Factor: Communication & Feedback

Figure 2: Interpretive Structural Modeling (ISM) Diagram Showing the Interrelationships Among Key Factors in Claims Management



Source: Self made

7.0 Conclusion and Key Takeaways

This study provides a structured approach to claims management by identifying CSFs and their interdependence using ISM. Key takeaways include:

Independent Variables (IDV):

- 1 (Adaptability to Change) and 5 (Management Support) are ultimate independent variables, meaning they influence other factors but are not influenced by themselves.
- These factors act as the driving force behind the system, impacting team performance and project execution.

Dependent Variables (DV):

- 3 (Communication), 4 (Conflict Resolution), 6 (Mutual Trust), and 7 (Problem Solving) are ultimate dependent variables.
- These outcomes are shaped by multiple preceding factors in the model.

Intermediary Factors:

- 2 (Clarity of Roles), 8 (Project Team Experience), 9 (Teamwork), and 10 (Tendering) serve as connecting elements.
- Project Team Experience (8) and Teamwork (9) play a crucial role in bridging independent and dependent variables.

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CHAPTER 10

Analysis of Safety Practices in High-Rise Building Construction for Developing Effective Safety Management System

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ABSTRACT

The construction industry in India is a cornerstone of economic growth, with high-rise and super high-rise buildings symbolizing modern urban development. However, the vertical complexity of such projects amplifies the risks associated with construction activities, making it one of the most hazardous professions globally. This research focuses on analysing safety practices in high-rise building construction and designing an effective Safety Management System (SMS) to mitigate safety hazards and promote safe working conditions. Through a comprehensive methodology involving site interviews and a Likert-scale-based questionnaire survey, data were collected from safety personnel across multiple high-rise construction sites. Advanced statistical techniques, including SPSS-based factor analysis, were applied to identify critical factors influencing safety practices and challenges. These findings provided a robust foundation for understanding relationships among variables, simplifying data, and tailoring the SMS to address the root causes of safety issues. The proposed SMS integrates these insights to systematically tackle safety challenges, aiming to reduce workplace accidents, minimize costs associated with safety failures, and enhance overall health and safety for workers and staff. Furthermore, by promoting organization-wide adoption, this SMS is designed to standardize safety practices across the construction industry, fostering a culture of safety and resilience. This research not only highlights the importance of safety management in high-rise construction but also provides a practical, data-driven framework that can significantly enhance safety outcomes, ensuring a sustainable and accident-free future for the industry.

Keywords: Safety Management System; High Rise Construction; Factor Analysis; Safety Practices; Workplace Hazard Mitigation.

1.0 Introduction

High-rise construction poses significant safety risks due to height, complex logistics, and heavy machinery use.

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Despite safety advancements, accidents persist, often due to falls, struck-by incidents, and structural failures. A structured Safety Management System (SMS) is crucial for risk mitigation, compliance, and enhanced worker safety. This research evaluates current safety measures, identifies gaps, and proposes an improved SMS.

1.1 Motivation

The construction industry is inherently hazardous, with high-rise projects facing amplified risks such as increased fall hazards, adverse weather conditions, and complex coordination among multiple trades. Emergency response at elevated levels is another major challenge. Frequent safety lapses highlight the need for a structured SMS to improve regulatory compliance and safeguard workers.

1.2 Purpose and objectives

This study aims to develop an SMS tailored for high-rise construction by:

- Assessing current safety practices.
- Identifying deficiencies through surveys, case studies, and expert input.
- Proposing an SMS integrating risk mitigation, compliance, and emergency preparedness.
- Offering practical recommendations to improve safety performance.

1.3 Scope of the study

Focusing on high-rise construction by CTBUH and NBC standards, this study examines:

- Risk assessment and hazard identification.
- Safety planning, training, and supervision.
- Emergency preparedness and compliance monitoring. Findings may also inform broader construction safety management practices.

1.4 Limitations

This study has limitations, including a potentially non-generalizable sample size and response biases in self-reported data. Its focus on high-rise construction limits applicability to other sectors, and it does not account for future safety technology advancements or regulatory changes. Despite these constraints, the findings offer valuable insights into enhancing safety management in high-rise projects.

1.5 Organization of the paper

The paper is structured to ensure clarity and coherence. Section 1 introduces the study's motivation, objectives, scope, and limitations. Section 2 reviews literature on safety frameworks in high-rise construction. Section 3 details the methodology, including data collection and analysis procedures. Section 4 presents research findings and discussions, while Section 5 concludes with safety improvement recommendations.

2.0 Literature Review

High-rise construction presents significant safety challenges due to complex designs and high-risk activities. A well-structured safety management system is essential to ensure worker safety. This review examines key studies on safety practices, risk management, and technological advancements in safety management.

2.1 Construction safety management and hazards

Yang *et al.*, (2015) identified hazardous zones in construction sites, particularly in high-wind-speed areas, using Computational Fluid Dynamics (CFD), Building Information Modeling (BIM), and Geographic Information Systems (GIS). Their study emphasizes the need for pre-construction, safety planning and risk management. Tetteh & Liang (2020) studied safety practices in Ghana's high-rise projects, revealing inadequate enforcement, frequent falls, and poor worker communication. They highlight the importance of stricter regulations, training, and awareness programs.

2.2 Critical safety factors

Yiu *et al.*, (2019) ranked major accident causes in Malaysian high-rise construction, emphasizing falls, lack of PPE, unsafe scaffolding, and environmental risks. Their findings stress the need for stricter enforcement and improved monitoring. Murali & Deraman (2021) found that voluntary safety measures, frequent hazard assessments, and leadership commitment reduce accidents. They highlight the role of safety culture and performance tracking in improving safety outcomes.

2.3 Technology in safety management

Limbasiya *et al.*, (2018) demonstrated BIM's role in fall prevention, real-time hazard monitoring, and better safety decision-making. AI-driven surveillance and predictive analytics further enhance risk identification and accident prevention.

2.4 Risk assessment and safety planning

Balkis *et al.*, (2018) analyzed risk assessment methods like Delphi and risk matrix modeling, identifying financial, operational, and legal risks. Their research highlights proactive risk management's role in improving safety and project efficiency. Khairuddin *et al.*, (2021) identified management support, structured inspections, and worker training as key factors for successful safety programs. They emphasize incentive-based programs and leadership involvement. These studies emphasize the importance of structured safety management, advanced risk assessment, and technology integration. Key recommendations include strict enforcement, comprehensive training, real-time hazard monitoring, and AI-driven predictive analysis. Future research should focus on cost-effective digital solutions to enhance safety in high-rise construction.

3.0 Research Methodology

This study adopts a mixed-methods approach, combining quantitative and qualitative analysis to evaluate safety practices in high-rise construction. Data collection includes structured questionnaires for statistical insights, semi-structured interviews for expert perspectives, and on-site observations for validation, ensuring a comprehensive assessment for developing a Safety Management System (SMS). The questionnaire consists of four sections: (1) Site safety, covering PPE compliance, training, hazard assessments, equipment checks, incident reporting, and emergency preparedness; (2) Safety challenges, addressing equipment access, budget constraints, communication barriers, compliance issues, scheduling pressures, and technology adoption; (3) Incident management, analysing reporting frequency, investigation depth, corrective actions, and risk mitigation; and (4) Open-ended responses on best practices, challenges, and lessons learned. Responses are collected using a Likert scale and distributed digitally and in print to safety officers, project managers, and site engineers.

Semi-structured interviews with safety professionals and project managers complement the questionnaire, lasting 30–60 minutes and covering safety policies, enforcement challenges, incidents, mitigation measures, and cultural improvements. Conducted with participant consent, interviews are transcribed and analyzed. Ethical considerations ensure informed consent, anonymity, confidentiality, and secure data storage. Data collection includes online surveys for broad outreach, interviews for qualitative insights, and on-site observations for validation. SPSS is used for statistical analysis, while qualitative data undergoes thematic analysis and comparison with industry benchmarks. This methodology ensures academic rigor and supports the development of an effective Safety Management System (SMS) for high-rise construction.

Table 1: Total Variance Explained

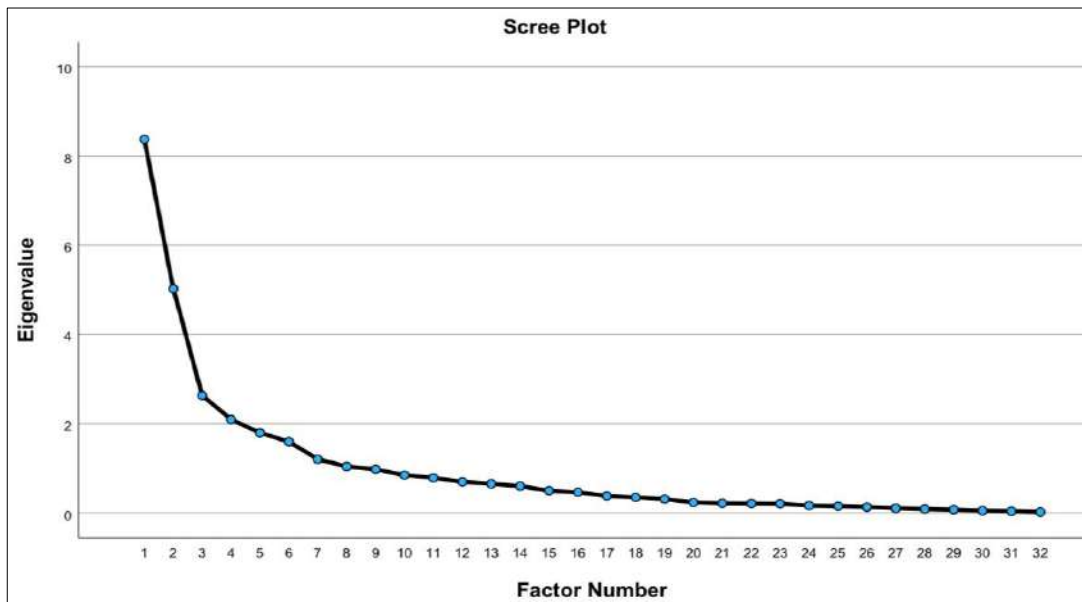
Factor	Initial Eigenvalues	% of Variance	Cumulative %	Rotation Sums of Squared Loadings (% of Variance)
1	8.375	26.171	26.171	16.381
2	5.027	15.709	41.880	12.671
3	2.630	8.219	50.099	9.864
4	2.093	6.541	56.640	7.199
5	1.792	5.601	62.241	6.396
6	1.595	4.983	67.225	5.114
7	1.202	3.755	70.980	4.429
8	1.041	3.255	74.234	4.048

4.0 Data Analysis and Findings

Factor analysis using Principal Axis Factoring (PAF) with Varimax rotation identified eight key safety factors in high-rise construction. The Kaiser-Meyer-Olkin (KMO) test and

Bartlett's test confirmed dataset suitability. The extracted factors form the foundation of a Safety Management System (SMS) integrating planning, supervision, technology, compliance, and risk mitigation. The Total Variance Explained table clearly identifies factors which have eigenvalues above 1 and explain more than 66% of total variance. The scree plot also flattens after the 8th factor on the graph shown below:

Figure 1: Scree Plot



The variables are identified and grouped based on their loadings in each factor from Rotated Factor Matrix Table 2.

The study identifies key factors influencing safety management in high-rise construction, categorized as follows:

- *Safety Planning & Budgeting:* Adequate budget allocation and integration of safety measures within project planning are crucial for hazard prevention. Management commitment and leadership support play a vital role in ensuring effective implementation.
- *Incident Reporting & Investigation:* A structured system for incident documentation, corrective actions, and near-miss analysis strengthens workplace safety. Proper investigation of safety violations helps identify recurring risks and improve protocols.
- *Technology & Safety Infrastructure:* The use of AI-driven safety monitoring, IoT-enabled wearables, and real-time hazard detection enhances accident prevention. Well-maintained safety equipment and digital tracking systems contribute to a secure construction environment.

Table 2: Rotated Factor Matrix

Factor	1	2	3	4	5	6	7	8
Budget constraints	0.802							
Safety in project planning	0.780							
Management support	0.776							
Communication barrier	0.651							
Safety infrastructure	0.638							
New technology implementation		0.627						
Work schedules		0.607						
Qualified safety personnel		0.541						
Equipment access		0.486						
Weather condition		0.373						
Incident investigation effectiveness			0.811					
Timeliness of incident response			0.795					
Safety technology integration			0.776					
Near-miss reporting			0.701					
Documentation of risk management				0.633				
Corrective actions post-incident				0.511				
Incident reporting frequency				0.768				
Risk management training					0.692			
Site inspection					0.682			
Equipment checks					0.593			
Safety signage					0.508			
Safety supervision					0.428			
First aid preparedness						0.774		
Safety equipment access						0.640		
Safety training						0.625		
Height safety measures							0.845	
Age of respondent							0.738	
Experience of respondent							0.793	
Emergency preparedness								0.456
Use of incident data								0.673
PPE usage								0.744
Incident reporting								0.526

- *Training & Safety Supervision:* Regular training, clear safety signage, and dedicated safety officers are essential for regulatory compliance. Continuous learning and on-site monitoring help mitigate risks and improve worker awareness.

- *Emergency Preparedness:* Ensuring first aid accessibility, firefighting equipment availability, and structured emergency response plans enhances accident management. Conducting regular drills strengthens site readiness for emergencies.
- *Work Environment & Conditions:* Factors such as extreme weather, work schedules, and the availability of safety personnel impact worker well-being. Managing environmental risks and optimizing work shifts help prevent fatigue-related incidents.
- *Construction-Specific Safety Practices:* Compliance with Personal Protective Equipment (PPE) standards, routine site inspections, and height safety measures minimize site-specific hazards, including falls and equipment-related injuries.
- *Incident Data Utilization & Risk Analysis:* Safety data analytics, predictive modeling, and audits aid in identifying high-risk areas. Analysing past incidents enables targeted interventions to enhance workplace safety.

These findings highlight the critical components necessary for improving safety outcomes in high-rise construction projects.

5.0 Conclusion, Limitations and Recommendations

5.1 Conclusion

This study identifies eight critical factors shaping safety management in high-rise construction, forming the foundation for an effective Safety Management System (SMS). These factors include safety planning and budgeting, incident reporting and investigation, technology and safety infrastructure, training and supervision, emergency preparedness, work environment conditions, construction-specific safety practices, and incident data utilization. Integrating these elements enables proactive risk mitigation, strengthens regulatory compliance, and supports data-driven decision-making. The findings underscore the importance of structured safety planning, technological advancements, continuous training, and emergency preparedness in fostering a safer construction environment. Implementing this SMS can significantly reduce workplace hazards, improve adherence to safety regulations, and promote a strong safety culture within high-rise projects.

5.2 Limitations

Despite its contributions, this study has certain limitations. Its focus on high-rise construction may limit the applicability of findings to other sectors, such as road infrastructure or industrial projects. The reliance on self-reported survey data introduces the possibility of response bias due to subjective perceptions of safety. Additionally, the factor analysis assumes independence among variables (Varimax rotation), whereas, in practice, some safety factors may be interrelated. The study also does not account for future technological advancements or regulatory changes that may impact the long-term effectiveness of the proposed SMS.

5.3 Recommendations

Future research should broaden the industry scope and sample size to enhance the generalizability of findings across different construction sectors. A longitudinal study assessing safety improvements over time could provide deeper insights into the real-world impact of the SMS. Exploring alternative factor analysis methods, such as Oblique rotation, could help identify interdependencies among safety factors. Further investigation into emerging technologies, including AI-based hazard detection and IoT-enabled safety systems, could refine safety management strategies. Additionally, piloting the proposed SMS in active construction projects would help validate its effectiveness and allow for practical refinement based on real-world implementation challenges.

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CHAPTER 11

Analysis of the Implementation of Effective Waste Management Practices in Construction Projects and Sites

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ABSTRACT

The building sector, which contributes significantly to global urbanization and environmental deterioration, generates a large amount of trash, including hazardous compounds that harm ecosystems and human health. The aim of this research is to examine how effective waste management strategies are implemented in Indian building projects and sites. A detailed methodology was used, including surveys of project managers and engineers, with data from 396 respondents. The study reviews practices throughout the design, planning, and execution phases, as well as compliance with legislative frameworks such as the Construction and Demolition (C&D) Waste Management Rules of 2016, and offers improvement recommendations. The findings show a substantial uptake of sustainable approaches such as material optimization and Building Information Modelling (BIM). However, there are still shortages in worker training, legal enforcement, and recycling infrastructure. Training programs, stakeholder participation, and new technologies are emphasized as ways to assure compliance, decrease waste, and fit with global sustainability goals. This research is critical for politicians, construction businesses, and environmental organizations because it provides actionable insights to promote environmentally friendly construction methods, economic efficiency, and resource conservation. It is especially relevant for India's rapidly urbanizing context and pursuit of sustainable development goals.

Keywords: Construction and Demolition (C&D) Waste; Waste management; Building Information Modeling (BIM); Sustainable construction; Environmental impact

1.0 Introduction

The study focuses on managing construction and obliteration (C&D) waste effectively, one of the most important issues facing the construction sector. The sector has come a major contributor to environmental deterioration as a result of the fast expansion of urbanization and the increase in construction exertion. Nearly one- third of all energy use and 40 of CO₂ emigrations worldwide are attributed to the construction sector. likewise, it produces nearly half of the world's monthly solid waste, which is primarily made up of construction and obliteration

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accoutrements including wood, bricks, and concrete. The environmental impact of the construction assiduity necessitates rapid-fire attention, notwithstanding its vital part in promoting social and profitable growth. According to the World Economic Forum, solid waste creation will increase from 1.3 billion tonnes in 2012 to 2.2 billion tonnes by 2025, with construction trash account for a significant quantum of this aggregate. In addition to harming the terrain, poor waste operation ways beget construction enterprises to lose plutocrat and come hamstrung. This study examines the being styles, difficulties, and prospects in waste operation within India's structure assiduity in light of the profitable, environmental, and social ramifications of construction and obliteration waste. It highlights the necessity of enforcing sustainable practices including recycling, trash reduction, and compliance with laws like the Construction and obliteration trash operation Rules, 2016. The study intends to offer practical suggestions for reaching a zero- waste future in structure by comprehending how construction associations view current legislative fabrics and probing creative approaches.

2.0 Literature Review

The management of construction and demolition waste (CDW) has drawn a lot of attention lately because of its effects on the environment, the economy, and society. Several studies have explored innovative approaches to minimize waste generation and promote sustainable construction practices. Heisal *et al.* (2024) proposed a disassemblable brick partition wall using Design for Disassembly (DfD) principles, demonstrating a potential reduction in waste by 95% and an improvement in construction efficiency by 15.8%. Similarly, Haitherali & Anjali (2024) highlighted the challenges of CDW disposal in emerging economies, emphasizing the need for stakeholder awareness and integrated waste management systems to align with Sustainable Development Goals (SDGs).

Caro *et al.* (2024) examined CDW recycling in the European Union, revealing that while the recovery rate is high, material value retention remains limited, suggesting policy interventions such as landfill taxes to enhance recycling efforts. Furthermore, Orbio *et al.* (2023) conducted a comparative study between developed and emerging countries, identifying key CDW estimation methods and advocating for business models incorporating reverse logistics to improve waste management efficiency. Other studies have focused on waste reduction strategies and material reuse in construction. Duan *et al.* (2022) investigated the use of recycled brick-based demolition waste in geopolymer mortar and concrete, finding that while certain waste fractions improved material properties, others resulted in lower structural performance.

Whyte *et al.* (2022) and Elshaboury *et al.* (2022) explored waste management practices in Malaysia and construction cost implications, respectively, both emphasizing the need for awareness, regulation, and efficient material handling. Janani *et al.* (2020) and Mhaske *et al.* (2017) identified key waste-generating activities such as excessive procurement and poor site management, proposing strategies like the 4R approach (Reduce, Reuse, Recycle, Recover) and

barcode tracking for waste reduction. Additionally, Sharkawai *et al.* (2018) and Thongkamsuk *et al.* (2017) analyzed CDW recycling in developing nations, underlining the importance of proper waste segregation and regulatory enforcement. All things considered, these studies demonstrate the need for technical developments, sustainable building methods, and legislative frameworks to reduce CDW and create a circular economy in the building industry.

3.0 Research Methodology

A classified research approach has been used in order to accomplish the study goal. Using a selection of survey questions derived from previous research initiatives, the existing legislative framework, and literature reviews, a survey is administered to Indian construction enterprises. A sample size of 384 will be gathered, with project managers and project engineers making up the majority of survey respondents. Information about the company and respondents, construction waste management during the design, planning, and construction phases, and the legal framework comprise the four areas of the survey. Convenience sampling is the method of sampling that is employed. To determine areas for improvement and commonly used waste management techniques, the survey data is examined. To find shortcomings in the current waste management paradigm and waste facilities, the data is studied. To achieve more sustainable construction waste management, the data is examined and tools and solutions are proposed.

4.0 Results

The study sought to investigate the use of effective waste management strategies in Indian building projects. The collected data yielded the following key findings:

4.1 Design phase

The study revealed that 97% of respondents focus on material optimization in their designs, demonstrating a strong commitment to minimizing waste. Additionally, 88.9% utilize Building Information Modeling (BIM) to enhance material efficiency, reflecting a high level of technology adoption in waste reduction. However, only 29.8% of respondents incorporate prefabrication and modular design, indicating a significant gap in adopting waste-reducing construction methods. Furthermore, only 46.1% design for disassembly, highlighting the need for greater awareness and resource allocation in this area. While efforts to reduce waste through design exist, the limited adoption of modular techniques and disassembly-friendly approaches suggests room for improvement.

4.2 Planning phase

Effective waste management planning is widely practiced, with 89.6% of respondents implementing detailed waste management plans. Additionally, 78.3% incorporate recycling

considerations into their designs, ensuring that recyclable materials are properly accounted for during project execution. However, the remaining 21.5% neglect recycling opportunities, indicating the need for more comprehensive policies and awareness to ensure recycling is a fundamental component of all construction plans. While planning efforts are strong, addressing gaps in recycling integration can enhance sustainability in the sector.

Figure 1: Comparison of Waste Management Measures in Design Phase

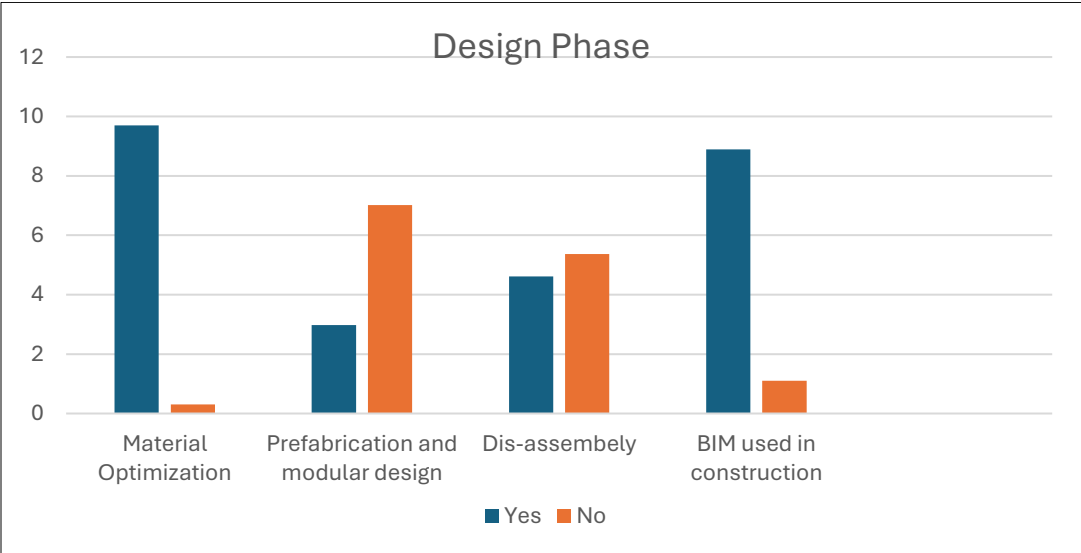
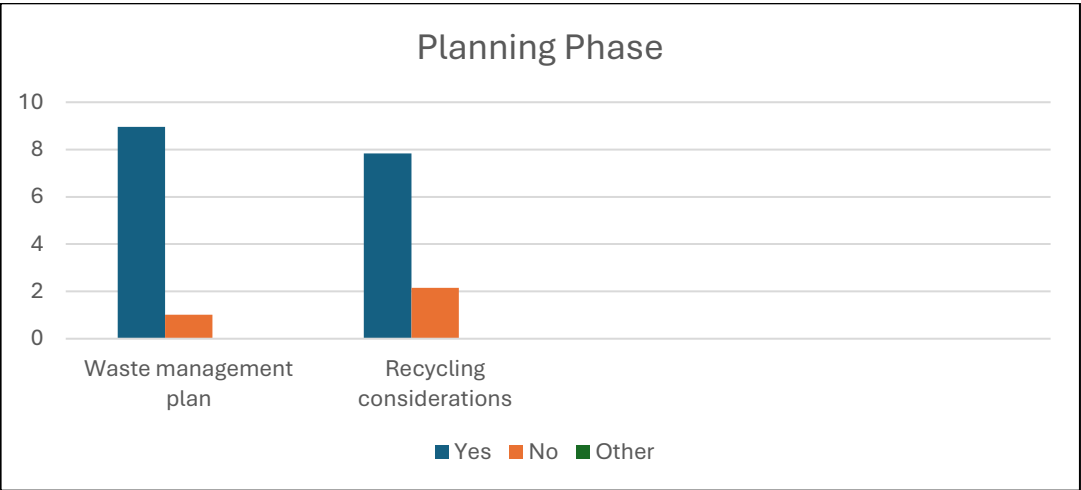


Figure 2: Comparison of Waste Management Measures in Planning Phase



4.3 Execution phase

During project execution, 95.4% of construction sites have designated storage areas for recyclables and hazardous waste, supporting proper waste segregation practices. Additionally, 90.9% of households contribute to waste segregation efforts, improving recycling efficiency. Compliance with hazardous waste regulations is also high, with 94.9% following proper storage and disposal standards.

Figure 3: Comparison of Waste Management Measures in Execution Phase

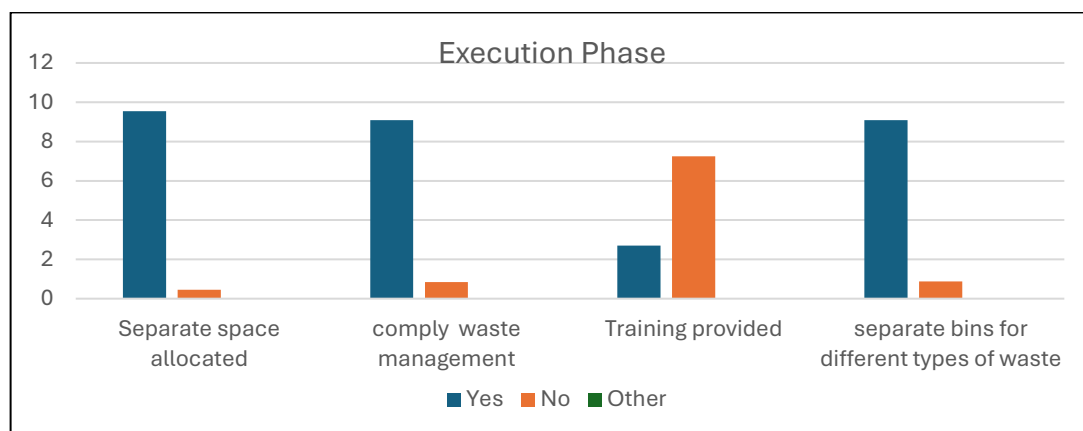
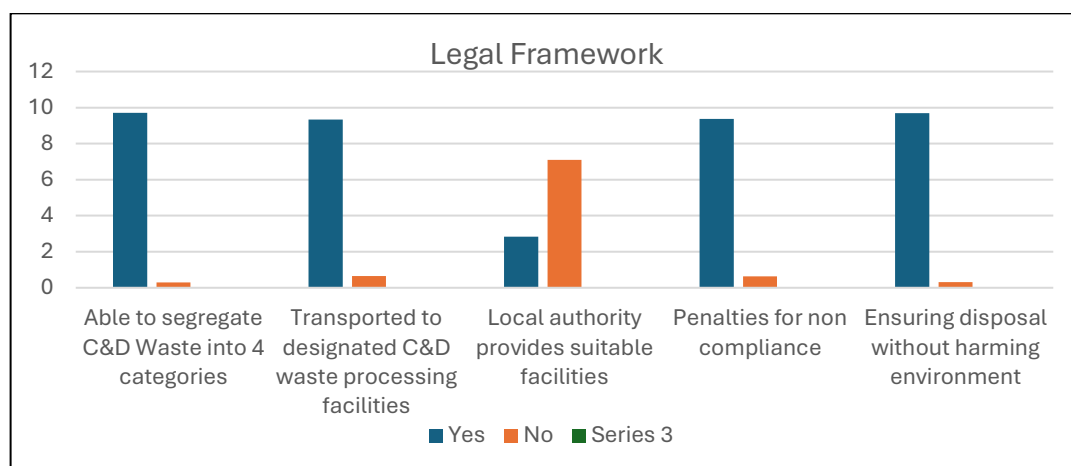


Figure 4 Comparison of Legal Compliance



However, a critical issue identified is the lack of training, with only 27% of on-site personnel receiving adequate instruction on waste handling. This gap training reduces the

effectiveness of otherwise well-planned waste management strategies. Enhancing training programs can significantly improve execution-phase waste management.

4.4 Legal framework

Compliance with the Construction and Demolition (C&D) Waste Management Rules, 2016, is strong, with 97% of respondents properly categorizing waste and 93.4% ensuring its transportation to designated facilities. However, only 70.9% report access to appropriate disposal facilities provided by local authorities, revealing inconsistencies in infrastructure support. While regulatory adherence is high, irregular enforcement and inadequate waste disposal infrastructure remain barriers to achieving comprehensive waste management. Strengthening local government involvement and improving waste management facilities can bridge this gap.

4.5 Overall insights and recommendations

The study highlights notable progress in waste management across different construction phases, particularly in material optimization, compliance with waste segregation laws, and planning efforts. However, challenges persist, such as the low adoption of prefabrication techniques, insufficient training, and inconsistent support from local authorities. To address these issues, recommendations include improving on-site training, enhancing infrastructure in collaboration with local authorities, incentivizing prefabrication methods, and ensuring stricter enforcement of regulations. By implementing these strategies, the construction industry can further minimize its environmental impact and move towards sustainable development.

5.0 Conclusion

The research highlights the essential role of efficient waste management in the construction industry to lessen its ecological footprint and promote sustainability. The results indicate an increasing implementation of strategies such as material optimization, on-site sorting, and compliance with regulations like the Construction and Demolition Waste Management Rules, 2016. Nonetheless, notable issues persist, such as inadequate training for workers, irregular enforcement of laws, and insufficient recycling facilities.

To overcome these obstacles, the construction sector should focus on integrating advanced technologies like BIM, raising stakeholder awareness, and promoting collaboration with local authorities. Sustainable waste management practices not only minimize environmental damage but also provide economic and social advantages by conserving resources, reducing expenses, and enhancing community welfare. By adopting the proposed strategies, the construction industry can make meaningful progress towards a zero-waste future while aligning with global sustainability objectives.

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CHAPTER 12

Analysis of University Campus Performance in Compliance with IGBC (Green Campus) Rating System

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ABSTRACT

In 1987 the United Nations Brundtland Commission defined sustainability as “the ability to meet the needs of the present without compromising the ability of future generations to meet their needs.” Over the past decade, sustainability science has emerged as a critical field that centers on assessing the intricate relationship between the natural environment and human society. This discipline emphasizes the ability of future generations to meet their needs. Academic campuses are microcosms of broader metropolitan ecosystems and hence are ideal locations to demonstrate the application of principles of sustainable development into reality. The Indian Green Building Council (IGBC) has served as a significant stakeholder in the drive for sustainable development by promoting green construction projects in the country. IGBC empowers the stakeholders from architects to construction professionals to further their understanding of sustainable construction practices by providing them with the necessary information and resources. This paper analyses University campus sustainability performance through the IGBC Green Rating Systems. Utilizing interviews, observations and other methods prescribed by IGBC for data collection an assessment of the existing building campus along eight important areas has been conducted. The results award a credit score of 44 which indicates a certified certification level. The paper concludes with a sequence of recommendations to target the shortfall of the campus in specific domains, which will empower the campus to reinforce its green credentials. By implementing these actionable steps, the university can serve as a role model for other institutions while enriching its environmental impact.

Keywords: Sustainability; Green Campus; Environmental Impact; Sustainable Performance; IGBC Green Rating.

1.0 Introduction

Construction has been accused of causing environmental problems ranging from excessive consumption of global resources both in terms of construction and building operation to the pollution of the surrounding environment. There is an intricate relationship that exists between society and nature, to address this complicated relationship sustainability has emerged as a critical field.

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Climate change, depletion of resources, loss of biodiversity, and environmental degradation are among the various environmental challenges faced by the society, and the educational institution will play a critical role in tackling these challenges.[1] The United Nations in 1987 published the Brundtland Report, which encompassed the definition of sustainability that has become one of the most preferred definition globally: “Sustainability is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” [7] This essential principle highlights the responsibility of institutions to not only provide an education to the current generation but also impress upon them the values, morals, and practices through which their work will be able to aid future generations.[2] Educational campuses are a representation of the vast societal landscape, they are uniquely stationed to be at the forefront of sustainability efforts. They have the potential to shape the upcoming sustainable practices that can affect the neighboring communities. By inculcating sustainability into the curriculum, operating strategies, and campus cultures, the institutions can popularize an ethos of environmental protection, encouraging the staff and students to embrace for responsible and sustainable behaviours. This will lead to the creation of ripples effect that will spread beyond the boundaries of the campus, modelling the aspirations of future innovators and leaders. [3]

The Green campus rating system has been formulated by the Indian Green Building Council (IGBC) to further the cause of sustainability in campuses. This rating system provides methodological process for evaluating the sustainability of campuses and encourage sustainable practices across various institutions throughout India.[6] This framework targets various fundamental areas that can result in meaningful reductions in the environmental impact of the institutions while enhancing the quality of life of the campus residents. The framework focuses on key areas such as water and electricity conservation, which are critical for reduction of the environmental footprint of the educational institutions. Institutions have considerable energy demands that are attributable to their operations and facilities, making efficiency a top priority.[4,5,6] Adopting water conservation practices, including but not limited to rainwater harvesting, wastewater recycling, and the use of efficient plumbing fixtures, is critical for fostering responsible water management.. Additionally, solar panels and wind turbines are among renewable energy sources, adoption of these renewable energy sources can significantly reduce the reliance of the institutions on fossil fuels and lower carbon emissions. Another important domain is waste management. [4,6]

A significant volume of waste is generated by educational institutes, thus to reduce the landfill share of the institutions an efficient waste management plan is required. Composting, waste segregation, recycling and other such initiatives can not only manage waste effectively but can also serve as a podium for creating awareness about the importance of sustainable waste practices among staff and students.[4,5] The improvement of health and well-being facilities is an indispensable part of the rating system. Both the physical and mental well-being of the occupants should be the focus of any campus area that is deemed to be sustainable. This can be

achieved through initiatives such as advocacy of active transportation, ample green spaces, and providing access to healthy food options. Such programs result in an enriching educational experience, due to the collaborative and vibrant environment for learning.[4,6]

The study analyzes the University campus along the criteria set by IGBC Green Campus rating system that focuses on different dimensions of sustainability that exist within the environment of the campus. A rigorous evaluation of the campus practices, such as efficient waste disposal, energy efficient infrastructure and sustainable resource utilization will highlight the strengths of the campus that can be reproduced across different institutions throughout the nation. The study will also identify key areas for development and improvement, allowing an existing university campus to create an environment for continuous developments in the university's sustainability efforts. The actionable insights that will be revealed from the analysis will not only add to the ongoing dialogue around inculcating sustainable practices into education, but also empower other institutions to participate into the drive for a sustainable future by utilizing similar sustainability frameworks. Adoption of sustainability by more educational institutions will lead to substantial development in regard to tackling the global environmental challenges.

2.0 Objectives

- Assess the University's compliance with IGBC Green Campus Rating parameters.
- Identify areas where the campus lags in sustainability and provide guidelines to enhance sustainability and green features on campus.

3.0 Methodology

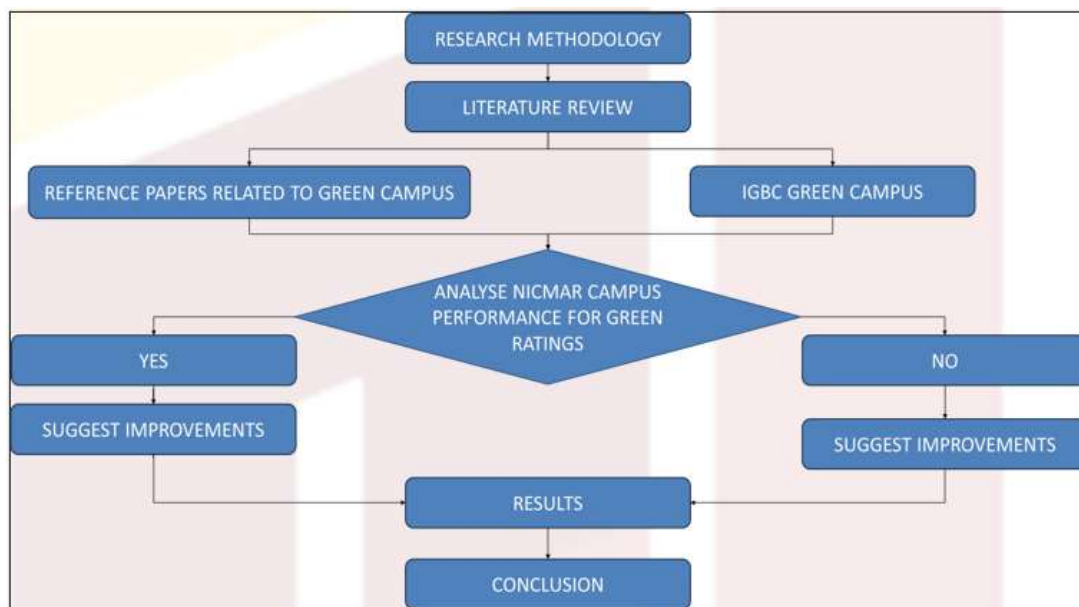
The methodology for this research involves a mixed methods approach to evaluate existing campus buildings for compliance with green building standards according to the Indian Green Building Council (IGBC) norms. (Figure 1) gives an overview of the methodology adopted to complete the research work.

3.1 Data collection

The first step of research begins with collection of data through surveys, site visits and document analysis for evaluating the university campus. In order to inspect the physical condition of the building and infrastructure, site visits are essential for examination purposes. Various parameters like water consumption, energy systems, ventilation quality and building materials used for construction can be closely evaluated. The surveys and questionnaires will help in collecting the basic information of students, faculties, administrative staffs and facility managers to give more insights about campus's sustainability practices and scope of improvement. The document analysis procedure will include a review of building blueprints,

maintenance logs, and any existing green certifications. In particular, certification records will shed information on the facilities' past compliance with sustainability standards.

Figure 1: Methodology Chart



3.2 Data analysis

To understand the performance of campus's green building performance in a better way dual analysis using appropriate quantitative and qualitative methods are used. Quantitative data from surveys and observations during site visits were statistically processed. Qualitative data, such as responses document analysis was done to identify the recurring patterns and areas of concern.

3.3 Credit system

IGBC Green Campus rating system addresses green features under the following categories: Site Planning and Management Sustainable Transportation Water Conservation Energy Efficiency Material and Resource Management Health & Well-being Green Education Innovation in Design. The guidelines detailed under each mandatory requirement & credit enables the design and construction of campuses of all sizes and types (as defined in scope). Different levels of green campus certification (Table 1) are awarded based on the total credits earned. However, every green campus should meet certain mandatory requirements, which are non negotiable. As per the various categories and credit scoring mentioned in IGBC document, rating was provided.

Table 1: Threshold Criteria for Certification Levels

Certification Level	New Campus	Existing Campus	Recognition
Certified	40-49	36-44	Best Practices
Silver	50-59	45-53	Outstanding Performance
Gold	60-74	54-66	National Excellence
Platinum	75-100	67-90	Global Leadership

4.0 Results and Discussion

IGBC Green Campus Rating System		Points Available	Scoring
Site Planning and Management			
SPM MR 1	Green Buildings within the Campus	Required	DNA
SPM MR 2	Soil Erosion Control	Required	DNA
SPM Credit 1	Green Buildings within the Campus	10	5
SPM Credit 2	Site Preservation	NA	NA
SPM Credit 3	Green Cover or Vegetation	6	6
SPM Credit 4	Heat Island Reduction, Non-roof	4	2
SPM Credit 5	Outdoor Light Pollution Reduction	2	NA
Sustainable transportation			
ST Credit 1	Pedestrian Network	3	3
ST Credit 2	Bicycle Lanes Network	4	4
ST Credit 3	Access to Sustainable Transportation	4	2
Water Conservation			
WC MR 1	Rainwater Harvesting	Required	Fulfilled
WC Credit 1	Rainwater Harvesting	6	-
WC Credit 2	Landscape Design	4	NA
WC Credit 3	Management of Irrigation Systems	2	1
WC Credit 4	Wastewater Treatment & Reuse	4	4
WC Credit 5	Optimise Water Use for Construction	1	DNA
WC Credit 6	Water Metering	2	2
Energy Efficiency			
EE Credit 1	Energy Efficiency in Infrastructural Equipment	10	2
EE Credit 2	On-site Renewable Energy	5	Nil
EE Credit 3	Off-site Renewable Energy	4	DNA
EE Credit 4	Energy Metering	2	2
Material and resource management			
MRM Mandatory Requirement 1	Segregation of Waste, Post-occupancy	Required	Fulfilled
MRM Credit 1	Organic Waste Management, Post-occupancy	3	2
Health & Well-being			
HWB MR 1	Tobacco Smoke Control	Required	Fulfilled
HWB Credit 1	Basic Amenities	1	1

HWB Credit 2	Health & Well-being Facilities	4	4
HWB Credit 3	Universal Design	1	1
HWB Credit 4	Basic Facilities for Construction Workforce	NA	NA
Green Education			
GE Credit 1	Green Education	2	1
GE Credit 2	Green Campus Guidelines	2	1
Innovation in Design			
ID Credit 1	Innovation in Design Process	4	DNA
ID Credit 2	IGBC Accredited Professional	2	0
	Total		44

DNA- Data Not Available, NA – Not Applicable

The total performance of the campus results in scoring of 44 out of 90 potential points scoring “Certified” rating. The campus has attained all possible credits in the domain areas of “Health & Well-being” and “Green Education”, signifying its flourishing sustainability practices. In other domain areas like “Material and Resource Management,” while the campus has a composting initiative in place for the generated garden waste, it missed out on potential points for waste management policies for the food waste generated on the campus. The domains of “Energy Efficiency” and “Water Conservation” require special focus to adopt innovative sustainable approaches and deploy equipment that are efficient. Campus still has the potential to score additional credits which could not be awarded due to lack of data at the present time.

5.0 Conclusion

The evaluation of NICMAR University’s sustainability performance using the IGBC Green Campus Rating System has given a thorough understanding of the university’s current green initiatives as well as potential directions for development. The University has achieved 44 out of potential 90 points scoring ‘Certified’ rating level, acknowledging both its successful sustainable practices and the substantial room for development. While the campus has demonstrated excellence in areas like Green Education and Health & Well-Being, the report emphasizes that specific interventions are needed to improve sustainability in other crucial areas including energy efficiency, site design, and material resource management. The institution must prioritize energy efficiency through expanding solar photovoltaic installations and improving HVAC and lighting systems in order to improve the overall efficiency thus paving way for increase in sustainability performance. Rainwater-fed irrigation and smart irrigation with soil moisture sensors can contribute to water conservation. Waste management techniques including composting and biogas for Food waste produced, will lessen dependency on landfills. The heat island effect can also be minimized by site planning enhancements including pervious surfaces, shaded parking, and high-SRI materials. By implementing these measures, Nicmar University has the potential to improve its sustainability rating considerably and set an example

for other academic institutions. The results highlight how crucial it is to continuously assess and modify the campus development in order to attain sustainability. By systematically implementing proposed strategies into practice, the university can strengthen its dedication to environmental stewardship and provide a benchmark for other educational establishments striving to create a more sustainable future. This research paper has provided valuable insights into the performance of IGBC Green Rating of University Campus, but due to lack of information and manpower, certain data was not collected which can be continued further by future prospects pursuing this topic. Future researchers can also explore the topic by comparing the current IGBC performance ratings with other International Green Rating systems like LEED, BREEAM, GRIHA, CSAF and STARS, and provide valuable comparison data and performance ratings with respect to these rating systems.

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CHAPTER 13

Analyzing and Comparing the Urban Sprawl in Tier-2 Cities of India: A GIS-Based Study

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ABSTRACT

Urban sprawl represents the uncontrolled, often unplanned spread of urban areas into rural landscapes, typically characterized by low population density, high car dependency, and inefficient land use. This study employs Geographic Information System (GIS) technology to examine urban expansion patterns in Tier-2 cities across India, focusing on growth drivers, such as migration, industrial development, and socio-economic changes. Using GIS, the research captures the impact of urbanization on land use, infrastructure, and natural resources, providing insights into the spatial dynamics over six decades. The study covers five cities and explores urbanization as cities expand to meet the demands for housing, services, and infrastructure. This research underscores the importance of sustainable urban development, strongly emphasizing social, economic, and environmental aspects, advocating for growth that preserves essential resources. Additionally, the research addresses a gap in urban planning, where strategies largely favor Tier-1 cities, often overlooking Tier-2 cities' needs. By integrating empirical data, the study advocates for informed urban planning that ensures equitable distribution of facilities and promotes sustainable development. Through predictive analysis, it aims to offer insights that can guide policymakers and urban planners in managing urban expansion effectively. This study's findings are expected to refine approaches to tracking and directing Tier-2 city growth, with an emphasis on achieving inclusive, sustainable urbanization that benefits all residents.

Keywords: Urban Sprawl; GIS; Tier-2 Cities; Urbanization; Land Use, Sustainable Development.

1.0 Introduction

The rush to urbanize is a hallmark of the 21st century, and one being witnessed mainly in the developing countries where economic growth, industrialization, and demographic changes are provoking urban expansion on a large scale. Such long and uncontrolled urban development is threatening the very existence of sustainable management systems by governments and planning organizations.

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As of the United Nations (2014), more than half of the world's population live in urban areas, and this figure is set to reach dizzy heights by 2050. By this time, approximately 90 of urban expansion is expected to occur in developing countries, placing immense pressure on infrastructure, resources, and social utilities (United Nations, 2015). Urbanization in the developed world is significantly slower than in some of the developing regions. Urbanization in developed regions is stable and mature, primarily in North America (82%), Latin America (80%), and Europe (73%). Conversely, urbanization in African (40%) and Asian (48%) developing regions occurs at a breathtaking pace, giving rise to a spectrum of problems, often characterized as unbridled or uncontrolled urban expansion (UN, 2014). The Indian definition of an urban area is specific; it should have a minimum population of 5,000, of which 75% or more of the male working population is engaged in non-agricultural activities, and inherently, a minimum population density of 400 persons per sq. km (Census, 2011). Hence, these criteria establish parameters for tracing urban growth and expansion patterns as opposed to areas on their way to becoming urban centers.

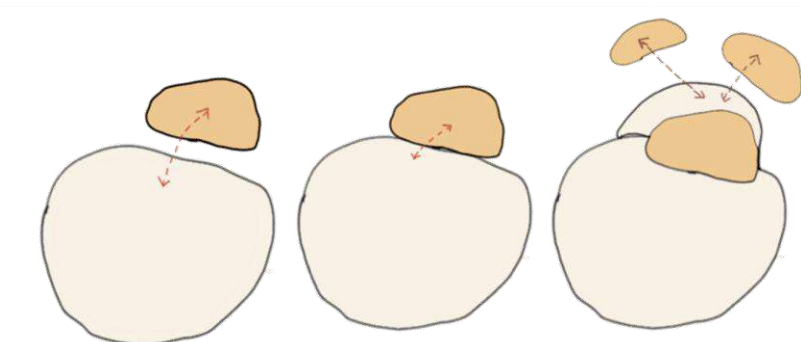
Urban sprawl is a type of spatial development characterized by low density, scattered, and leapfrog growth (Noor NM, 2013). Urban sprawl is generally unplanned urban growth and does not respect zoning laws; it usually leads to patterns of fragmented development. Urban sprawl, by definition, refers to those types of urban expansion that occur beyond the established city limits and generally involve isolated residential, commercial, or industrial zones where infrastructure development begins in an unregulated manner over predominantly rural and agricultural land. Proliferation of urban land-use patterns countering their rural counterparts is a major driving force behind sprawl, including the loss of agricultural land, environmental degradation, and increasing demand for resources (Nejadi, 2011). Sprawl, on the other hand, typically witnesses traffic congestion, inefficient land use, and ecological unfriendliness, in stark contrast with well-behaved and well-planned urbanization. Tier-2 cities like Nashik, Gandhinagar, and Thiruvananthapuram are witnessing massive urban expansion in India. These cities have emerged as economic hubs and are crucial for strengthening the balanced development of a region. Factors triggering the speedy growth of these cities include rising out-migration from rural to urban areas for better employment and living standards and emerging businesses and commercial hubs to attract investments, all at comparatively cheaper land prices than Tier-1 metro cities. Infrastructure improvement and enhanced easily without guidelines and the absence of space infrastructure along various profiles, environmental stress is but a few of the challenges that have visited these Tier-2 cities. The key to holding this rapid growth in check is to manage this growth fairly for a sustainable context.

Geographic Information Systems (GIS) is a powerful technique for analyzing and understanding urban sprawl through spatial analysis of land-use patterns, urban densities, and trends of development over time. It involves superimposing satellite image above census information and land cover information to reflect land-use changes such as the transitions involved in agricultural land to settlements in the urban envelope and maps of city growth

patterns across time. GIS critically assesses the environmental endue unsuitable expansion which accelerates future growth trends through a data-backed approach to policymakers and planners coming up with sustainability strategies for urban planning. Urban planners evaluate spatial dynamics concerning growth, future development trends, and strategies in sustainable urbanism through GIS analysis. In this manner, growth management is realized equitably with minor environmental footprints that are without neglecting the socio-economic rights of burgeoning urban citizenry.

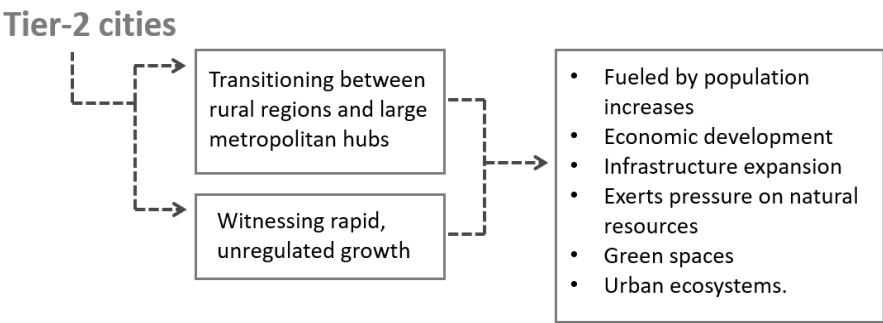
Using GIS-based analyses of Tier-2 cities, this research seeks to provide a complete view of the dynamics of urban sprawl. Important insights for policymakers, urban planners, and developers in formulating balancing acts between urban sprawl and other competing interests such as environmental conservation, infrastructural development, and social equity are provided by this study. As Tier-2 cities evolve, so will their role and importance of planning interventions powered through GIS for continual and sustainable growth and development.

Figure 1: How Cities Expand and Engulf the Neighboring Outgrowths, thus Extending the City’s Boundaries



Source: Urbandesignlab

Figure 2: Tier 2



1.1 Aim

This research utilizes GIS technology to assess urbanization dynamics and the factors driving growth in Tier-2 Indian cities. It examines spatial expansion and its impact on urban development, aiming to improve urban planning and policy formulation in India.

1.2 Objective

- To use GI tools to analyze the spatiotemporal urban growth patterns in selected Tier-2 cities.
- To examine the major socio-economic, infrastructural, and environmental causes of urban sprawl in these cities.
- To estimate the effects of urban sprawl on land use, infrastructure, and natural resources in the study areas.
- To evaluate the rate and growth of urban expansion in various Tier-2 cities and identify region-specific challenges.
- To explore sustainable urban development policies and strategies that can mitigate the problem of urban sprawl.

1.3 Need

Tier two cities in India are changing rapidly with better migration from the rural locales into the urban clusters. However, such rapid urbanization often results in unplanned urban sprawl that puts a lot of pressure on the existing infrastructure, eliminates farmland, and disturbs the ecosystem. To mitigate these situations, adequate urban planning, which is reliant on data, becomes a necessity. This research will analyze urban sprawl patterns using GIS and compare them, which aids in the preparation of better sustainable development and infrastructure planning. It will also be useful to fill in the policy voids as Tier-2 cities are easily neglected on a reasonable basis due to their sizeable assignments, unlike Tier-1 cities. The results will assist in more equitably directed and sustainable urbanization in the short term, cities with a rapid metabolic rate of changes.

1.4 Gap

Most studies and policies focus mainly on Tier-1 cities while very few seek to understand issues related to the rapid urban sprawl of Tier-2 cities. Little information is available concerning their patterns of urban sprawl, the effect on the growth of the city, how the city has been developing as a counter magnet over the decades, or the increase in the existing municipal boundaries over the decades. Further, scanty policies exist to meet these cities' specific needs. This study proposes addressing those gaps with the help of a GIS-based analysis of which city has growth potential as a Tier 1 city and enhance the sustainability of growth in Tier 2 cities.

1.5 Novelty

This research brings novelty by shifting focus to Tier-2 cities, where urban growth is rapidly becoming critical but remains under-researched compared to Tier-1 cities. It addresses the gap by analyzing emerging urban centers and comparing their traditional development plans, often created without the use of GIS. By integrating GIS-based analysis, this study offers a fresh perspective on urban planning in these cities, providing more precise and data-driven insights for managing future growth.

1.6 Motivation

From the perspective of sustainable development, the unplanned, abrupt, and quick growth of cities—particularly in India's Tier-2 cities—is problematic. These cities are expanding quickly due to a lack of gender parity, widespread industrialization, economic growth, and environmental and agricultural land loss. They are also experiencing increased traffic from urbanization, poor basic infrastructure, and other issues. Understanding the patterns and processes of urbanization becomes crucial since these developing urban areas receive far less attention than Tier-1 cities. This effort aims to leverage the GIS capabilities to travel towards the geographical spread and is motivated by the requirement to provide timely responses about how these Tier-2 cities are expanding. Thus, this research will pinpoint present patterns, forecast future expansion, and develop strategies to help policymakers and urban planners control city expansion within their boundaries to prevent urban degradation and encourage constructive social, economic, and environmental development.

1.7 Studied theories

Various theoretical frameworks have shaped urban development and growth by providing insight into spatial order, social dynamics, and economic influences. Theories like those of the Garden City Movement, the Concentric Zone Model, and Multiple Nuclei Model emphasize spatial patterns that affect city expansion, zoning, and other land uses. Community-oriented models like the Theory of Community Development and Right to the City advocate for equitable land inclusive urban growth. Economic theories like Bid Rent Theory and Central Place Theory conceptualize the land value of goods and the distribution of services along urban hierarchies. Furthermore, theories spurred by sociological and behavioral understanding, such as the Theory of Creative Class, Broken Windows, and Drive-in Culture, analyze how prevailing societal trends and behavior in urban areas result in sprawl patterns and infrastructure. It is through an interaction with such a plethora of theories that this research aims to better understand urban sprawl and what can be done about it from the standpoint of sustainable urban planning and development.

2.0 Study Area

Uncontrolled urban growth, commonly resulting in urban sprawl, hurts the ecology, socioeconomic processes, and land use structures. The research explores the process of sprawl in

Tier-2 Indian cities that are rapidly urbanizing, experiencing in-migration, and industrialization through GIS tools and LULC data. The findings seek to promote sustainable urbanization in these new economic centers.

Table 1: Details of Studied Theories

Theory/Model	Category	Focus Area	Key Implications for Urban Sprawl
Garden City Movement	Spatial Model	Planned self-contained cities surrounded by greenbelts.	Promotes controlled urban growth with green space preservation.
The Theory of the City	Urban Development	Explains city formation and spatial organization.	Provides a framework for understanding city expansion and dynamics.
Concentric Zone Model	Spatial Model	Urban growth as a series of concentric rings.	Highlights urban core expansion and land use zoning.
Sector Model	Spatial Model	Urban growth along transportation routes forming sectors.	Emphasizes the role of transport in guiding urban sprawl.
Multiple Nuclei Model	Spatial Model	Cities with multiple centers of activity rather than one central core.	Identifies polycentric urban growth patterns.
Theory of Community Development	Community Theory	Focuses on inclusive development for urban communities.	Promotes sustainable, equitable growth in urban and peri-urban areas.
Right to the City	Community Theory	Advocates for equitable access to urban spaces and resources.	Guides policies for inclusive urbanization.
Range and Threshold	Economic Theory	Explains the minimum population needed to support services.	Affects service distribution and urban land use patterns.
Rank Size Rule	Economic Theory	Describes the distribution of city sizes within a country.	Helps in understanding urban hierarchy and sprawl dynamics.
Bid Rent Theory	Economic Theory	Land value decreases as the distance from the city center increases.	Explains urban land use zoning and density variations.
Central Place Theory	Economic Theory	Explains the spatial arrangement of cities based on market areas.	Supports city planning for service allocation and development.
Theory of Creative Class	Economic/Social	Emphasizes the role of creative professionals in urban growth.	Highlights the impact of creativity and innovation on urban expansion.
Ladder of Citizen Participation	Governance/Community	Explains levels of public involvement in decision-making.	Encourages participatory urban planning and reduces resistance to sprawl policies.
Theory of Broken Windows	Urban Behavior	Suggests that visible signs of disorder encourage further crime and neglect.	Highlights the importance of maintaining urban spaces to reduce social decay.
Theory of Drive-in Culture	Cultural	Explores how automobile dependence shapes urban form.	Explains sprawl due to car-centric infrastructure development.

Source: Urban Design Lab

2.1 Study area selection

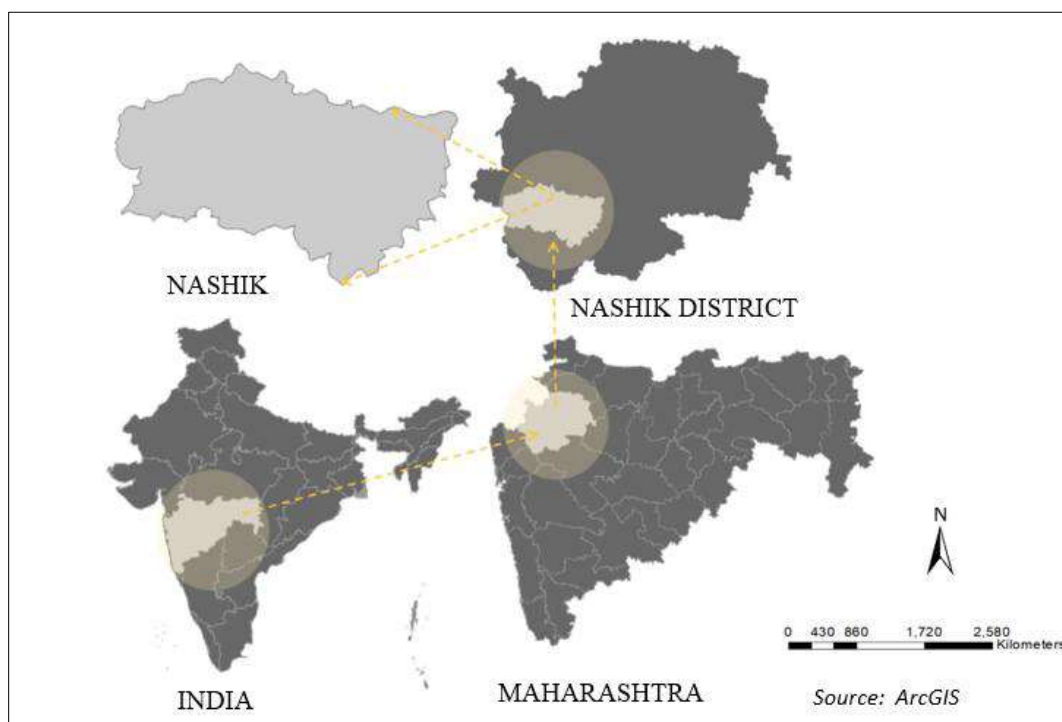
The study area chosen is Class II cities, which are characterized by a population size of 50,000 to 99,999. Three criteria for selection are used: the definition of Class II cities, an extensive study of the population, and the choice of appropriate cities. In Nashik, Maharashtra, the population has increased dramatically over the years. Nashik had a population of 330,000 in 1975, which rose to 886,000 in 1995. In 2015, the population decreased marginally to 782,000 but is expected to grow to 1,767,000 by 2025. Gandhinagar, Gujarat, also had steady population growth. The city was home to a population of 2,050,000 in 1975, and this rose to 4,140,000 by 1995. In 2015, the population was 7,109,000 with a forecasted value of 9,062,000 by 2025. Thiruvananthapuram, Kerala, had a similar pattern of growth. Its population was 550,000 in 1975, increasing to 998,000 in 1995. Its population grew to 2,058,000 in 2015 and is estimated to reach 3,073,000 by 2025. These are patterns of accelerated urbanization and population growth in these major cities over the decades.

2.2 Nashik, Maharashtra

Nashik, in the state of Maharashtra, enjoys a rich history. It was renamed from Gulshanabad in 1734, and Nashik district came into existence formally in 1869. Nashik lies

geographically in the Western Ghats on the Deccan Plateau at an elevation of 700 meters above sea level, with coordinates ranging from 19°35'–20°50' N latitude and 73°16'–74°56' E longitude. The climate of the city measures approximately 25°C, with winter seasons having temperatures almost up to 20°C and summer seasons reaching 38°C, especially in May. Nashik has economic as well as cultural importance as it flows through the Godavari River and is renowned throughout the world as the “Wine Capital of India”, merging classical as well as contemporary elements. Economically, Nashik has earned its status based on the Smart City initiative and acts as a hub of industries related to automobile, engineering, and agricultural manufacturing. The city has good connectivity, located 180 km from Mumbai and Pune, thus making it open for trade and travel. According to the 2011 Census, Nashik had a population of 1.49 million, with a significant 22.3% growth rate, indicating its increasing urban growth and economic opportunities.

Figure 3: Location Map of Nashik, Maharashtra



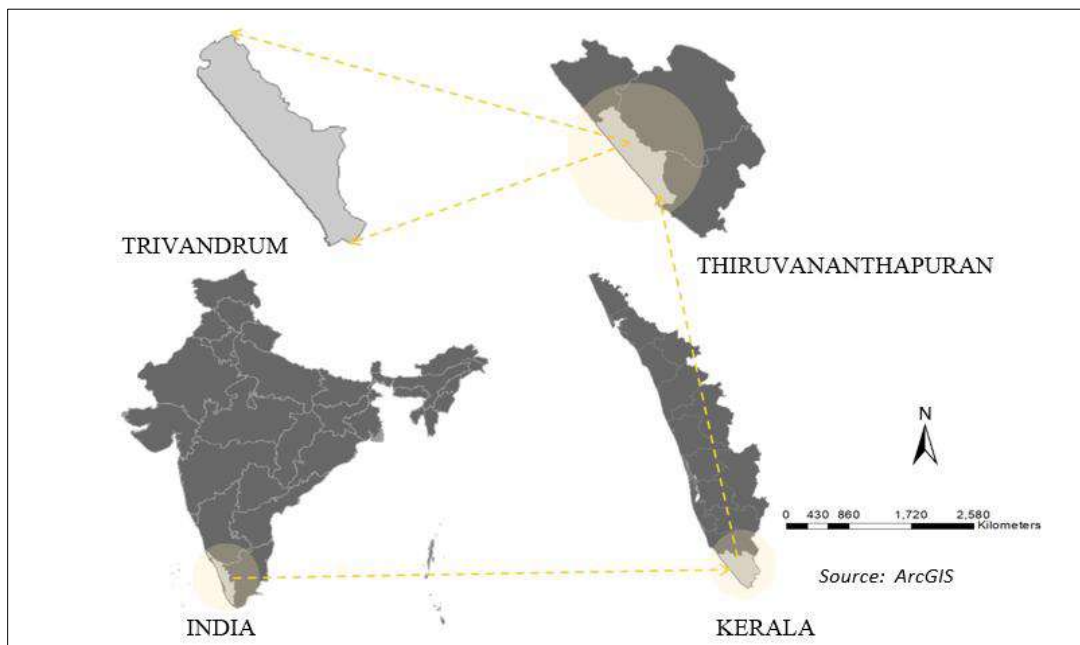
Source: Survey of India

2.3 Thiruvananthapuram, Kerala

Thiruvananthapuram, also in Kerala, has been steeped in history as the capital of Travancore since 1745, founded by Marthanda Varma. The city’s geographical location is

between the Western Ghats and the Arabian Sea and at an altitude of 16 feet above sea level. The climate of the city is of tropical savanna and monsoon type, with maximum and minimum temperatures rising to 34°C and falling to 19°C, respectively. Thiruvananthapuram is important as the capital of Kerala and a major cultural center. It is famous for its beautiful beaches such as Kovalam and Varkala, as well as notable landmarks including the Sree Padmanabhaswamy Temple. The city is economically prosperous through its IT industry, led by Technopark, and its thriving services and tourism sectors. According to the 2011 Census, the population of Thiruvananthapuram was 3.3 million, with a reported 3.25% growth rate, demonstrating consistent growth and urbanization.

Figure 4: Location Map of Thiruvananthapuram, Kerala



Source: Survey of India

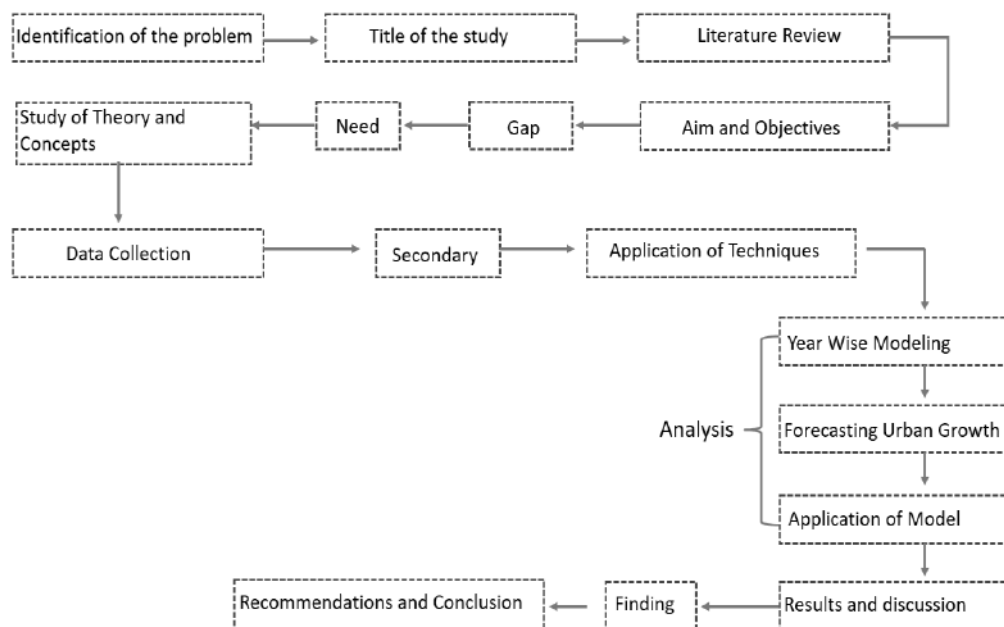
2.4 Gandhinagar, Gujarat

The state capital of Gujarat, Gandhinagar, is a planned city formed in 1960 upon the creation of the state of Gujarat. Mahatma Gandhi-inspired, Gandhinagar is an organized and systematically planned city with large open spaces. In geography, Gandhinagar sits at the shores of the Sabarmati River and is set around 81 meters above mean sea level. The city has a semi-arid climate, with mean temperatures of 42°C for summer and approximately 14°C for winter. Gandhinagar is famous for its importance as Gujarat's administrative capital and contains important landmarks like the Akshardham Temple, Indroda Nature Park, and Sarita Udyan. The

city is economically flourishing as an emerging Information Technology, electronics, and textile hub. The establishment of GIFT City (Gujarat International Finance Tec-City) has also reinforced its position as a financial and business hub. With good connectivity to major cities such as Ahmedabad (only 23 km away) and well-planned road infrastructure, Gandhinagar provides effortless commuting possibilities. According to the 2011 Census, Gandhinagar had a population of 292,000, indicating its well-planned growth and consistent development as a key urban hub

3.0 Methodology

Figure 5: Schematic Representation of Methodology Followed in the Study



4.0 Literature Review

Urban sprawl has become a central theme in urban studies, especially in rapidly developing countries like India, where urban growth often outpaces planning frameworks. The phenomenon is characterized by the unplanned expansion of cities into rural hinterlands, leading to inefficient land use, ecological disruption, and social disparity. Scholars such as Angel (2011) emphasize that urban sprawl is largely driven by increasing demand for residential and commercial space, fueled by population growth and economic expansion. This is particularly true for Tier-2 Indian cities, which are transitioning into key economic hubs amid rising rural-to-

urban migration (Sharma, 2019). Research by Sudhira *et al.* (2004) and Singh (2018) highlights the multifaceted impact of urban sprawl, including the degradation of agricultural land, loss of green cover, stress on water resources, and exacerbation of infrastructure deficits. Socioeconomic consequences such as informal settlements and service inequality in peri-urban areas further illustrate the adverse effects of unmanaged growth. These findings underscore the urgency of adopting tools and frameworks that can better monitor and manage urban expansion.

A notable methodological advancement in the study of urban sprawl is the use of Geographic Information Systems (GIS) and Land Use/Land Cover (LULC) analysis. GIS facilitates spatial and temporal monitoring of urban growth patterns, providing crucial data to assess land-use transitions and predict future expansion. Herold *et al.* (2003) and Jat *et al.* (2008) demonstrated the effectiveness of GIS in capturing urban sprawl in Indian cities like Jaipur, where significant encroachment into agricultural zones was detected. Similarly, studies in cities such as Surat and Indore (Verma, 2020) reveal rapid, uncoordinated expansion, illustrating a pan-Indian pattern in Tier-2 cities.

Further, Bharath *et al.* (2012) stress the relevance of predictive modeling using tools like Cellular Automata (CA) and CA-Markov models, which allow researchers and planners to forecast urban growth by simulating various land-use scenarios based on historical data. These models are especially critical for Tier-2 cities, where formal planning often lags behind ground realities. Thematic reviews of the literature cluster urban sprawl research into four domains: LULC analysis, sprawl measurement through indices like Shannon's entropy, exploration of socioeconomic and environmental drivers, and urban growth modeling. The paper under review aligns well with this framework, integrating LULC analysis with spatial metrics and socio-environmental insights to develop a comprehensive understanding of urban expansion in Tier-2 cities. However, despite this body of work, a significant research gap remains. Most empirical studies and planning initiatives are concentrated on Tier-1 cities, leaving Tier-2 cities under-researched and underrepresented in policy frameworks. This study addresses that gap by employing a comparative GIS-based approach to analyze sprawl in cities like Nashik, Gandhinagar, and Thiruvananthapuram. The novelty lies in examining these mid-sized cities not only as passive growth recipients but as active nodes shaping India's urban future

5.0 Results

After conducting an exhaustive literature review of 1,319 research publications on urban development simulation and management were evaluated both qualitatively and quantitatively; the majority of these studies used the use of geographic information systems (GIS) to analyze changes in land use and land cover (LULC). Of these, 126 research examined LULC data to comprehend urban sprawl, while 98 studies focused on prediction models. With only ten publications, LUCC research lacked compactness. The main focus of 782 papers was the use of AHP in GIS to urban land use planning and suitability evaluations. Using remote

sensing and regional analysis, 41 of these projects addressed urban sprawl without exposing the threat of GIS, demonstrating its significance in planning and preventing urban invasion. Urban sprawl has been a major area of research worldwide, particularly in emerging countries where cities are growing at previously unheard-of speeds. According to (Angel, 2011) the desire for more residential and commercial space, population growth, and economic development are the main causes of urban sprawl. In India, migration from rural to urban regions is a significant element in the fast growth of metropolitan areas, particularly in Tier-2 cities. These cities are changing from being important regional centers to major economic hubs, which is putting a lot of strain on the infrastructure and causing major changes in land use (Sharma, 2019).

Table 2: Paper Studied

Sr. No.	Keywords	Number of Papers
1	Forecast AND Urban growth simulation AND Urban sprawl AND GIS	98
2	GIS AND LU/LC AND Urban Sprawl AND Urbanization	126
3	Growth patterns AND Land Use/Cover Change (LUCC) and GIS AND compactness	10
4	Urban Development AND land suitability AND planning AND urban sprawl AND Land use change AND GIS	262
5	GIS-AHPAND land suitability AND planning AND urban sprawl	782
6	GIS; Land Use/Cover Change (LUCC) AND Regional Comparison AND Remote Sensing AND Urban Sprawl	41

Source: Scopus

The effects of urban expansion on the environment and socioeconomics are widely known. Uncontrolled urban expansion, according to (Sudhira, 2004), has several detrimental effects, including the loss of green space and agricultural land, increased pollution of the air and water, and stress on nearby ecosystems. In addition, the unplanned urbanization of rural regions worsens socioeconomic inequality and upends traditional livelihoods. According to (Singh, 2018) peri-urban informal communities frequently lack access to essential utilities like power, water, and sanitary facilities, making it difficult for local governments to provide enough infrastructure. Land Use and Land Cover (LULC) datasets and Geographic Information Systems (GIS) are widely used to quantify and evaluate urban sprawl. According to (Herold, 2003) GIS-based spatial analysis offers important insights into how cities expand over time. Researchers may follow changes in land cover and quantify urban expansion by classifying diverse land uses, such as residential, commercial, agricultural, and forest regions, using satellite-based LULC data. When (Jat, 2008) used GIS to analyze urban sprawl in Jaipur, India, they discovered that the city has greatly grown into the rural and agricultural areas. Cities like Surat and Indore have shown similar tendencies of unchecked expansion (Verma, 2020). Future urban growth models are increasingly crucial for forecasting sprawl and designing sustainable development

policies. The use of spatial models that forecast future urban growth based on existing population patterns, economic conditions, and land-use regulations is highlighted by (Bharath, 2012), Urban planners in Tier-2 cities, where the infrastructure is frequently ill-prepared to manage increasing urbanization, depend heavily on these models. By taking proactive steps based on GIS-based analysis, sprawl's negative consequences may be lessened, encouraging balanced and sustainable urban growth.

Table 3: Thematic Literature

Theme	Description	Number of Paper
Land Use/Land Cover (LULC) Analysis	Utilizing remote sensing to analyze LULC changes is a foundational tool for understanding urban expansion. Researchers can track spatial changes and urbanization over time by categorizing satellite images into types like built-up areas, vegetation, water bodies, and agricultural land.	12
Measuring Urban Sprawl	Metrics like Shannon's entropy and landscape metrics provide insights into the structure of urban sprawl, helping to assess spatial patterns, fragmentation, and dispersion, which are key to understanding the intensity and extent of sprawl.	58
Drivers and Impacts of Urban Growth	Identifying the key drivers, such as population growth, economic factors, and policy decisions, sheds light on urban sprawl's causes. Recognizing these drivers is essential for managing and mitigating the environmental and societal impacts of rapid urbanization.	12
Urban Growth Modeling and Prediction	Predictive models, such as Cellular Automata (CA)-Markov and regression-based analyses, allow researchers to forecast urban growth patterns. These models utilize historical data and identify growth drivers to anticipate future urban expansion and guide proactive planning.	6

Understanding urban sprawl and its mechanisms is necessary for future city growth management to be successful. Unchecked urban growth into “natural” areas compromises land management, environmental protection, and socioeconomic stability. Once again, because of the speed at which cities are growing, particularly in developing nations, GIS and remote sensing have become essential tools for tracking and analyzing the trends and mechanisms of urban sprawl. The existing research is arranged in four —Land Use/Land Cover (LULC) Analysis, Measuring Urban Sprawl, Drivers and Impacts of Urban Growth, and Urban Growth Modeling and Prediction—each of which focuses on a distinct facet of managing urban sprawl, according to a thematic literature review on the chosen topic. In this research work, urban growth trends in Tier-2 Indian cities are evaluated using both GIS analysis and LULC change over time as a result of social, industrial, and migratory changes. The analysis of five cities—Kochi, Surat, Indore, Nagpur, and Udaipur—reveals evidence of occupancy expansion and its related effects, which include poor management of the growth, resource depletion, environmental degradation,

and social issues. This research can help guide more sustainable and effective city development by highlighting frequently overlooked features of Cities.

6.0 Conclusion

According to the research, unplanned urban sprawl—the ease with which older Tier-2 cities grow—poses a threat to sustainable urbanization during periods of controlled resettlement. For this reason, policy directives must be clear, balanced, and proactive. Growth management and the requirement for equality in urban development depend heavily on the usage of GIS and LULC data. These results urge actions to improve Tier-2 Cities’ sustainability, which is a crucial component of India’s urbanization problem.

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CHAPTER 14

Analyzing and Investigating Pedestrian Safety in Urban Environments

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ABSTRACT

Pedestrian safety is of extreme significance in the case of sustainable urban transport and mobility systems due to the direct effect it poses on the collective health and safety of individuals on the move in urban areas. In selecting a study area with dense pedestrian flow and mixed traffic conditions, the aim was to ensure an intensive analysis encompassing the range of pedestrian problems and traffic management issues. By adopting a structured approach through visual observations, checklist surveys, and gathering user views along specific road sections, the present study delves into the realm of pedestrian road safety. The survey uncovered a string of shared issues, from the inadequate maintenance of pathways and the absence of appropriate traffic-calming features to the inadequate provision of clear signage for pedestrians. Concluding the study, it not only identifies these key problems but also presents actionable solutions that can be a crucial guide for decision-makers, urban planners, and traffic authorities striving for overall road safety and giving paramount importance to pedestrian health within urban environments.

Keywords: Road safety; Road maintenance; Pedestrian safety; Pedestrian movement; Pedestrian crossing.

1.0 Introduction

India is the third largest road network in the world with rapid increase in the vehicles. The increase in the number of vehicles has increased the risk of accidents in the urban and rural areas. A road safety audit is a method of assessing the safety parameters of the road to provide safe and clear movement for the commuters. Road safety audit is a systematic approach for evaluation of safety parameters for new or existing roads to enhance the overall safety of the road.(Jain *et al.*, n.d.) This Road safety audit survey show the utilization of the safety protocol and pedestrians commutation problems.(Rahoof & Singh, 2017) The Road safety audit includes void range of strategies, policies and actions aimed at improving safety of pedestrians in urban environment for the reduction in pedestrians' safety in high volume traffic areas.(Factors Influencing Pedestrian Safety: A Literature Review by A Martin (TRL Limited) PPR241 Published project report, 2006).

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Road Accidents are increasing at a high rate all around the world day by day and one of the major cause for these accidents is ignoring the traffic rules.(Patel *et al.*, 2013) Conducting road safety audits and acting on the results can prevent or reduce the severity Road safety audits are appropriate for all types of road construction, including rehabilitation, upgrade, and new construction.(Galanis *et al.*, 2017)This study presents the analysis of the pedestrian traffic flow for each road segment for the selected road stretch. (Hnoohom *et al.*, 2024) Assessment of pedestrian safety based on the number of accidents is no longer sufficient. Accidents occur rarely and their number is expected to gradually decrease in the coming years, along with the improvement of road safety.(Olszewski *et al.*, 2016)Accidents for pedestrians occurs due to entering of motorized vehicles or while crossing roads are ranked high amongst the dangerous activities for pedestrians.(Gerogiannis & Bode, 2024)The Urban planners and government agency need innovative ideas and methods in improving both traffic operations and commuters safety. This data is helpful in providing solutions for the existing road conditions particularly in urbanized areas where the acquisition of additional land is limited. (Mohammed Almatar *et al.*, 2024)

2.0 Literature Review

The role of road safety audit (RSA) in their identification and relief of safety hazards on road networks already built, especially in India, where most routes can't be easily changed. Studies show that checklists based on pre-set guidelines, such as IRC: SP: 88, are capable of systematically assessing road conditions, such as signs, markings, and pedestrian facilities. The study supports frequent monitoring and enhancement of road safety features to prevent accidents and increase user safety.(Patidar *et al.*, 2020)With respect to Russian road safety the number of studies and methods reflect the improvement for road safety according to European Union Directive 2008/96 guidelines.(Baklanova *et al.*, 2021) The need for road safety analysis (RSA) as a preventive intervention in road safety by identification and prevention of potential road safety issues. It also focuses on the increasing global concern about road safety (Kanuganti *et al.*, 2017) This study helps in concerted safety actions, combining education, enforcement, and engineering interventions to mitigate hazards and enhance pedestrian safety in different settings.(Pampapathi *et al.*, 2023) This study focuses on the various factors affecting pedestrian safety, with the observation that there are significant factors such as age, gender, socio-economic status, and environmental conditions that affect the behaviour of pedestrians. It is imperative to understand how pedestrian conduct relates to safety results, especially concerning crossing approaches and obedience to traffic rules.(Awsarmal *et al.*, 2020)

The document also recognizes the need to disseminate special needs for pedestrians, particularly vulnerable road users such as women, children, older citizens, and people with disabilities, in traffic management and road safety. It brings into context the high risk to which such groups are subjected under road transport systems and demands certain interventions to

enhance their safety. Pedestrian security is a critical element of the overall road safety strategy of the report as a whole.(Report of the committee on road safety and traffic management, 2007) The report indicates that there are poor facilities to help pedestrians' cross highways safely, and hence a high rate of pedestrian deaths. It recommends that in the construction of highways, adequate provision for pedestrian crossings and safety features, such as central verges and railings, be made. Additionally, speed calming features need to be implemented along pedestrian-dense sections to enhance safety.(Koti *et al.*, 2012)

3.0 Problem Statement

The 7.4 km stretch from Radhachowk to University Circle in Pune city is one of the high-risk stretches for road users, with frequent accidents risk and severe pedestrian safety concerns. Despite ongoing efforts to enhance road safety, the area continues to witness high accident risk often resulting in serious injuries or fatalities. One of the major challenges is the lack of safe pedestrian infrastructure like narrow or missing sidewalks, inadequate pedestrian crossings, and the absence of proper traffic measures for the pedestrians. Pedestrians including students, daily commuters, and local residents often have to navigate fast-moving traffic without proper crossings, making their journey unsafe and unpredictable.

4.0 Objectives

- Identify High-Risk Pedestrian Areas
- Identify Obstructions on Pedestrian Pathways
- Assessing Pedestrian Infrastructure for Safer movement
- Evaluating the Effectiveness of Existing Road Safety Measures

5.0 Method and Materials

Road Safety Audit (RSA) is one of the basic and easy ways to assess the road safety parameters for traffic conditions and pedestrians' safety. The data collection for this study starts with the selection of location for the audit and then with data collection by visual imprints for the complete stretch. The checklist was prepared for the analysis and problem identification for pedestrians and collection of feedback from the road users is collected to understand the problem faced by commuting. The flow chart below provides the step-by-step approach for the road safety audit process.

5.1 Site selection

India is home for many new developing cities across its length and breadth; Pune is one of the fast-developing cities in the state of Maharashtra.

Figure 1: Flowchart of Research Methodology

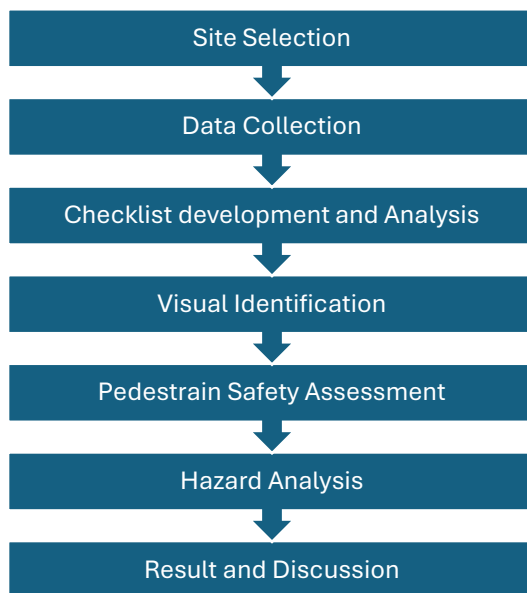
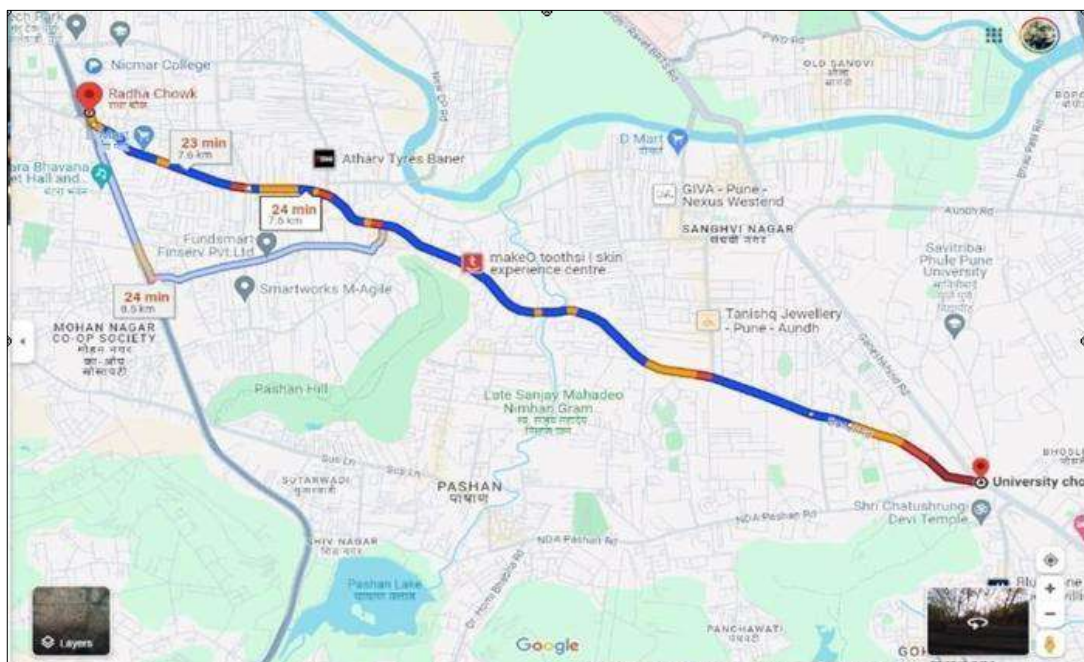


Figure 2: Map of Selected Study Area



As the city is merging in traffic volume, the necessity of Road safety audit has increased in the recent years, and this case focuses on the Road safety audit for pedestrian safety was conducted. In this case a 7.40 km stretch from Radhachowk to University circle was selected for this study. The location was selected based on the high commuter traffic and more intersection. The case study focuses on pedestrian safety over this stretch for improving the accessibility for the users and to reduce the risk. The road safety audit is conducted as per the guidelines of IRC 83:2015 and Sundar committee recommendation.

Figure 3: Checklist for the Pedestrians

SL.NO	ISSUE
1	Is width of the walkway comfortable for movement?
2	Is pedestrian's footpath paved or unpaved?
3	Presence of obstricles on walkway?
4	Is the adequate amount of street lighting facility provided?
5	Is there any encroachment along the walkway?
6	Are the adequate signage's provided for the pedestrians (stop, slowdown, work in progress)?
7	Are the ramps or slopes provide for wheelchairs provided?
8	Is the footpath having tactile paving for visual impaired person?
9	Is the plantation provided for good aesthetic?
10	Are the bollards provided at important locations?
11	Is the cyclist route provided?
12	Is there adequate separation between pedestrians and vehicles?
13	Is the footpath has any type kerb's stone?
14	Is visibility clear line of sight for walkers?
15	Are there resting areas provided for pedestraims?
16	Is the intersection has zebra cross?
17	Is the pedestrian movement easy at the intersection?
18	Visible pedestrian warning signs for drivers?
19	Are the ramps provided at intersection?
20	Stoppage Sign at Intersection?
21	Are handrails and guardrails are provided?
22	Is the pedestrian surface free of gravel and sand, and with good skid resistance?
23	CCTV survey lines is available?
24	Are barriers in place near high-risk zones?
25	Are there signs warning of potential hazards?

The road safety audit is conducted using 3 prolonged strategies.

1. Checklist
2. Visual imprints
3. Commuters feedback.

Checklist: The Checklist is prepared using IRC 103(Koti *et al.*, 2012) guidelines for this road safety audit for pedestrian's safety. This checklist is prepared based on the consideration and requirements that should be provided for the safety of the pedestrians. The checklist includes the walkway parameters like providing bollards, pavers, kerbs and zebra crossings for the pedestrians.

Visual imprints: Visual imprints were collected at every 100m distance to identify the condition of walkways, intersections, and signage's. The visual imprints provide the current condition of the pathways and what are the safety measures provided for the pedestrians for easy and comfortable movement across the road.

Figure 4: Image of Road Conditions



Feedback collection: The pedestrian's data was collected by questionnaire survey over the complete stretch of the study road. The study included various parameters related to the pedestrian walkway condition and utilization. The study shows asymmetric in views and more improvements across the complete stretch.

6.0 Results and Discussion

The data collected on the basis of the strategies for the road safety audit are categorized and are colour coded for easy identification and rectifying the complication faced by the pedestrians on the path. The colours are coded on the basis for availability on basic infrastructure like CCTV, proper maintenance, presence of paved walkways and encroachment.

Table 1: Color for Representation

Green- Sufficient walkway
Yellow – walkway with minor correction without maintenance
Orange – improper maintenance with a breakdown
Red – major correction is required, and a new walkway is to be developed

Table 2: Color Coding Methodology

Sr. No.	Color	Issues	Images
1	Green	CCTV is not provided at the intersection	
2	Yellow	- Plantation is not present at some stretch - Lighting is not installed at some stretch - Required cycle path - Traffic sign boards are missing - No proper ramp is provided at the intersection - Tactile tiles are missing - Kerb stone is missing	
3	Orange	- Signals are not provided at the intersection - People have Encroachment the Pedestrian - No zebra crossing at the intersection - Requires Replacement of bollards	

4	Red	- No parking space for vehicles - The pedestrian walkway is not suitable for comfortable movement - No pedestrian walkway at some stretch - Pedestrian walkway repair	

Figure 5: Color Coded Map along Stretch

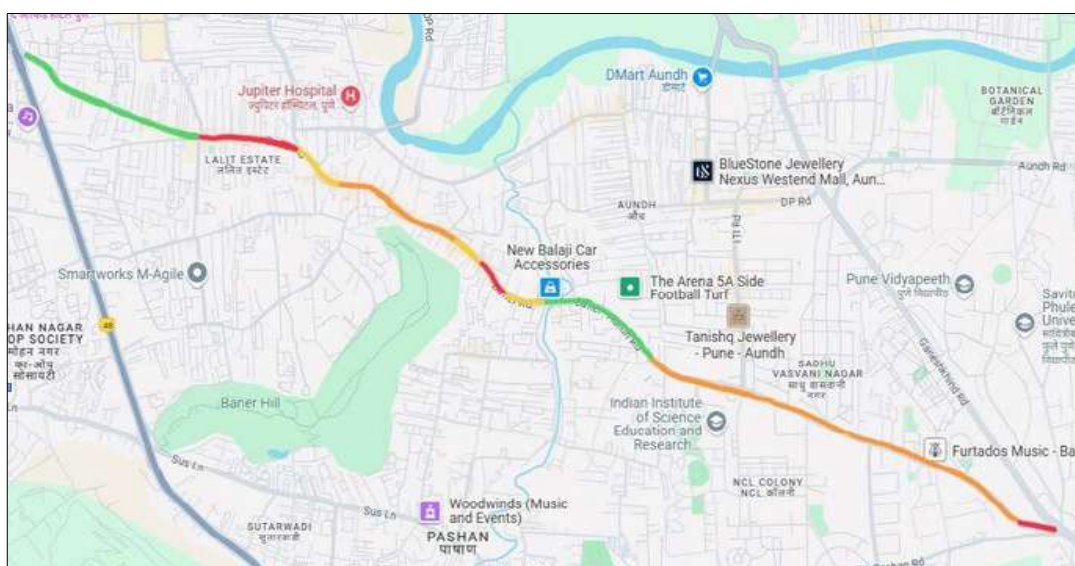


Table 3: Risk Matrix for Pedestrian Safety Issues

Likelihood\ Severity	Low	Medium	High
Low	Tactile tiles missing	Traffic signals at intersections	Missing traffic signboards
Medium	No proper ramp at intersections	No parking space for vehicles	Kerb stone missing
High	Bollards missing	Walkway not comfortable Pedestrian walkway repair Encroachment on the pedestrian walkway.	No pedestrian walkway at some stretches No zebra crossing at intersections

6.1 Hazard analysis

The study shows the identification and analysis of occurrence of hazard along the stretch. Analysis provides the reason for the issues identified for the commuters and end users.

Table 4: Analysis of Hazard Occurrence

Sr. No.	Issue	Likelihood of Occurrence	Severity Level	Reasoning	Remarks / Action Plan
1	Pedestrian walkway repair	High	High	Unmaintained walkways can directly lead to slips, trips, and falls.	Immediate repair to prevent trips & falls.
2	People have encroached on the pedestrian walkway	High	High	Forces pedestrians onto the road, increasing the risk of accidents with vehicles.	Strict enforcement & clearance required.
3	No pedestrian walkway at some stretch	High	High	Pedestrians have no safe area to walk, leading to conflicts with vehicular traffic.	Construct proper walkways to prevent pedestrian-vehicle conflicts.
4	The walkway is not suitable for comfortable movement	Medium	Medium	May result in detours, minor injuries, or discomfort for users.	Upgrade and maintain walkway surface.
5	No parking space for vehicles	Medium	Medium	This leads to illegal parking, narrowing roads, and causing congestion that may result in accidents.	Implement designated parking zones.
6	Requires replacement of bollards	Medium	Medium	Missing or damaged bollards reduce segregation, exposing pedestrians to vehicular threats.	Replace bollards to separate pedestrian and vehicular traffic.
7	Tactile tiles are missing	Low	Low	Primarily affects visually impaired individuals, with less frequent incidents.	Install tactile tiles to improve accessibility for visually impaired pedestrians.
8	Kerb stone is missing	Medium	Medium	Increases the risk of vehicles mounting the pedestrian path.	Replace kerb stones to prevent vehicle intrusion.
9	No zebra crossing at the intersection	High	High	Pedestrians crossing roads without designated zones are highly vulnerable to accidents.	Install marked zebra crossings for pedestrian safety.
10	No proper ramp is provided at the intersection	Medium	Medium	Affects accessibility for wheelchairs, and strollers, but less direct risk of accidents.	Construct ramps for wheelchair and stroller access.
11	Signals are provided at the intersection	Low	Low	Proper signals reduce risks if followed.	Ensure proper maintenance of traffic signals.
12	Traffic signboards are missing	Medium	High	Miscommunication or lack of awareness for drivers may lead to accidents.	Install appropriate road safety signs.
13	Required cycle path	Medium	Medium	Lack of cycling paths can result in conflicts between cyclists and pedestrians or vehicles.	Create separate cycle lanes to avoid conflicts.

7.0 Findings of the Study

The study identifies several critical road safety issues along the 7.4 km stretch from Radha Chowk to University Circle in Pune, highlighting risks for pedestrians, cyclists, and motorists. The findings reveal three major concerns:

- *Pedestrian safety deficiencies:* Lack of proper walkways, encroachments, missing zebra crossings, and inadequate pedestrian infrastructure significantly increase the risk of pedestrian-vehicle conflicts.
- *Traffic management issues:* Missing signboards, improper parking spaces, and absence of dedicated cycle paths lead to congestion and unsafe road conditions.
- *Infrastructure and accessibility gaps:* The absence of ramps, damaged kerb stones, and missing tactile tiles impact accessibility for differently abled pedestrians and the elderly.

8.0 Recommendations

- Pedestrian safety improvements
 - Construct or repair walkways to ensure continuous pedestrian pathways with well-maintained surfaces, reducing the risk of falls.
 - Eliminate encroachments through strict enforcement policies to remove unauthorized vendors and structures obstructing pedestrian movement.
 - Install proper zebra crossings and ramps at intersections to enhance accessibility for wheelchair users and strollers.
 - Improve lighting and CCTV surveillance in poorly lit areas and key intersections for better security and traffic monitoring.
- Traffic management and road infrastructure
 - Provide designated parking areas to prevent illegal parking and road congestion.
 - Replace or install bollards to ensure pedestrian safety by restricting vehicle intrusion into walkways.
 - Develop dedicated cycle lanes to reduce conflicts between cyclists, pedestrians, and vehicles.
 - Install missing traffic signboards and road markings at intersections and key locations to provide clear guidance for pedestrians and drivers.
- Road safety audit and monitoring
 - Implement a periodic road safety audit to identify and rectify hazards proactively.
 - Enhance awareness and enforcement through public awareness campaigns, educating pedestrians and drivers on traffic safety and compliance.
 - Utilize technology such as AI-based video surveillance to monitor pedestrian movement, traffic flow, and accident-prone zones for data-driven decision-making.

9.0 Conclusion

The study highlights the specific areas for more improvement and to improve the maintenance of existing infrastructure. This study reinforces the urgent need for pedestrian-friendly infrastructure to reduce accident rates and improve walkability. By implementing effective safety interventions and regulatory measures, urban roads can become safer for all users. By following this methodology, communities can systematically assess the safety of their streets and sidewalks for pedestrians. This information can then be used to develop plans to make improvements and create safer walking environments for everyone

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CHAPTER 15

Analyzing Construction Delays using Microsoft Project and Earned Value Analysis

Saif Shafi Qureshi¹ and Pravinchandra Gaikwad²

ABSTRACT

Efficient construction project management is the key to ensure projects are completed on time, within budget, to the required quality standards and with proper safety management system. By incorporating proper planning, timely decision making and strategies, construction project managers can ensure efficient project delivery, minimize risks and maximize stakeholder satisfaction. In the present study MSP schedule is prepared for a multistoried building project. Tracking of the project progress against schedules, budgets is carried out in order to identify construction project delays and mitigation measures have been suggested. The study highlights the importance of planning and strategic decision making from the beginning of the project in order to ensure its timely completion. Numerous factors, including team member's qualifications, mandatory approvals from local authority, timely appointment of subcontractor and external environmental concerns are identified as major drivers to project delays. Project delays can be reduced by putting best practices in place for coordination, planning, progress monitoring and frequent meetings. This will result in successful project outcome.

Keywords: Project management; Planning; decision-making; construction delays; preventive measures.

1.0 Introduction

Construction projects often face delays and cost overruns, making it hard to finish them on time and within budget. These problems lead to financial losses, contract disputes, and wasted resources. Common causes of delays include poor site management, weak communication, and inadequate planning. Analyzing past project data helps with cost control and risk management, there is still a need for better methods to identify and manage delays effectively. By tracking project progress and assessing performance metrics, better project planning, communication, monitoring and execution is possible in construction project. In the present study, residential building project (G+8) is analysed for construction delays using tools like Earned Value Analysis (EVA) to find out key performance indicators.

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However, the study has some limitations. It focuses on a single multi-story building, so the findings may not apply to all types of projects. The accuracy of the results depends on site progress data, which may have errors or missing details. External factors like economic changes, policy updates, and unexpected events are not deeply analyzed. The study mainly relies on Microsoft Project and EVA, without considering other project management tools. It also does not include indirect costs or expenses related to interiors.

2.0 Literature Review

The integration of Earned Value Management (EVM) with big data analysis enhances cost control and risk management by utilizing historical project data for accurate forecasting (Li, 2023). Earned Value Analysis (EVA) provides clear performance metrics that significantly improve project management effectiveness in construction projects (Costa *et al.*, 2022). The Earned Value Method (EVM) serves as a crucial tool for managing construction projects by providing a clear picture of project performance through the integration of scope, costs, and schedules (Czemplik, 2014). Additionally, the application of EVM as a performance measurement tool in construction highlights the need for a balance between financial data and actual project progress (Candido *et al.*, 2014).

Effective scheduling plays a vital role in construction project success, with key factors influencing scheduling activities during planning and implementation (Hansen *et al.*, 2023). Delays in construction projects are often caused by poor site management, inefficient communication, and inadequate data management (Radman *et al.*, 2021). Delay analysis methods, such as As Planned vs. As Built, are essential for identifying the causes of delays and determining accountability (Lari *et al.*, 2019). Owner-related causes account for a significant portion of delays in infrastructure projects, underscoring the need for improved planning and decision-making (Elawia *et al.*, 2016).

The oil and gas sector in Oman faces delays due to poor site management and ineffective communication among stakeholders (Ruqaishi *et al.*, 2013). Similarly, in international development projects funded by the Asian Development Bank, understanding cultural and local factors is crucial for improving planning and execution (Ahsan *et al.*, 2010). In the United States and India, organizational culture plays a role in project delays, with a “clan” culture in U.S. firms leading to fewer delays compared to the “market” culture prevalent in Indian firms (Arditi *et al.*, 2016).

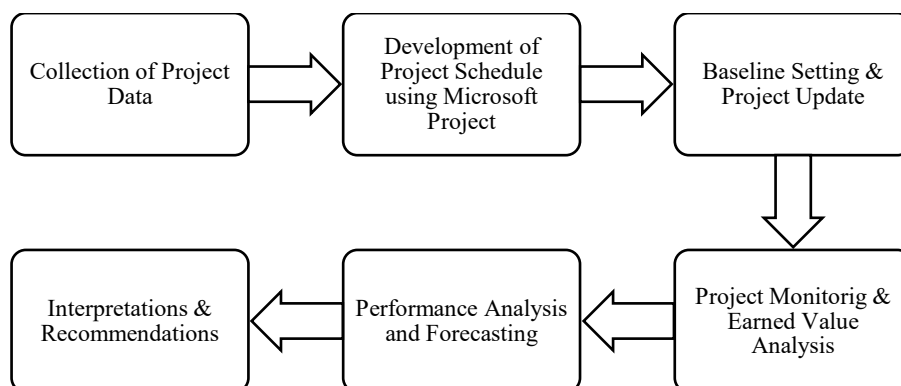
Stakeholder engagement is another critical factor in construction project success, requiring strong relationships among all involved parties (Marzouk *et al.*, 2014). The Technology Acceptance Model (TAM), when integrated with safety management practices, enhances the acceptance of Personal Protective Equipment (PPE) among construction workers (Wong *et al.*, 2021). Moreover, safety performance in construction is influenced by multiple factors, necessitating a hierarchical framework to understand their interactions (Mohammadi *et*

al., 2018). A comprehensive approach to project management is necessary due to the interconnections among various delay factors (Doloi *et al.*, 2012). Identifying these causes is crucial for recommending effective practices to mitigate and avoid project delays (Vacanas *et al.*, 2021).

3.0 Methodology

In the present work a systematic approach is used to analyze construction delays by integrating qualitative and quantitative methods. In this study, a G+8 residential building project from Andheri East, Mumbai is selected, with actual site progress data recorded as 43% completion. A comparative analysis between planned progress and actual progress is recorded. Data collection consist of actual project records, including site progress reports, approved schedules and cost tracking documents. These records are analyzed to evaluate past performance, identify key delay factors and assess their impact on project timelines through comparative analysis between planned and actual progress. To facilitate the analysis, Microsoft Project and Earned Value Analysis (EVA) was utilized. A baseline schedule was developed using Microsoft Project. Deviations were tracked and adjustments were made using Earned Value Analysis (EVA) to assess the efficiency of rescheduling techniques. Key EVA metrics such as Cost Performance Index (CPI) and Schedule Performance Index (SPI) are evaluated to determine efficiency trends and identify potential risks. The data collected is then analyzed to identify key factors contributing to delays and assessing their impact on project timelines and costs. Based on this analysis, practical recommendations are developed to mitigate delays in future construction projects, focusing on improving planning, communication and stakeholder engagement. The findings and recommendations are validated through discussions with industry experts and stakeholders involved in the project, ensuring the relevance and applicability. The methodology adopted in the present work is depicted as shown in Figure 1.

Figure 1: Methodology Flowchart



4.0 Project Monitoring and Earned Value Analysis

Evaluation of project performance is examined in its 43% completion report. Using MS Project, the analysis compares planned and actual progress, identifies delays and evaluates resource use.

4.1 Project schedule overview

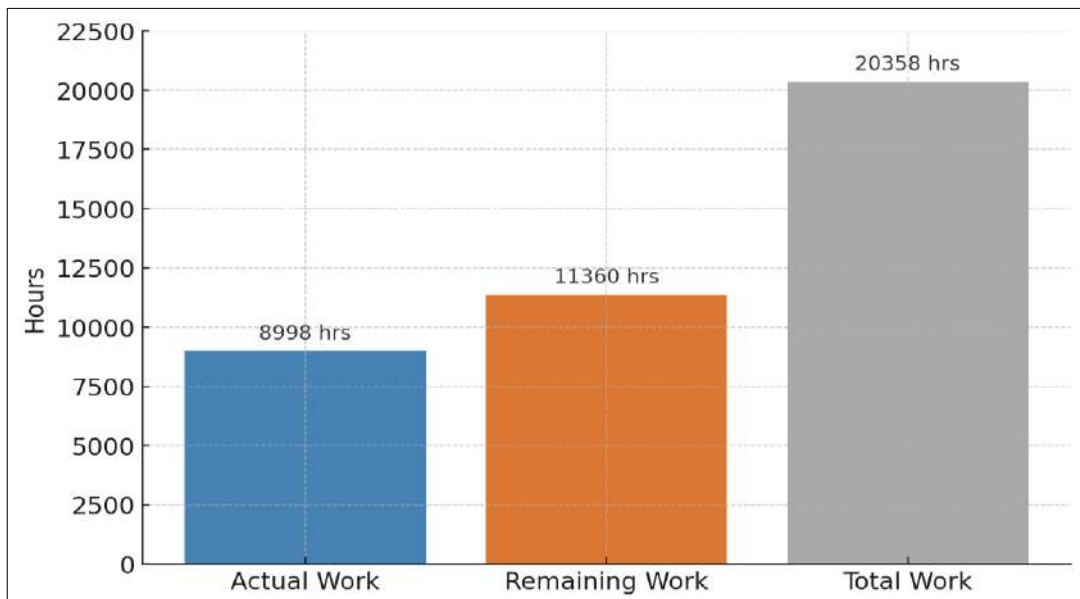
Microsoft Project Software was utilized to establish a baseline schedule and track actual progress. Key scheduling parameters, including baseline start and finish dates, scheduled start and finish and the current percentage of project completion, were analyzed to assess project performance. Table 1 compares planned and actual timelines, offering insights into schedule adherence.

Table 1: Project Schedule Overview

Baseline Start	Baseline Finish	Scheduled Start	Forecasted Finish	% Complete
Fri 01-12-23	Fri 15-11-24	Fri 01-12-23	Tue 10-12-24	43%

To assess the project's current status, a performance evaluation was conducted. The figure below illustrates the comparison between actual work completed, remaining work and the total planned work. This visualization helps in understanding the progress made and the pending work hours as shown in Figure 2.

Figure 2: Project Work Performance Chart



As observed in Figure 2, out of the total planned 20,358 hours, only 8,998 hours of actual work have been completed, leaving a remaining work balance of 11,360 hours. This indicates that significant efforts are still required to meet the project deadline.

4.2 Delay analysis

The following Table 2 provides a detailed breakdown of delays encountered in individual construction activities. It compares baseline durations with actual progress to quantify the extent of delays in early start or early finish phases.

Table 2: Analysing Delay for Individual Activities

Sr. No.	Task Name	Baseline Duration	Updated Duration	Delay in Early Start of activity	Delay in Early Finish of the activity	Cumulative Delay
	G+8 Residential Building	294 days	315 days			
	Sub Structure	110 days	127 days			
1	General	110 days	127 days			0
2	Surveying & Layout	2 days	2 days			0
3	Pilling	60 days	73 days	3	13	16
4	Excavation	4 days	5 days		1	17
5	Pile Caps	7 days	7 days			17
6	Column upto Plinth Level	13 days	13 days			17
7	Plinth Level Beam and Slab	24 days	24 days			17
	Super Structure	184 days	188 days			
	Ground Floor	20 days	24 days			
	Ground Floor Column	7 days	11 days			
8	Reinforcement	3 days	3 days			17
9	Formwork	2 days	4 days		2	19
10	Concrete Pouring	1 day	1 day	2		21
11	Deshuttering	1 day	1 day	1		22

4.3 Cost variance analysis of individual activities

To evaluate the project's financial efficiency, cost variance was analyzed for each activity. Cost variance analysis of individual activities helps to compare the planned and actual costs for each task in a project. It highlights cost deviations, enabling better budget control and decision-making during further execution of the project.

The Cost Variance Analysis in Table 3 highlights a total project cost overrun of ₹352,822.50, primarily due to increased expenses in superstructure (₹241,095.00), slab construction (₹136,495.00) and reinforcement (₹60,572.50).

Table 3: Analysing Cost Variance of Individual Construction Activities

	Task Name	Total Cost	Baseline Cost	Actual Cost	Cost Variance
	G+8 Residential Building	₹ 11,105,522.5	₹ 10,752,700.0	₹ 4,301,465.00	₹ 352,822.50
	Sub Structure	₹ 3,913,517.50	₹ 3,319,600.00	₹ 3,913,517.50	₹ 593,917.50
1	General	₹ 3,913,517.50	₹ 3,319,600.00	₹ 3,913,517.50	₹ 593,917.50
2	Surveying & Layout	₹ 7,800.00	₹ 7,800.00	₹ 7,800.00	0.00
3	Pilling	₹ 2,084,062.50	₹ 1,710,000.00	₹ 2,084,062.50	₹ 374,062.50
4	Excavation	₹ 47,662.50	₹ 37,200.00	₹ 47,662.50	₹ 10,462.50
5	Pile Caps	₹ 203,062.50	₹ 199,500.00	₹ 203,062.50	₹ 3,562.50
6	Column up to Plinth Level	₹ 560,935.00	₹ 491,600.00	₹ 560,935.00	₹ 69,335.00
7	Plinth Level Slab	₹ 1,009,995.00	₹ 873,500.00	₹ 1,009,995.00	₹ 136,495.00
	Super Structure	₹ 7,192,005.00	₹ 7,433,100.00	₹ 387,947.50	₹ 241,095.00-
	Ground Floor	₹ 860,847.50	₹ 807,300.00	₹ 387,947.50	53,547.50
	Ground Floor Column	₹ 387,947.50	₹ 300,300.00	₹ 387,947.50	87,647.50
8	Reinforcement	₹ 193,472.50	₹ 132,900.00	₹ 193,472.50	₹ 60,572.50
9	Formwork	₹ 16,000.00	₹ 8,000.00	₹ 16,000.00	₹ 8,000.00
10	Concrete Pouring	₹ 175,100.00	₹ 156,400.00	₹ 175,100.00	₹ 18,700.00
11	Deshuttering	₹ 3,375.00	₹ 3,000.00	₹ 3,375.00	₹ 375.00

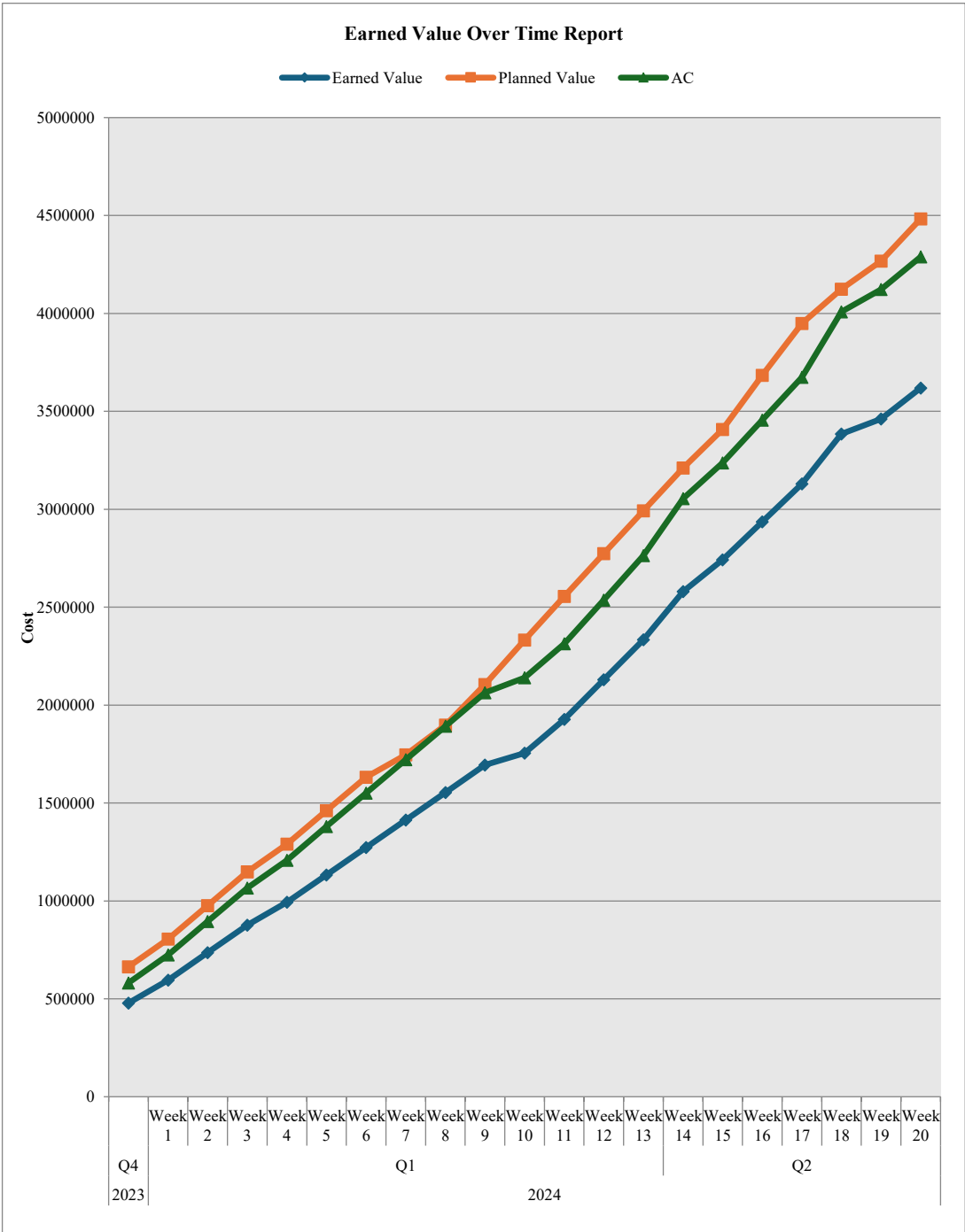
4.4 Labor cost variance analysis

Labor cost variance analysis helps to track differences between estimated and actual labor costs in a project. It identifies cost overruns or savings, allowing better budget control and resource management.

Table 4: Cost Variance Analysis of Labor Expenses

Name	Cost	Baseline Cost	Cost Variance
Site Engineer	₹ 180,937.50	₹ 201,000.00	-₹ 20,062.50
Supervisor	₹ 119,500.00	₹ 118,000.00	₹ 1,500.00
Head Mason	₹ 45,100.00	₹ 46,400.00	-₹ 1,300.00
Mason	₹ 32,025.00	₹ 35,400.00	-₹ 3,375.00
Helper	₹ 244,687.50	₹ 252,000.00	-₹ 7,312.50
carpenter	₹ 343,125.00	₹ 336,000.00	₹ 7,125.00
Mixture with operator	₹ 135,937.50	₹ 140,000.00	-₹ 4,062.50
Vibrator with operator	₹ 81,562.50	₹ 84,000.00	-₹ 2,437.50
Bar Bender	₹ 154,200.00	₹ 174,400.00	-₹ 20,200.00
Helper (Bar Bender)	₹ 96,375.00	₹ 109,000.00	-₹ 12,625.00
Excavator	₹ 34,850.00	₹ 27,200.00	₹ 7,650.00
Piling	₹ 2,287,125.00	₹ 1,909,500.00	₹ 377,625.00

Figure 3: Earned Value Over Time Report



The analysis of labor cost variances in Table 4 presents a cost overrun in several categories. Significant overruns are observed in Piling (₹377,625), Excavator (₹7,650) and Carpenter (₹7,125), while cost savings (underruns) are seen in Bar Bender (₹20,200) and Vibrator with Operator (₹2,437.50).

4.5 Earned value analysis over time

Earned Value Analysis (EVA) is a key project management tool used to assess project performance over time by comparing planned value, earned value and actual cost. The following Figure 3 and Table 5 provide a detailed insight into the project's financial progress, highlighting deviations and trends in cost and schedule performance.

Table 5: Earned Value Data Over Time

Year	Quarter	Week	Earned Value	Planned Value	AC
2023	Q4	Week 48	₹ 7800	₹ 7800	₹ 7800
		Week 49	₹ 80876.92308	₹ 178800	₹ 96862.5
		Week 50	₹ 221184.6154	₹ 349800	₹ 267862.5
		Week 51	₹ 361492.3077	₹ 520800	₹ 438862.5
		Week 52	₹ 478415.3846	₹ 663300	₹ 581362.5
2024	Q1	Week 1	₹ 595338.4615	₹ 805800	₹ 723862.5
		Week 2	₹ 735646.1538	₹ 976800	₹ 894862.5
		Week 3	₹ 875953.8462	₹ 1147800	₹ 1065862.5
		Week 4	₹ 992876.9231	₹ 1290300	₹ 1208362.5
		Week 5	₹ 1133184.615	₹ 1461300	₹ 1379362.5
		Week 6	₹ 1273492.308	₹ 1632300	₹ 1550362.5
		Week 7	₹ 1413800	₹ 1745700	₹ 1721362.5
		Week 8	₹ 1554107.692	₹ 1897500	₹ 1892362.5
		Week 9	₹ 1694415.385	₹ 2105761.538	₹ 2063362.5
		Week 10	₹ 1755000	₹ 2332653.846	₹ 2139525
		Week 11	₹ 1926500	₹ 2555287.5	₹ 2314087.5
		Week 12	₹ 2129328.349	₹ 2773662.5	₹ 2536391.346
		Week 13	₹ 2334005.44	₹ 2992037.5	₹ 2763283.654
	Q2	Week 14	₹ 2579561.077	₹ 3210412.5	₹ 3054065.563
		Week 15	₹ 2741332.08	₹ 3408200	₹ 3236542.003
		Week 16	₹ 2935457.283	₹ 3684180	₹ 3455513.73
		Week 17	₹ 3129582.486	₹ 3949300	₹ 3674485.458
		Week 18	₹ 3385017.03	₹ 4123900	₹ 4007655
		Week 19	₹ 3460500	₹ 4267800	₹ 4122990
		Week 20	₹ 3619566.667	₹ 4483445	₹ 4289190
Grand Total			₹ 3619566.667	₹ 4483445	₹ 4289190

Figure 3 presents three different S-curves that synthesize the analysis using the Earned Value Management (EVM) approach. The Actual Cost (AC) mostly follows the Earned Value (EV) but exceeds it at several points, indicating cost overruns. The Planned Value (PV) remains higher than EV for most of the project, suggesting slower-than-expected progress. This results in an overall CPI slightly below 1, indicating a cost overrun and an SPI below 1, confirming schedule delays. Figure 3 shows trends of Earned Value, Planned Value and Actual Cost over time. Table 5 presents weekly Earned Value (EV), Planned Value (PV) and Actual Cost (AC) data over multiple weeks, providing insight into the project's financial and schedule performance. This data corresponds to the trends illustrated in Figure 3, where the Earned Value Management (EVM) approach is used to track project progress.

5.0 Performance Analysis and Forecasting

Performance analysis evaluates project progress using key metrics like CPI and SPI, ensuring cost and schedule adherence. Forecasting predicts final costs and completion time through techniques like EAC and ETC. Together, they help with proactive decision-making and risk mitigation for successful project completion.

5.1 Earned value metrics and cost variance analysis

An analysis of key earned value metrics, including Total Cost, Budgeted Cost of Work Scheduled (BCWS), Actual Cost of Work Performed (ACWP) and Budgeted Cost of Work Performed (BCWP) is carried out. These values help to assess project performance in terms of cost and schedule adherence.

Figure 4: Earned Value Performance Analysis

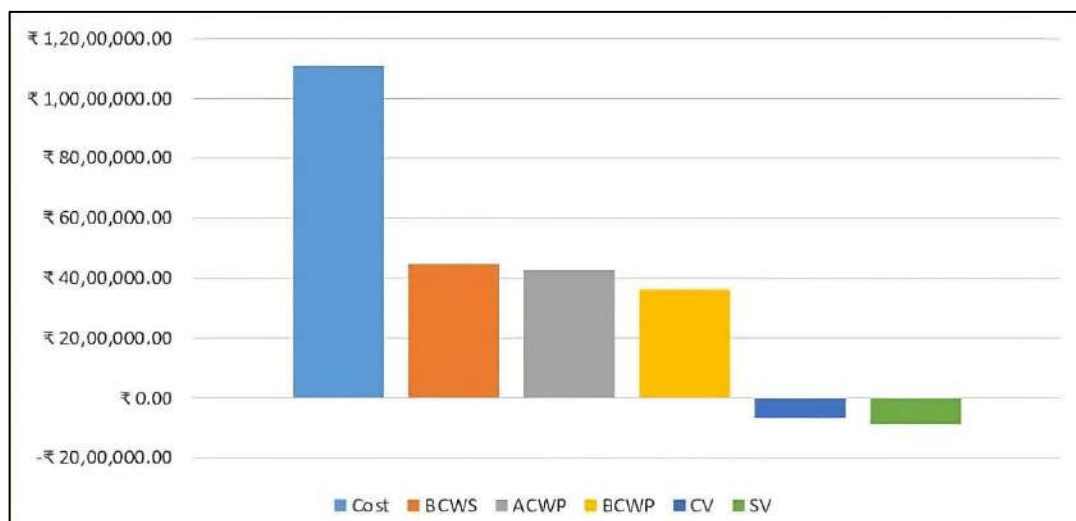


Figure 4 illustrates the Earned Value Performance Analysis, visually representing key project performance indicators. Table 6 provides the corresponding numerical values, including Total Cost, Budgeted Cost of Work Scheduled (BCWS), Actual Cost of Work Performed (ACWP) and Budgeted Cost of Work Performed (BCWP). Additionally, it includes Cost Variance (CV) and Schedule Variance (SV).

Table 6: Earned Value Performance Metrics

Cost	BCWS	ACWP	BCWP	CV	SV
₹1,10,93,622	₹44,83,445	₹42,89,190	₹36,19,525	-₹6,69,665	-₹8,63,920

According to Table 6 the Cost Variance (CV) is ₹6,69,665, indicating an over-expenditure compared to the work performed. Similarly, the Schedule Variance (SV) is ₹8,63,920, showing a lag in progress relative to the planned schedule. These deviations suggest potential budget overruns and delays, requiring corrective actions for project control.

5.2 Earned value performance metrics and indicators

Table 7 presents key Earned Value performance metrics calculated based on project cost and schedule data. These values, derived using standard EVM formulas, provide insights into cost and schedule variances, efficiency indices and future performance expectations.

Table 7: Earned Value Performance Indicators

Metric	Formula	Calculated Value
Cost Variance (CV)	BCWP – ACWP	- ₹ 669,665.00
Cost Variance % (CV%)	$(CV / BCWP) \times 100$	-18.50%
Schedule Variance (SV)	BCWP – BCWS	- ₹ 863,920.00
Schedule Variance % (SV%)	$(SV / BCWS) \times 100$	-19.27%
Cost Performance Index (CPI)	BCWP / ACWP	0.84
Schedule Performance Index (SPI)	BCWP / BCWS	0.81
Estimate at Completion (EAC)	$EAC = BAC / CPI$	₹1,31,48,457
Estimate to Complete (ETC)	$ETC = EAC - AC$	₹88,59,267
Variance at Completion (VAC)	$BAC - EAC$	- ₹ 1,989,421.14
To-Complete Performance Index (TCPI)	$(BAC - BCWP) / (EAC - ACWP)$	1.1
Delay in project	Scheduled Finish - Baseline Finish	ays

6.0 Interpretation

1. A negative cost variance indicates that the project is over budget. The project has spent 19% more than the planned budget at this stage.

2. A negative schedule variance signifies that the project is behind schedule. The work completed so far is 19% less than planned, indicating delays.
3. Since CPI is less than 1, the project is not cost-efficient. A CPI of 0.84 means that for every ₹1 spent, only ₹0.84 worth of work has been completed, indicating cost overruns.
4. Since SPI is below 1, the project is progressing slower than planned. An SPI of 0.81 means that the project is achieving only 81% of the scheduled work at this stage.
5. If the current cost inefficiency continues, the total project cost is expected to be ₹1,31,48,457, which is ₹20,54,835 over budget.
6. To complete the remaining work, an additional ₹88,59,267 is required.
7. The project is expected to exceed its initial budget by ₹1,989,421.14, showing a significant budget overrun.
8. A TCPI value above 1 indicates that the remaining work must be executed more efficiently than the current performance to stay within the budget. The project team needs to improve cost control to meet the planned budget.
9. The project is projected to cost ₹12,742,121.14 at completion, exceeding the original budget estimate. This highlights the need for cost control measures to mitigate overruns.
10. The project has a delay of 25 days compared to the baseline schedule, indicating that corrective measures should be taken to bring the project back on track.

7.0 Causes of Delay

Delays in construction projects are common and can result from multiple factors, affecting timelines, costs, and overall project efficiency. Proper planning and proactive management are essential to minimize disruptions and ensure smooth execution. The key delays identified in this project include:

1. *Inadequate Planning and Scheduling:* Poor scheduling, unrealistic deadlines, and lack of backup plans can disrupt project execution. Inaccurate time estimates for tasks often lead to delays and cost overruns.
2. *Delays in Approvals & Decision-Making:* Construction projects often require permits, design approvals, and regulatory clearances. Delays in approvals or sudden rule changes can significantly slow down the project.
3. *Resource Management Issues:* Shortage of skilled workers, lack of coordination between suppliers and site managers, delays in material delivery, and poor subcontractor management can slow down the project.
4. *Weak Coordination and Communication Among Teams:* When project stakeholders are not aligned and responsibilities are unclear, misunderstandings can arise, delaying decision-making and execution. Poor collaboration between engineers, contractors, and consultants can result in errors, rework, and missed deadlines.
5. *Unpredictable External Factors:* Changes in weather, site conditions, and material costs can disrupt construction work. Factors such as ground conditions, project location, and

regulatory requirements further impact progress, leading to potential delays and cost increases.

8.0 Conclusions

This study evaluates the performance of a G+8 residential construction project using Microsoft Project and Earned Value Analysis (EVA). The analysis reveals that the project is currently 25 days behind schedule and has exceeded its planned budget by ₹1,989,421, highlighting inefficiencies in both time and cost management. At 43% completion, performance metrics indicate the following:

- The Cost Performance Index (CPI) of 0.84 indicates a 16% cost overrun, meaning only 84% of the value is realized for every ₹1 spent.
- The Schedule Performance Index (SPI) of 0.81 shows the project is progressing at 81% of the planned rate, resulting in a 19% delay.
- The Estimate at Completion (EAC) is ₹1,31,48,457, which is 18.5% over the initial budget, amounting to an overrun of ₹20,54,835 if current inefficiencies continue.
- The To-Complete Performance Index (TCPI) of 1.1 means the remaining work must be done 10% more efficiently to stay within budget.
- Given these findings, immediate corrective actions are necessary to control costs, improve efficiency, and reduce further delays.
- Regular progress tracking, resource optimization, and early risk mitigation strategies will help realign the project with its planned objectives and ensure successful completion.

9.0 Recommendations for Reducing Construction Delays

To ensure timely project completion and minimize disruptions, the following practices should be followed:

1. *Detailed Planning and Scheduling:* A well-structured project timeline with realistic deadlines helps prevent delays. Including buffer time for unexpected issues ensures flexibility.
2. *Early Permit Approvals:* Securing all necessary approvals from local authorities in the early stages avoids unnecessary stoppages during construction.
3. *Proper Resource Allocation:* Ensuring the availability of labor, materials, and equipment at the right time helps maintain steady progress.
4. *Clear Communication and Coordination:* Regular site meetings and clear instructions among team members, subcontractors, and suppliers improve efficiency and reduce misunderstandings.
5. *Ongoing Progress Tracking:* Monitoring the project through periodic reviews helps identify potential delays early, allowing for corrective actions.

6. *Risk Management Strategies*: Identifying potential risks, such as weather disruptions or material shortages, and preparing contingency plans can help mitigate delays.
7. *Workforce Skill Development*: Providing training for workers and supervisors ensures that tasks are completed correctly and efficiently.
8. *Use of Technology*: Implementing project management tools for scheduling, documentation, and communication can improve overall efficiency.

By adopting these common construction management practices, projects can be completed on time, within budget, and with minimal disruptions.

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CHAPTER 16

Application of Lean Tools in Precast Manufacturing

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ABSTRACT

To meet the fast-paced demand for quicker, cheaper, and green solutions, the construction industry is undergoing rapid transformation. There are several advantages of the precast concrete construction method that includes improved quality, increased durability, and lower construction time. However, its complex manufacturing process requires major resources and coordination to optimize and reduce waste. Lean manufacturing, known for its reduced waste and improved workflows, is useful for these obstacles. The primary objective of this research paper is to identify the waste generated in the precast industry and to explore how lean tools can be applied to increase the efficiency in workflow, reduce waste, and enhance the delivery process in the precast industry. This research paper maps the entire process of the precast manufacturing to identify the non-value-added activities and optimize them. It also helps in identifying the types & sources of waste and develop a framework to enhance the productivity at site. The research methodology includes detailed literature review, live case study, empirical data collection, waste analysis, implementation of lean tools, and a thorough evaluation of results. Through site visits & interviews, it captures the current production inefficiencies & explores how lean principle & tools can be applied. Through the site visit observations, it was observed that the entire process could be optimized using the value stream mapping technique to optimize and eliminate non-value added but necessary & non-value-added activities. Two tools TAKT & KANBAN are analysed & are used to minimize the waste & increase the efficiency. The study concludes with recommendations for continuous improvement, to meet the growing demand for precast elements.

Keywords: Lean tools; Precast manufacturing; Waste reduction; KANBAN; Takt; Value stream mapping.

1.0 Introduction

1.1 Background

The construction industry has evolved significantly, driven by the need for faster,

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cost-effective, and sustainable building methods. One major innovation is precast concrete, where concrete elements are manufactured in a controlled factory environment and later assembled on-site. This approach improves quality, speeds up construction, and enhances durability. However, precast manufacturing remains complex, requiring careful coordination, efficient resource use, and strict quality control. Challenges such as material waste, project delays, and logistical inefficiencies can impact costs and timelines, especially in large projects. Poor coordination between factories and on-site teams often leads to further setbacks. To address these issues, Lean Construction offers a practical solution by reducing waste, optimizing resources, and improving workflow efficiency.

Originally developed in the automotive industry, Lean principles focus on eliminating unnecessary processes, improving coordination, and fostering continuous improvement. When applied to precast manufacturing, Lean methods help streamline operations, minimize delays, and reduce waste, making production more efficient and cost-effective. Techniques such as better inventory management, workflow optimization, and improved scheduling can significantly enhance productivity. By integrating Lean principles with precast manufacturing, companies can deliver high-quality products faster and at lower costs, meeting the growing demands of urbanization and infrastructure development. This study explores how Lean strategies can transform precast manufacturing, creating a more efficient and sustainable construction process.

1.2 Research problem

This research examines inefficiencies in precast manufacturing and explores how Lean tools can reduce waste, improve production flow, and enhance project delivery. Key issues include excess inventory, delays in production and transport, defects causing rework, and installation time constraints. Lean methods like VSM, Takt Time, and Kanban offer solutions.

1.3 Research objective

This research aims to identify waste in precast manufacturing and explore how Lean tools can improve efficiency and delivery. It focuses on pinpointing key waste sources, assessing Lean methods like VSM, Takt Time, and Kanban, and developing a framework to boost productivity in precast production and installation.

2.0 Proposed Methodology

This study uses a mixed-method approach, combining literature review, case study, and empirical data collection to assess the impact of lean tools in precast manufacturing. A case study at a precast factory in Maharashtra was conducted, focusing on workflow inefficiencies and lean implementation.

2.1 Data collection

2.1.1 Literature review

A detailed review of lean principles, waste elimination, and process optimization in construction was conducted. Key lean tools—VSM, Takt Time, and Kanban—were analyzed for their applicability in precast workflows.

2.1.2 Production time observations

Direct observations and historical production data were collected to assess current inefficiencies.

Production Monitoring: Recorded cycle times for precast elements.

Interviews: Discussions with plant managers, engineers, and workers identified delays, rework causes, and customer demand trends.

2.2 Lean tool implementation

2.2.1 Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is a lean management tool used to visualize and analyse the flow of materials, information, and processes required to deliver a product or service. It helps identify inefficiencies, waste, and areas for improvement, making it particularly useful in construction management and strategic planning.

Key elements of VSM are – Customer requirements, Process steps, Material flow, Information flow, Lead time, Cycle time, Value added and non-value-added activities. In precast manufacturing a Current State Map identified non-value-added activities affecting production flow. After optimization, a Future State Map reduced lead time by 33%, enhancing process efficiency.

2.2.2 Takt time

The Takt System is a lean production tool that aligns the production pace with customer demand. In precast manufacturing, the use of the Takt system helps in setting a steady rhythm or “takt time” for production processes, ensuring that each production stage is synchronized with the overall workflow. *Takt time formula:*

$$\text{Takt Time} = \text{Available Working Time} / \text{Customer Demand}$$

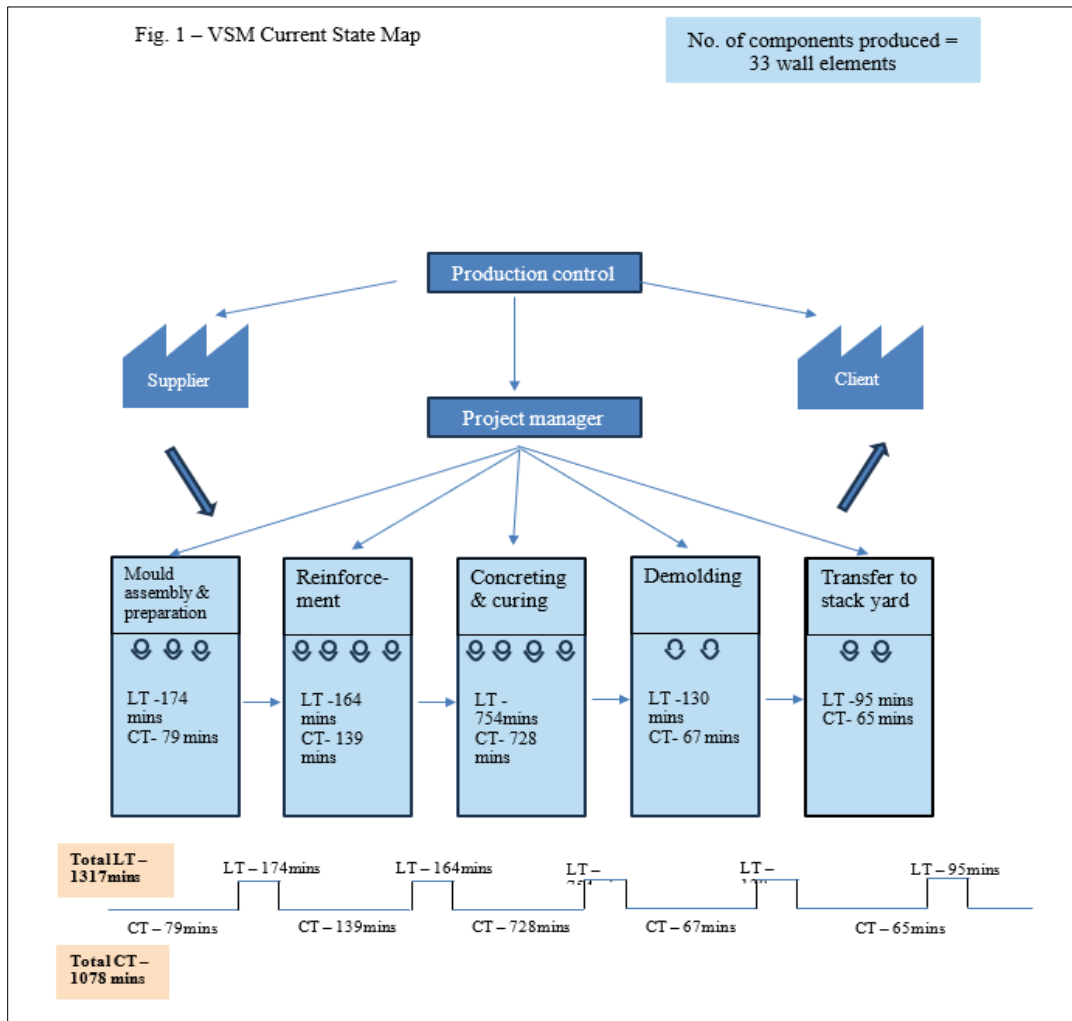
In precast manufacturing, Takt Time was calculated based on customer demand and available production hours. Adjustments like reducing handling time, automation in reinforcement bending, and optimized curing methods helped align production pace.

2.2.3 Kanban

The Kanban System is another lean tool that is utilized to manage the inventory of precast materials and to ensure a continuous, uninterrupted flow of production. Kanban operates

on a pull system, where production is driven by real-time demand rather than forecasted projections, thus avoiding overproduction and excess inventory. In precast manufacturing, Kanban streamlined inventory management and communication, reducing waste and delays through a pull-based system that prevented overproduction and shortages.

Figure 1: VSM Current State Map



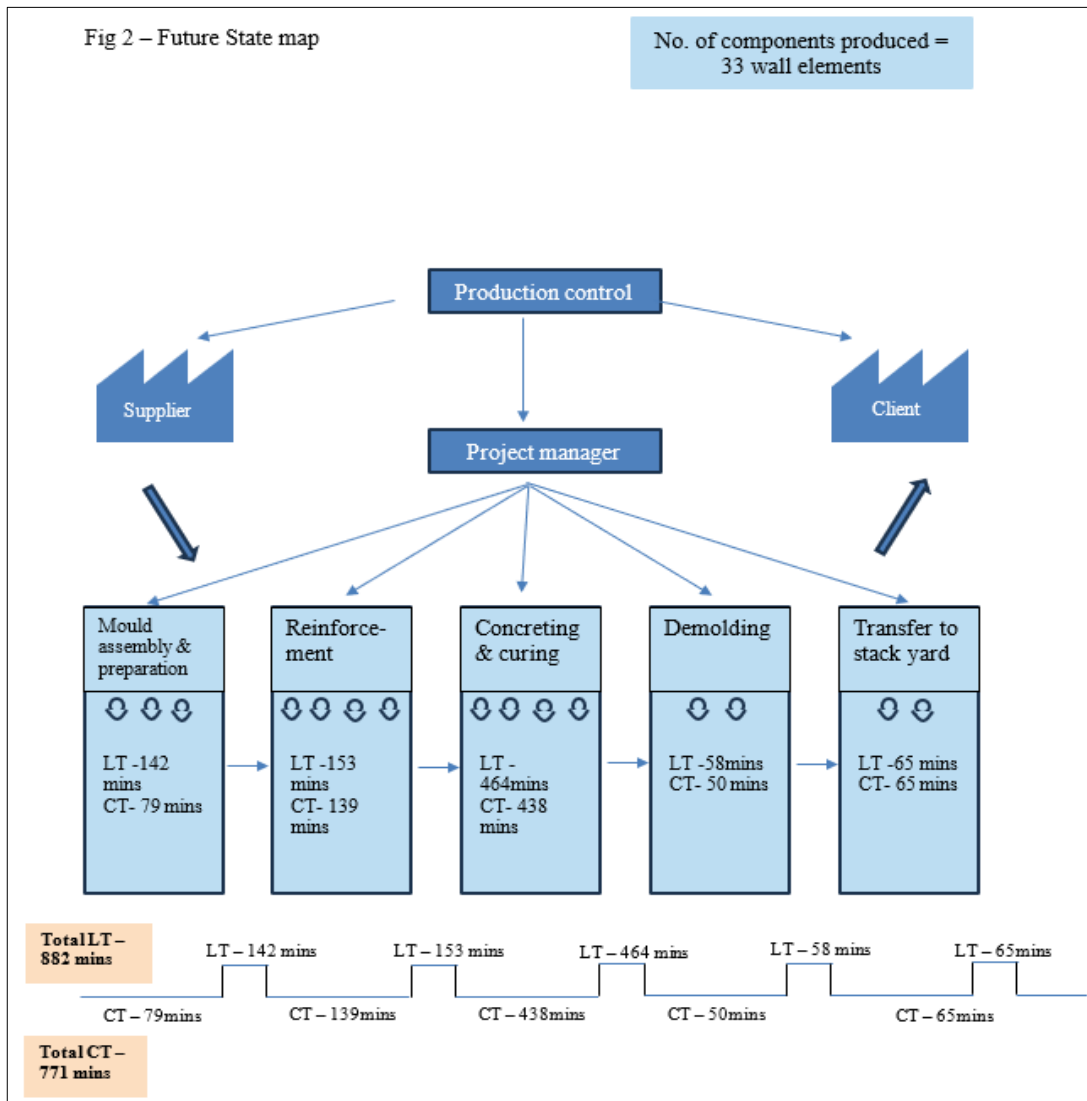
2.3 Data analysis

The impact of VSM, Takt Time, and Kanban was measured by comparing pre- and post-implementation data. Key improvements included:

- Higher productivity and reduced waiting times.
- Optimized material flow, minimizing inventory waste.
- Improved workflow synchronization between teams.

These lean tools successfully enhanced efficiency and reduced waste in precast manufacturing.

Figure 2: VSM Future State Map



3.0 Literature review

Lean production is a methodology focused on maximizing value while minimizing waste. Originating from the Toyota Production System, it emphasizes continuous improvement, efficiency, and responsiveness, optimizing operations while reducing costs and improving quality. By eliminating waste and streamlining workflows, lean principles foster productivity and sustainability. The construction industry, despite its significant contribution to global GDP, suffers from inefficiencies, delays, and cost overruns. Studies indicate that improving productivity could save the global economy \$1.6 trillion annually (Prasad, 2021). Given low profit margins and rising competition, contractors have increasingly adopted lean construction techniques to eliminate non-value-adding activities (Salem, 2005).

Lean Construction: Definitions & Core Principles: Lean construction applies lean production principles to design, project management, and execution, shifting the industry from traditional fragmented approaches to a systematic production mindset. Leading researchers and institutions define it as a production-based approach to project delivery, focusing on eliminating waste, improving flow, and maximizing value. A key aspect of lean philosophy is eliminating eight types of waste (DOWNTIME): Defects, Overproduction, Waiting, Non-Utilized Talent, Transportation, Inventory, Motion, Extra Processing (Prasad, 2021). By systematically addressing these inefficiencies, organizations can enhance quality, reduce costs, and streamline operations.

Application in Precast Manufacturing: Research highlights lean's role in optimizing precast workflows, reducing cycle times, and improving production flow. VSM helps identify bottlenecks, improve process synchronization, and enhance efficiency (Sirajudeen, 2021). Kanban reduces inventory waste and ensures a steady material supply, preventing overproduction. (Karthik, 2020) Takt-based scheduling enhances workflow predictability and coordination, minimizing idle time. (Kozlovská, 2021). Despite lean's potential, adoption in construction remains slow, hindered by organizational resistance and lack of awareness (Prasad, 2021). However, research validates its applicability in precast manufacturing, ensuring smoother operations, cost efficiency, and waste reduction.

4.0 Data Analysis and Findings

4.1 Value stream mapping (VSM) analysis

A Current State Map of precast wall panel production revealed inefficiencies in mould assembly, reinforcement, concreting, demoulding, and transport. The total lead time was 1317 minutes, with major delays in curing and material handling.

After optimizing non-value-added activities, the Future State Map showed a 33% reduction in lead time (to 882 minutes) and improved cycle times, allowing more efficient production flow.

4.2 Identified wastes and proposed solutions

Key wastes identified:

- Waiting: Delays due to long curing times.
- Transport: Congestion in deliveries caused inefficiencies.
- Inventory: Excess storage led to high holding costs.

Optimizations applied:

- Steam/membrane curing reduced waiting time.
- Night deliveries improved transport efficiency.
- Just-in-time (JIT) inventory management prevented overstocking.

4.3 Takt time implementation

Takt Time was used to synchronize production with customer demand, reducing bottlenecks and process delays. Key improvements:

- Handling & welding time reduced through automation.
- Optimized reinforcement cage movement cut transfer time.
- Faster curing techniques aligned cycle time with production goals.

Table 1: Takt Time Calculation

Activities	Current time	Takt Time
Mould assembly & preparation works	$174/38 = 4.5\text{mins}$	$115/38 = 3\text{ mins}$
Reinforcement	$164/38 = 4.31\text{ min}$	$118/38 = 3.1\text{ min}$
Concreting & curing	$754/38 = 20\text{ min}$	$715/38 = 19\text{ min}$
Demoulding	$130/38 = 3.42\text{ min}$	$82/38 = 2.15\text{ min} \sim 2\text{ min}$
Transfer to stock yard	$95/38 = 2.5\text{ min}$	$65/38 = 1.71\text{ min} \sim 2\text{ min}$

4.4 Impact of Kanban

A lack of communication was a major challenge at the precast unit. Kanban boards improved coordination by visually tracking progress, ensuring even work distribution, and increasing transparency. Tasks were listed on a master plan, with sticky notes moving as production progressed, helping teams stay aligned.

The use of VSM, Takt Time, and Kanban streamlined processes, reduced waste, and improved efficiency. VSM identified bottlenecks, Takt Time synchronized production with demand, and Kanban optimized inventory management. Together, these tools enhanced productivity and workflow efficiency in precast manufacturing.

Figure 1: KANBAN Board- Master Sheet

Master Plan				
No.	Task	To Do	In Progress	Done
1	Conceptualization and Planning	Wall panels 30 No.		Columns 10 No.
2	Pre-Production Setup	Wall panels 15 No.	Wall panels 15 No.	Columns 10 No.
3	Manufacturing of Precast Elements	Wall panels 30 No.	Columns 5 No.	Columns 5 No.
4	Storage and Inventory Management		Columns 10 No. Wall panels 30 No.	
5	Pre-Transportation Preparation	Columns 10 No. Wall panels 30 No.		
6	Transportation to Site	Columns 10 No. Wall panels 30 No.		
7	On-Site Handling	Columns 10 No. Wall panels 30 No.		

5.0 Conclusion and Recommendations

5.1 Conclusion

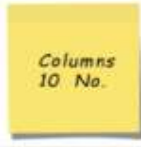
This research confirms that lean construction methods significantly improve productivity, reduce waste, and enhance efficiency in precast manufacturing. Derived from the Toyota Production System, lean principles were successfully adapted to optimize workflows and minimize non-value-added activities.

Key findings include:

- Better resource utilization and cost savings through lean adoption.
- Takt Planning reduced bottlenecks and synchronized workflow.
- VSM identified inefficiencies, improving cycle times.
- Kanban optimized material flow and inventory control.

Challenges persist, particularly resistance to change, lack of training, and poor planning, limiting lean adoption. However, structured training, better organizational commitment, and process standardization can overcome these barriers, making lean a viable, long-term solution for the construction industry.

Figure 2: Departmental KANBAN Board

Conceptualization and Planning				
No.	Activity	To Do	In Progress	Done
1	Identify project requirements			
2	Design structural elements			
3	Feasibility analysis			
4	Develop shop drawings			
5	Approve designs			
6	Plan logistics			

Pre-Production Setup				
No.	Activity	To Do	In Progress	Done
1	Procure raw materials		Wall panels 30 No.	Columns 10 No.
2	Prepare and calibrate molds		Wall panels 30 No.	Columns 10 No.
3	Set up quality control	Wall panels 30 No.	Columns 10 No.	
4	Train workers		Columns 10 No. Wall Panels 30 No.	
5	Arrange curing facilities	Columns 10 No. Wall Panels 30 No.		
6	Schedule production workflow	Columns 10 No. Wall Panels 30 No.		

5.2 Limitations

This study is limited by its focus on a single precast unit, making broader applicability uncertain. Resistance to change in the industry and lack of structured training hinder lean adoption. Additionally, the long-term impact of lean implementation requires further study.

5.3 Recommendations

- *Structured training*: Educate employees on lean methods at all levels.
- *Formal planning*: Standardize workflows using VSM and Kanban.
- *Takt planning*: Synchronize production with demand to minimize delays.
- *Change management*: Engage stakeholders and provide incentives for lean adoption.
- *Technology integration*: Use BIM, automation, and real-time tracking for efficiency.
- *Waste reduction*: Optimize material use and implement recycling models.
- *Policy support*: Government incentives to promote lean construction.
- *Performance monitoring*: Regular KPIs, audits, and assessments to track progress.

By implementing these strategies, the construction sector can accelerate lean adoption, enhance efficiency, and achieve sustainable growth.

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CHAPTER 17

Arbitration in Dispute Management

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ABSTRACT

Disputes are common in construction projects. These disputes should be resolved in a timely manner so that it least effect the time and the cost of the project. Arbitration can be used as a dispute resolution mechanism for the speedier and cost-effective method. With more complex projects being developed in India, the need for effective dispute resolution techniques like arbitration will play a crucial role in dispute management in construction industry. The study focuses on challenges faced by arbitration and changes that should be brought to resolve the disputes in construction industry to avoid cost overrun and completion of project on time.

Keywords: Arbitration; Dispute resolution; Construction industry; ADR; Contract management; Arbitration and Conciliation Act, 1996; Legal framework; Cost overruns.

1.0 Introduction

1.1 Background

The Construction sector has a large number of stakeholders such as in other various stakeholders, i.e., employers, regulators, contractors, consultants, and project owners. Thus, on this ground, it gives rise to common disputes that occur due to delays, contract violations, design faults, and unforeseen events. Routine litigation is typically lengthy and costly; therefore, arbitration becomes an emerging viable option. The writer introduces the use of arbitration in the resolution of construction-themed disputes in this paper and its advantage over traditional legal procedures

1.2 The role of arbitration in construction disputes

Arbitration is a structured but adaptive and agile means of resolving conflicts and awarding legally binding substitutes for court battles. Arbitration is codified under India's Arbitration and Conciliation Act, 1996, allowing parties to settle divergences through unbiased arbitrators, trade experts, and legally binding decrees.

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1.3 Advantages of settling the dispute by arbitration

ADR employs some of these methods like adjudication, conciliation, and mediation. Research targets arbitration as the most effective method of resolving construction disputes in mega construction projects. Gamage (2024) and Soni & Pandey (2017) argue that arbitration is the most favored method of resolving mega construction infrastructure disputes because it is enforceable by law and can be enforced. The power of arbitration is enforceability, confidentiality, and speed. Research, however, points out some of the disadvantages like arbitrators' appointment bias, delay in enforcing the award, and costly arbitration. Gamage (2024) offers a reflection on how ADR methods, in this case, arbitration, have helped in the management of delay and cost overruns in projects through the provision of a formal but flexible alternative. Similarly, Karpe & Joshi (2018) cite contractual imbalances, technical issues, and behavioral issues as key causes of dispute in the construction industry and arbitration as an effective solution method.

1.4 Research objectives

This study aims to:

- Identify and examine the most common causes of disputes in construction projects.
- Evaluates the effectiveness of arbitration in resolving construction disputes.
- Analyze arbitration case studies to highlight key trends and outcomes.
- Compare arbitration with other dispute resolution methods to determine its relative advantage.

2.0 Research Methodology

This study follows a qualitative research approach, using case studies, legal precedent reviews, and comparative analysis to assess arbitrations effectiveness in resolving construction disputes. By examining real world arbitration cases in the construction industry, the research identifies key trends and patterns in dispute resolution, challenges faced, and arbitration effectiveness.

The research follows a structured methodology that includes:

- *Literature Review*: Systematic and critical review of arbitral case law, literature and laws to develop a theoretical framework.
- *Case Study Analysis*: Examine some construction arbitration cases to see the common issues and observe the remedy process.
- *Legal Framework Analysis*: Indian law of arbitration in terms of its effect on resolving disputes, including Indian disputes.
- *Comparative Analysis*: Comparative analysis of arbitration vis-à-vis other methods for dispute resolution, i.e., litigation and mediation, to ascertain its positives and negatives.
- *Med-Arb Approach*: Med-Arb is a blend of mediation and arbitration to resolve construction disputes expeditiously at reduced cost in a binding manner.

3.0 Literature Review

3.1 Alternative Dispute Resolution (ADR) in construction

ADR covers multiple approaches, including mediation, conciliation, and adjudication. Studies highlight that arbitration is the most effective method in resolving disputes in large scale construction projects. Study by Gamage (2024) and Soni & Pandey (2017) highlights that arbitration has become the most preferred method in large-scale infrastructure disputes due to its legally binding nature and enforceability. The advantages of arbitration include enforceability, confidentiality, and time efficiency. However, studies also find several problems, such as arbitrator selection biases, delay in award enforcement, and high arbitration fees. A study by Gamage (2024) highlights how ADR techniques, especially arbitration, have contributed to reducing project delays and cost overruns by offering structured yet adaptable solutions. Similarly, Karpe & Joshi (2018) identify contractual disputes, technical issues and behavioral factors as a leading cause of conflicts in the construction sector, with arbitration emerging as an effective resolution strategy.

3.2 Arbitration and Conciliation Act, 1996

India's arbitration law is regulated by the 1996 Arbitration and Conciliation Act. As required by law, the Act adopts international standards of arbitration. In spite of such legislation, there are some issues, which also include judicial interference too deeply and institutional arbitration lack. Party autonomy by which the parties are entitled to select the arbitrators, can arbitral procedure, and the law applicable, is an essential provision of the Act. It is neutral since it offers equal and fair apportionment of procedure. Last but not least, it brings finality to the awards so that the arbitrators' awards are binding and enforceable in law. Non-governing arbitration is also known as "hoc" arbitration. Although efficient and economically advantageous, the process will always produce procrastination and inefficiency in the process without highly structured parties. Institutional arbitration provides formal rules with official processes and bureaucracy assistance from arbitral institutions like the International Chamber of Commerce (ICC) or Singapore International Arbitration Centre (SIAC), although these provide official processes and bureaucracy assistance. Institutional arbitration is a highly formal process but one widely available to be used less than optimally in India. Raju's study demonstrates that institutional arbitration can make dispute resolution more reliable and effective.

4.0 Case Study Analysis and Findings

A critical review of construction industry disputes in arbitration to achieve primary trends regarding dispute resolution. Findings provide an overview of the efficacy of arbitration and what are some of the prime factors behind its success. Major findings reveal the need for explicit contracts because clearly written contracts lower conflict to a great extent, as can be

seen in the case of Mumbai International Airport Ltd. Although arbitration is intended to be fast in solving disputes, it leads to delays due to difficulties in enforcing the awards. Although generally faster than litigation, arbitration in complex matters can be expensive.

4.1 Key case studies

Case Study 1: SEPCO vs. Power Mech Projects Ltd. (2021): The point of contention was interim relief under Section 9 of the Arbitration Act when SEPCO had appealed an arbitral award in favor of Power Mech. The question was whether such interim relief could be granted once an arbitral award was appealed. The Supreme Court held the validity of such relief by noting how crucial it was for the protection of arbitration orders even after an award.

Case Study 2: Tunnel Construction Arbitration: Here, a contractor brought action for extra charges owing to adverse rock conditions as opposed to conditions indicated in the notice of tender. The issue was whether the contractor was or was not to be paid for such unexpected conditions at site. The tribunal went against the contractor, but here one should refer to the requirement to carry out comprehensive pre-bid site investigation.

Case Study 3: Road Construction Arbitration: A contractor had demanded additional for delays in the project under the cover of weather conditions and poor ground. The underlying issue in dispute was whether there was merit in the form of additional compensation for the delays. Minimum compensation was ordered by the tribunal but demanded the contractor to pay for risk appraisal and poor planning for the project.

Case Study 4: Change Orders in Building Construction Arbitration: Here, a contractor sought extra costs due to a series of change orders that resulted in drastic changes to the scope of work for the project. Whether cumulative changes warranted extra costs by the contractor was the question. The tribunal concluded that drastic change orders justified the contractor's claim and entitled the contractor to extra costs and extended project durations.

Case Study 5: Defective Work in Bridge Construction Arbitration: A conflict existed regarding faulty workmanship during bridge construction. The crux point was whether contractor negligence or design faults caused the defects. The tribunal held joint liability between contractor and designer group, with the recognition that each was at fault.

Case Study 6: Mumbai International Airport Ltd. vs. Airports Authority of India: This was a matter of honouring lease terms in a major infrastructure undertaking. The question on the table was whether conditions under a lease can be enforced. The tribunal had recourse to the importance of well-enforceable terms in a contract in a bid to eschew such controversy.

Case Study 7: Union of India vs. Mago Construction Pvt. Ltd.: A client had been awarded damages due to delay resulting from client non-conformity through delayed approvals. Whether delay was justified or not to qualify for awarding damages was in question. The arbitration relied on the assumption that delay was on the client for insufficiency in site readiness as basis to award damages.

Case Study 8: Forum projects private ltd. vs. berhampur development authority: This was a case of a dispute over payment terms and the performance of a contract. The issue was whether payment disputes arising from non-adherence to contracts were legitimate. The tribunal dismissed the contractor's claim since they failed to adhere to the terms of the contract agreed upon.

Case Study 9: Union of India vs. Popular Construction Co.: The Union of India challenged an arbitral award where the period of limitation provided under Section 34 of the Arbitration Act itself had lapsed. The issue was whether the period of limitation could be extended under Section 5 of the Limitation Act. The Supreme Court held that it was not feasible and upheld the strict period of limitation to challenge arbitral awards.

5.0 Legal Framework Assessment

The Arbitration and Conciliation Act, 1996, was taken over into the UNCITRAL Model Law for the adoption of the best international practices. The Arbitration in India is governed by the Arbitration and Conciliation Act, 1996. The second time procedure was overhauled in 2015, 2019, and 2021. The 2015 amendment introduced time limitations for arbitral awards, reduced judicial interference, and enhanced the independence of arbitrate proceedings. The amendment of 2019 necessitated the establishment of the Arbitration Council of India and made provisions for the appointment of arbitrators rather than institutional arbitration. The amendment of 2021 covered conflict of laws for enforcement of awards by making the grant of an automatic stay subject to conditions. All these advances have restored the legitimacy, effectiveness, and enforceability of arbitration in India and put it on its feet as a more respectable means of dispute resolution.

5.1 Impact of disputes on project schedule, cost and quality

Construction disputes have tangible implications for schedule, cost, and quality and are likely due to contract interpretation, delay, payment, and faulty work. They lead to delays in projects, incur costs in terms of claims and litigation expenses, and interrupt cash flow, with performance consequences. Cutting corners contractors will be likely when contractors are diverted. Intractable conflict also leads to tension on stakeholder relations and working together. Conflict resolution is crucial to continuous progress, quality, and legality. Interim relief, rock classification, delays, change orders, faulty work, enforcement, interpretation of the contract, payment disputes, non-performance, and time-barred claims are issues that adversely affect project timeliness, increase costs, and decrease quality. They result in work stoppages, cost overruns, cash flow issues, rushed implementation, and sub-standard work, eventually deteriorating project results. Pre-arbitration litigation of construction projects induces serious delay, excessive legal expenses, interruption of cash flow, and compromised quality with financial costs. Following arbitration, binding awards accelerate settlement, permit work to

continue, limit costs above litigation, provide easier cash flow, and ensure quality by way of expert rulings.

Table 1: Comparison of Dispute Impact Before and After Arbitration (Case Study)

Impact Area	Before Arbitration (High Negative Impact)	After Arbitration (Improved Impact)
Project Schedule	• Major delays and stoppages. • Slow enforcement and decisions • Penalties and overruns.	• Faster settlements. • Work continues during disputes • Quicker closure than litigation.
Project Cost	• High legal fees. • Cash flow disruptions. • Increased costs.	• More cost-effective • Stable cash flow • Reduced cost escalation.
Project Quality	• Poor workmanship from financial strain. • Quality compromises.	• Expert resolutions maintain quality.

Table 2: Comparison of Dispute Resolution Methods (Case Study)

Identified Causes of Dispute	Adjudication	Litigation	Conciliation	Arbitration
Interim Relief Dispute	Quick but Temporary	Time-Consuming	Informal, non-binding	Binding & Flexible
Rock Classification Dispute	Expert Decision	Legal Complexities	Mutual Agreement	Technical Expertise
Delay Dispute	Specialized Review	Court Backlogs	Encourages Settlement	Binding & Enforceable
Change Order Dispute	Fast Decision	Costly & Lengthy	Mutual Agreement Possible	Fair & Confidential
Defective Work Dispute	Construction Knowledge	Expensive Litigation	Amicable Resolution	Detailed & Technical
Contract Interpretation Dispute	Expert Decision	Legal Complexities	Negotiation Based	Enforceable & Clear
Payment Dispute	Quick Resolution	Court Delays	Mutual Agreement	Strong Enforcement
Contract Non-Fulfilment Dispute	Partial Relief Possible	Prolonged Legal Battle	Encourages Settlement	Legally Binding & Final
Time-Barred Dispute	Some Relief Possible	Rigid Legal Framework	Informal, Limited	Flexible & Case-Specific

6.0 Comparative Analysis

Arbitration offers a binding, flexible, and technologically responsive method of resolving construction disputes. Compared to the temporary relief of adjudication, the non-binding solutions of conciliation, or the expensive time-wasting of litigation, arbitration offers faster, expert-guided, and enforceable solutions. It effectively resolves disputes like interim relief, payment claims, and interpretation of contracts in equal proportions of legal authority and industry expertise, thus ideal for construction disputes of robust nature.

7.0 Implementing Hybrid Resolution Models: Med-Arb Approach

While arbitration ensures capable and binding decisions, it is sometimes rigid and time-consuming. Mediation, based on cooperation and early resolution, settles disputes quickly and preserves relations. Med-arb, in which arbitration is combined with mediation, offers the best compromise, is faster, more flexible, and enforceable, and therefore an even better hybrid solution to adjudication or litigation. Med-arb is a combination of mediation and arbitration ideas. The parties try to settle first by way of mediation. In case the matter is not settled, it defaults to arbitration, wherein a final and binding award is made. This offers flexibility at the beginning and certainty at the end. For Med-Arb to be utilized effectively, contracts need to include clearly stated Med-Arb procedures. Appoint neutrals trained in arbitration and mediation. Create a carefully planned timeline for both phases and maintain neutrality in case the same person is acting as the mediator and the arbitrator. The use of arbitration institutions and increased awareness among stakeholders within a project are invaluable to the application of this model but making arbitration the first option for binding settlement. The model has many strengths: it accelerates dispute resolution by facilitating early resolution through mediation, gives enforceability in the event of arbitration, if necessary, reduces the cost of law overall, conserves business relationships, and is adaptable as regards finality of orders. All these advantages combined make it most appropriately suited to complex construction disputes.

7.1 Real case example of Med-Arb in construction dispute

In a commercial building project, a design company supplied materials to a construction company. A dispute emerged regarding the material specifications, leading to withheld payments and a standstill in project progress. The parties, despite their longstanding business relationship, could not resolve the issue through legal advisors. They opted for the Med-Arb route as defined in their contract. The process began with mediation, which clarified misunderstandings but failed to resolve monetary disagreements. The dispute was then referred to the same neutral for arbitration, who issued a legally binding decision within two weeks. This swift and structured process helped resume project work while preserving the working relationship.

8.0 Challenges and Recommendations

8.1 Challenges in arbitration

Despite its advantages, arbitration has many shortcomings as well. Its greatest weakness is being prohibitively expensive, particularly in the case of foreign cases where arbitration may be way too expensive. Costs in certain cases may even be on equal terms or even more expensive than regular litigation, particularly where multiple arbitrators and expert witnesses are employed. Also, enforcement of awards is delayed to some extent because courts take time to enforce arbitral awards, hence diluting the efficacy of arbitration. Differences in national laws and court rulings also complicate enforcement. This creates a feeling of injustice and dilutes the trustworthiness of the arbitration process. Also, unavailability of certain arbitration hearings can destroy the confidence among the parties concerned.

8.2 Recommendations for improvement

For ensuring efficiency in arbitration, certain steps are advised. Institutional arbitration would be made possible through persuasion of parties to make use of well-known arbitration institutions so that consistency and objectivity of process may be enhanced. Court support could be supplemented by streamlining the legal process, which also would go towards making enforcement of an arbitration award much faster. There is also a need for robusting the training of the arbitrators so that the arbitrators are adequately well-equipped with technical expertise in given fields such as construction disputes.

9.0 Conclusion

Arbitration assumes an essential role in the dispute resolution process and achieves the perfect balance between cost-effectiveness, efficiency, and expert determination. While arbitration is blessed with many advantages over traditional litigation, it faces challenges such as delays in enforcement and inefficiencies in procedure. Accordingly, institutional arbitration and legal enforcement can be strengthened further, and Hybrid models propagated, which have the potential to mostly increase the arbitration mechanism. With its remedy, the construction sector will be able to derive more accurate and timely resolution of disputes, hence ensuring smoother delivery of projects and financial risk diminution.

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CHAPTER 18

Assessing the Cost Effectiveness and Feasibility of Piezoelectric Tiles in India

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ABSTRACT

Piezoelectric technology converts mechanical energy, such as pressure or vibrations, into electrical energy using materials that generate an electric charge when stressed. However, current research on this technology faces several challenges, such as limited data, feasibility issues, implementation challenges, and a lack of studies needed for real-world implementation. This study aims to evaluate the feasibility and effectiveness of piezoelectric tiles, as this technology could help achieve the Sustainable Development Goals (SDGs) by supporting clean energy and sustainable urban development. As part of the research, field visits were conducted at high-footfall metro stations like Ghatkopar, Airport Road, and Andheri stations in Mumbai. These observations and footfall count analysis helped identify suitable locations for installing the tiles. The project analyzed footfall data from these areas to estimate the potential energy generation and studied the economic & location feasibility by analyzing installation and construction costs. The goal is to understand whether piezoelectric tiles can be scaled up and have a significant impact in India. If widely adopted, this technology could support the achievement of SDG-9 by driving innovation in industry and improving infrastructure. The findings will determine if piezoelectric tiles are a cost-effective solution for creating sustainable and efficient energy, which can power street lighting, public transport systems, and other urban infrastructure.

Keywords: Piezoelectric tiles; Renewable energy; Sustainable urban development; Green India movement; Cost-effectiveness.

1.0 Introduction

India's rapid industrialization and urbanization have significantly increased its energy demands, reaching 1,553.9 TWh in 2022-23 (CEA). While the government has promoted renewable energy sources such as solar, wind, and hydro, innovative solutions like footstep-generated energy using piezoelectric tiles offer a promising complement. Piezoelectric technology converts mechanical pressure into electricity, making it suitable for densely populated areas like metro stations, railway hubs, and shopping centers.

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This study evaluates the feasibility and cost-effectiveness of implementing piezoelectric tiles in Indian metro stations by analyzing energy generation potential, economic viability, and adaptability. “India has achieved 95% of its 175 GW renewable energy target set in 2015,” declared RK Singh, Minister of Power and New and Renewable Energy, in Parliament (cnbctv18, 2023). By 2026-27, non-fossil fuel capacity is expected to reach 57.4%, with further growth to 68.4% by 2031 (Singh, 2022). The government aims to reduce fossil fuel reliance to 30% by 2047 (Puri, 2020). While large-scale renewable projects are crucial, decentralized solutions like piezoelectric tiles can provide localized power. Metro stations in Mumbai, Delhi, and Bangalore, with millions of daily commuters, present a viable setting for energy harvesting. Each step can generate 5-10 watts (Sharma, 2016), enabling lighting, display screens, and ticketing systems to operate sustainably (Chandra, 2022).

Large renewable projects like solar and wind require significant land, making urban implementation difficult. Piezoelectric tiles offer an alternative by harnessing continuous foot traffic to generate electricity, unlike solar panels dependent on sunlight. Successful applications in Shibuya Station, Tokyo, and O’Hare Airport, Chicago, highlight their potential. However, adoption in India is still in its infancy, necessitating further exploration of energy output, costs, and long-term durability (Chaudhary, 2022). Piezoelectric tiles, composed of materials like quartz and ceramics, generate electricity when pressure is applied a principle discovered by Pierre and Jacques Curie in 1880 (Sciencefacts, 2024). Advances in nanotechnology have improved their viability, yet high initial costs for production, installation, and maintenance remain significant barriers (Chandra, 2022). Mechanical wear and exposure to dust and moisture may further reduce efficiency (Deekshitha, 2024).

Additional financial concerns include energy storage and conversion complexities (Anand, 2021). Limited large-scale pilot projects in India hinder research, making economic comparisons with solar and grid power essential (Naderipour, 2021) This research assesses the feasibility of piezoelectric tiles in metro stations, particularly in high-footfall locations such as Ghatkopar, Andheri, and Airport Road in Mumbai. By evaluating pedestrian flow, energy generation potential, and economic viability, this study aims to determine whether piezoelectric tiles provide a cost-effective alternative to other renewable sources. Additionally, it explores policy interventions and economic incentives to promote their adoption. However, limitations exist, as findings are based on case studies, pedestrian traffic data, and simulations rather than extensive field trials (Dagdeviren, 2014). Factors such as variations in pedestrian movement and environmental conditions may impact efficiency (Nakamura, 2019). Field experiments and interdisciplinary research are needed for practical validation and technology enhancement.

Piezoelectric technology in flooring systems has gained global traction due to its potential to generate electricity from mechanical stress, particularly in high-footfall areas such as airports and railway stations (Ramakrishna, 2014). In India, where energy expenses constitute 52% of industrial costs (Anand, 2019), the rising electricity demand necessitates sustainable alternatives like piezoelectric tiles (Yingyong, 2021).

These tiles align with India's emissions reduction goals and infrastructure sustainability targets (Shanmugam, 2020). Their development traces back to the discovery of piezoelectricity by Jacques and Pierre Curie in 1880, with advances in ceramics and polymers improving their efficiency (Smith, 2014). Research across the UK, Netherlands, and Japan has demonstrated their viability in high-traffic areas, influencing commercialization prospects in India (Jones, 2016) (Haertling, 1999) (Praharaj, 2023) (Nakamura, 2019). Current research on piezoelectric tiles focuses on energy harvesting potential, material durability, and urban integration. Studies show significant energy generation in high-footfall locations such as stadiums and metro stations (Glynne, 2018) (Roy, 2015). Material advancements highlight trade-offs between ceramic and polymer-based tiles, balancing durability and efficiency under India's diverse climates (Tiwari, 2019). The feasibility of integrating these tiles into urban infrastructure remains debatable due to economic constraints and policy gaps (Ramanathan, 2022) (Rao, 2023). Global and Indian case studies, including projects at O'Hare International Airport and Delhi Metro stations, reveal both promise and challenges related to installation costs and maintenance (Kumar, 2021) (Gupta, 2022) (Sustainable Energy Solution at O'Hare International Airport., 2019). Despite the promise of sustainable energy, challenges include technological limitations, economic feasibility, and policy frameworks (Johnson, 2019).

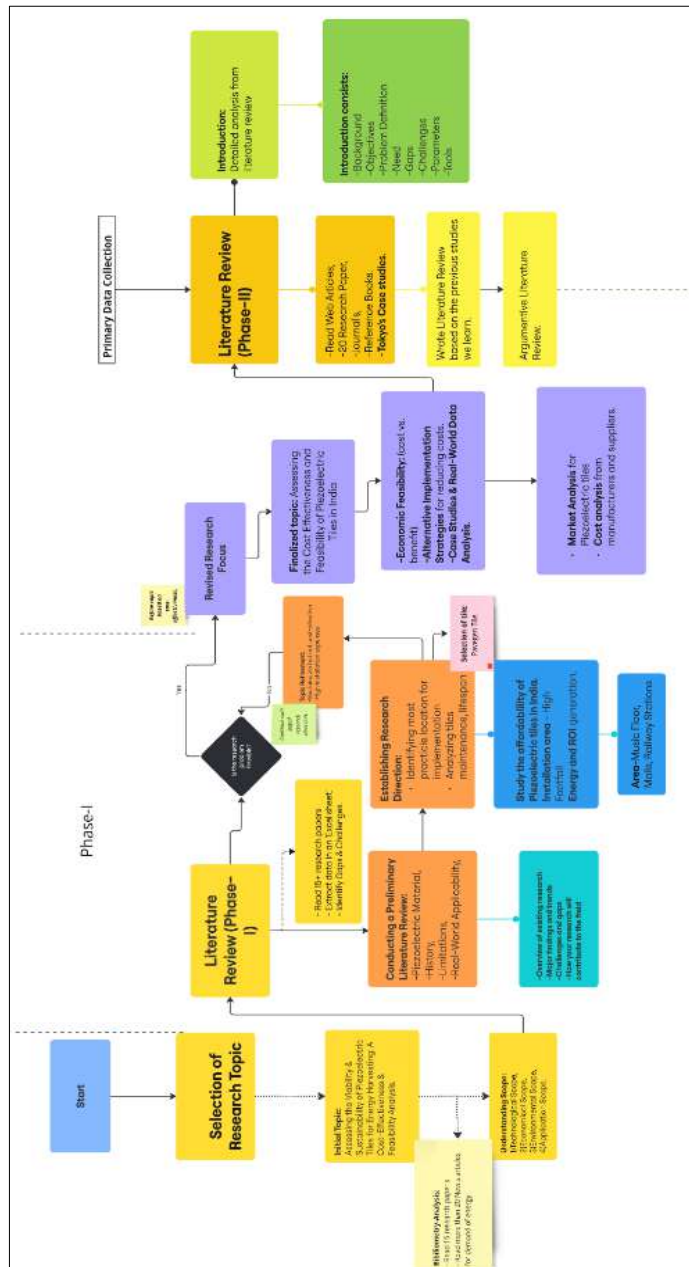
The lack of research on social acceptance and long-term environmental impacts in India presents further obstacles (Mukherjee, 2022). While some argue high installation costs hinder widespread adoption (Singh, 2021), others believe advancements in materials and government support could make the technology viable (Patel, 2020) (Kumar, 2020). Addressing these barriers through interdisciplinary research, pilot projects, and strong policy measures could enhance India's green energy transition (Agarwal, 2021) (Sharma, 2023) (Gupta, 2022). This research will examine pedestrian footfall as well as the potential for power generation through piezoelectric tiles in metro stations to find out whether or not these tiles can be implemented. This study investigates the cost-effectiveness of installing and generating energy through piezoelectric tiles in comparison with conventional forms of energy generation. In addition, the research presents a detailed comparison of solar, wind, and piezoelectric energy solutions on economy, environment, and technology dimensions. By understanding how much energy can be produced from piezoelectric technology and if it can be economically feasible, the research would study what role such technology could play toward India's clean energy goals. The results will help set the stage for understanding better sustainable urban energy solutions and for future policy formulation regarding the adoption of piezoelectric tiles in metros.

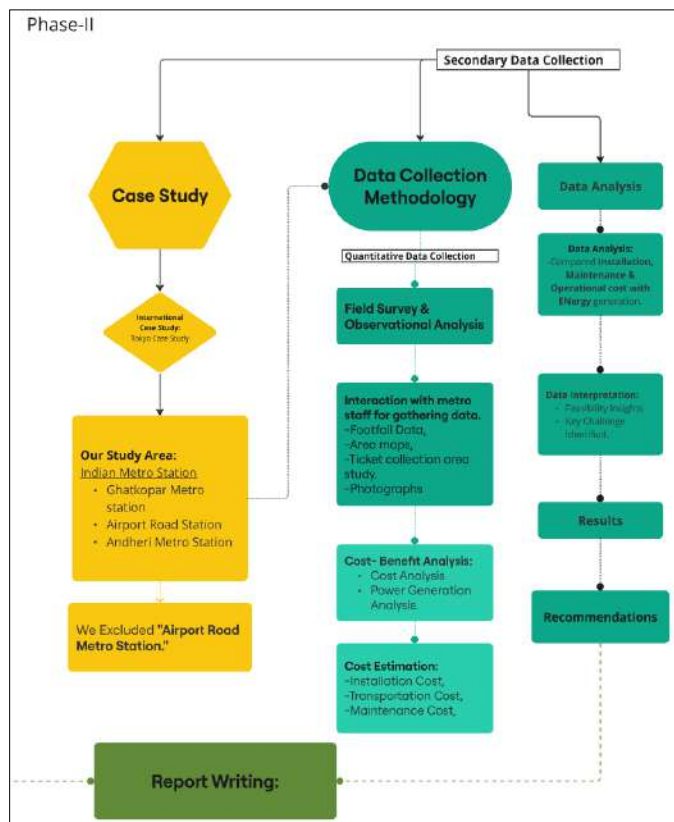
2.0 Research Methodology

This research adopts a structured and systematic methodology to assess the feasibility and cost-effectiveness of piezoelectric tiles in metro stations as a sustainable energy alternative. The methodology integrates multiple research techniques, including bibliometric and thematic

analysis, comparative assessments, and field surveys, to develop a comprehensive understanding of the technology's practicality in the Indian metro system.

Figure 1: Flowchart of Research Methodology





A bibliometric analysis of 15-20 research papers, case studies, and industry reports provided insights into the properties, applications, efficiency limitations, and economic considerations of piezoelectric materials. Thematic analysis was then employed to categorize key findings, identify literature gaps, and highlight challenges such as unproven large-scale implementation, integration with metro infrastructure, high initial investment costs, and long-term durability concerns. A major issue that emerged was the lack of real-world case studies on the use of piezoelectric tiles in high-footfall areas like Indian metro stations. While international projects, such as Tokyo Metro's piezoelectric floor-tile system, provide reference points, they do not account for the unique infrastructural, economic, and environmental conditions of Indian metros. The detailed structure of our methodology is shown in the research methodology flowchart (Figure 1).

Field surveys at Mumbai's Ghatkopar, Andheri, and Airport Road metro stations analyzed foot traffic patterns, commuter density, and energy harvesting potential. Observations covered peak and off-peak movement, environmental factors like dust and moisture, and mechanical stress on tiles. Discussions with metro staff highlighted concerns about durability, maintenance, and high installation costs. Metro authorities favored solar power over

piezoelectric tiles due to cost-effectiveness and reliability issues, as foot traffic fluctuations raised doubts about consistent energy generation. Additionally, secondary data collection involved analyzing technical reports and case studies from existing piezoelectric installations worldwide. Studies on energy conversion efficiency, material performance, and real-time energy utilization highlighted limitations in large-scale applications. Despite the potential of piezoelectric tiles, findings from site visits and literature review indicate that while they may contribute to supplementary energy generation, they are unlikely to serve as a primary power source due to cost and efficiency constraints. The integration of hybrid energy solutions, combining piezoelectric technology with solar panels, may offer a more sustainable alternative.

Ultimately, the study concludes that although piezoelectric flooring holds promise, its economic and technical feasibility in Indian metro stations remains uncertain. Further advancements in material efficiency and cost reduction are needed to make this technology a viable option for public infrastructure projects.

3.0 Results

The ticket collection areas at Ghatkopar and Andheri metro stations were selected for footfall analysis and power estimation due to their high commuter concentration. These areas ensure uniform pressure on the proposed piezoelectric tiles, maximizing energy generation potential. Based on station staff data and manual recordings, Andheri receives approximately 700,000 daily commuters, while Ghatkopar accommodates around 300,000. Footfall was divided among the ticket machines, with each machine handling an estimated 19,444 footfalls at Andheri and 11,111 at Ghatkopar. With a 65% activation efficiency and 5 Joules of energy generated per footstep, the energy produced at Andheri is approximately 0.972 kWh daily, while at Ghatkopar, it reaches 0.416 kWh. This energy can power LED lighting or signage within the station. Initially, triangular piezoelectric tiles were planned due to their structural efficiency. However, the ticketing area's rectangular layout led to uneven foot traffic distribution. Installing triangular tiles would have incurred high costs due to excessive cutting and installation efforts. Instead, the peripheral sections were covered with regular tile pieces, optimizing costs without affecting efficiency. This improved sustainability and economic feasibility while ensuring precise tile placement under high-footfall zones.

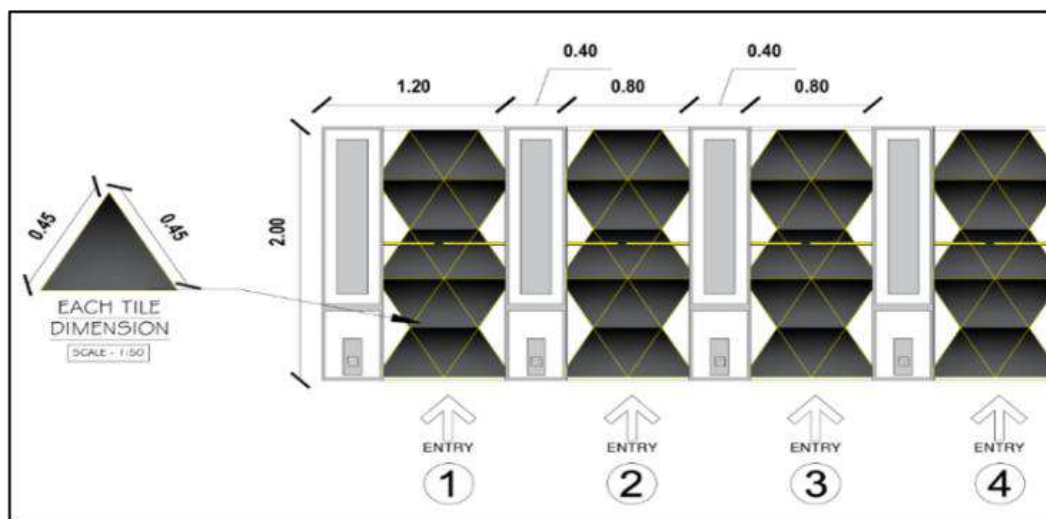
4.0 Prototype Design

The proposed piezoelectric tile prototype (as shown in Figures 2 & 3) is designed to efficiently harvest kinetic energy from foot traffic in high-footfall areas such as metro stations. The tile system follows a modular structure, ensuring scalability, durability, and ease of maintenance. The prototype consists of triangular-shaped tiles, arranged in a repeating modular pattern. The triangular design enhances load distribution and structural stability while

maximizing the number of active pressure points for energy generation. Each tile is composed of multiple layers: a top layer made of a durable, high-friction surface to withstand constant pedestrian movement, a middle layer with a flexible mechanical structure that enhances footstep impact transfer, and a bottom layer embedded with piezoelectric transducers arranged in a structured grid pattern to convert mechanical pressure into electrical energy.

The working mechanism of the prototype is based on the piezoelectric effect, where mechanical stress from foot traffic induces an electrical charge in the piezoelectric material. When a pedestrian steps on the tile, the generated energy is transferred to a power conditioning circuit, which stabilizes and stores it in an integrated battery or capacitor. The system is further connected to a central energy management unit, allowing real-time energy monitoring and grid integration. Initial simulations and testing suggest that each footstep generates approximately 0.105 mW, which, when accumulated over thousands of daily footsteps, contributes to an overall energy generation of 1.388 kWh/day for both metro stations. However, challenges such as low per-step energy output, wear-and-tear, and high initial costs (₹4.88 Cr for Ghatkopar and Andheri stations) limit the large-scale implementation of this technology. While the prototype successfully demonstrates a proof of concept, further advancements in material efficiency, energy storage integration, and hybrid energy solutions (e.g., combining with solar energy) are essential to enhance its feasibility as a practical renewable energy source.

Figure 2: Popup of Tile Installation Design at Andheri & Ghatkopar



Tile Selection: Based on various research studies and a comparative analysis of the tile products listed in Table 1, including lifespan and cost comparisons, Pavegen tiles were chosen for our study due to their efficiency, flexibility, and smart technology integration.

Figure 3: Tile Installation Design

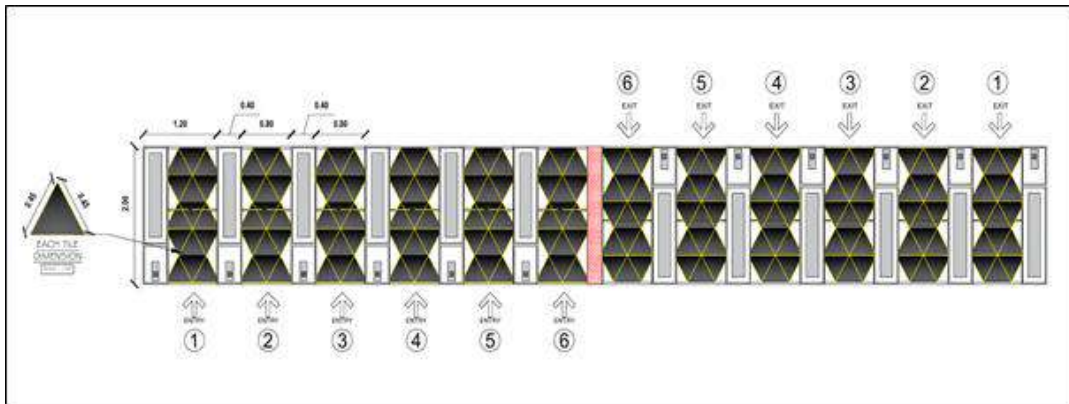


Table 1: Tile Comparison based on Various Product Types

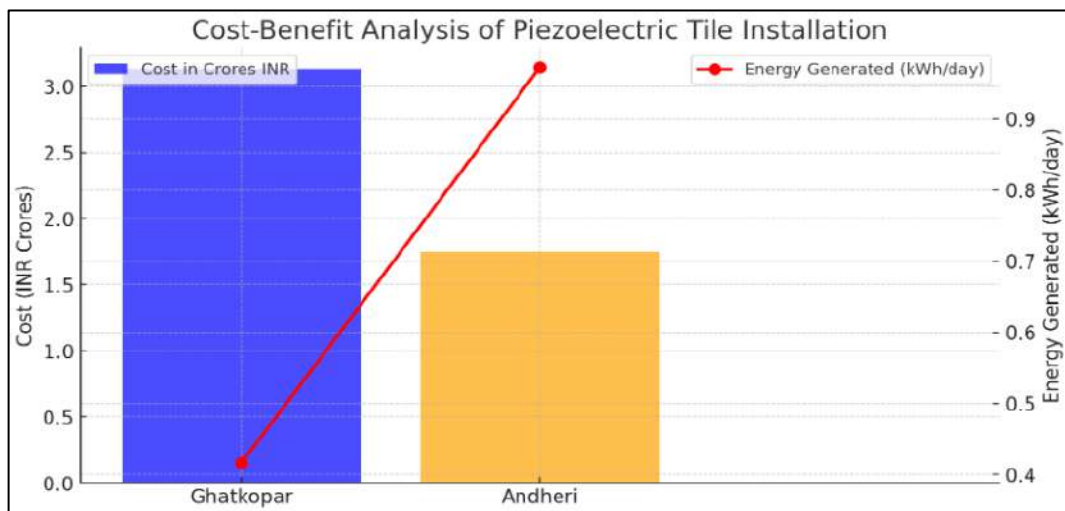
Sr. No	Product Type	Tile Size / Dimensions	Energy Produced	Price (US\$)	Estimated Lifespan	Source
1	Waynergy Floor Tiles	40×40 cm	10 W per step	451.5	20 years	Rodrigues, 2011
2	SEF Tiles	75×75 cm or 50×50 cm	Up to 30 W continuous, avg 7 W per step	1693	15 years	Solban & Moussa, 2019
3	Pavegen Tiles	45 x 45 x 45 cm	5 W	395	20 years	Pavegen, 2021
4	EAPs	Sheets	1 W	Not available	20 years	Balouchi, 2013
5	Sound Power Tiles	50×50 cm	0.1 W per 2 steps	270.9	20 years	Hassan et al., 2014
6	Parquet PVDF Layers	Thickness: 10 µm	2,100,000 W per pulse (70 kg load)	Not available	20 years	Elhalwagy, 2017
7	Drum Harvesters - Piezo Buzzer	40 mm - 25 mm	2,463,000 W (35.6 mW for 70 kg)	56.4	20 years	Mishra et al., 2015
8	Power Leap (PZT) Tiles	60×60 cm	500,000 W per step	Not available	20 years	Balouchi, 2013
9	HEF	75×75 cm or 100×200 cm	Up to 250 kWh per year per tile	1693	20 years	Solban & Moussa, 2019

Each tile generates 5W per step and has a 20-year lifespan, making it a long-term solution. While PZT ceramic tiles generate higher power, Pavegen tiles offer real-time data analytics and modular designs, making them suitable for metro stations, airports, and shopping centers. These tiles have been successfully used in projects like Mercury Mall in London, demonstrating their capability to power signage and lighting through pedestrian movement.

Footfall Analysis: Observational studies at the ticketing hubs of Ghatkopar and Andheri metro stations recorded passenger movement patterns. Ghatkopar handles 300,000 commuters daily, while Andheri manages nearly 700,000. These numbers highlight the necessity for efficient infrastructure and management to accommodate such high commuter volumes.

Power Estimation: The ticket collection zones were identified as the areas of maximum foot traffic, ensuring optimal pressure on the tiles. Based on peak and off-peak hour footfall intensity, energy generation potential was estimated as follows:

Figure 4: Cost Benefit Analysis



Tile and Machine Area Calculation:

Equation 1: Area of equilateral triangle

Area of an equilateral triangle: $(\sqrt{3} / 4) * \text{side}^2$

- Tile Size: 450 mm = 0.45 m
- Tile Area: sq. meters
- Machine Area: converted to meters: sq. meters
- Tiles per Machine: 14

Energy Generation:

- Energy per Step: 5 Watts = 5 Joules
- Operating Hours: 17 hours/day
- Footfall per Machine: at Ghatkopar; at Andheri
- Total Energy: Joules at Ghatkopar; Joules at Andheri
- Energy in kWh: kWh at Ghatkopar; kWh at Andheri

Cost Estimation: The cost of installing piezoelectric tiles was calculated based on tile pricing, shipping, and labor expenses. The total tile requirement was 882 tiles, with an average cost of ₹35,550 per tile. The costs for both stations are estimated as follows:

Table 2: Ghatkopar & Andheri Energy Generation Data

Parameter	Ghatkopar	Andheri
Total Footfall	300,000	700,000
Machines	27	36
Tiles/Machine	14	14
Total Tiles	378	504
Footfall/Machine	11,111	19,444
Total Energy (J)	15,00,000	35,00,000
Energy (kWh)	0.416	0.972
Total Tile Weight (kg)	11,340	15,120

Table 3: Ghatkopar & Andheri cost Estimation Data

Expense Component	Ghatkopar (₹)	Andheri (₹)	Total (₹)
Tile Cost	1,34,37,900	1,79,17,200	3,13,55,100
Shipping Charges	87,31,800	87,31,800	1,74,63,600
Installation Cost	21,500	21,500	43,000
Total Cost	2,21,91,200	2,66,70,500	4,88,61,700

Shipping was calculated based on standard charges for 17,640 kg of tiles at ₹990 per 1000 kg. Installation costs included five workers at ₹1,000 per day and two experts at ₹3,000 per day, completing the project in three days.

As shown in Figure 3, our study represents that this project needs “High Initial Cost”, mainly due to the expensive nature of piezoelectric technology & shipping charges. To make this project more financially viable partnerships with technology providers, government subsidies, or future advancements in cost-effective piezoelectric material could be explored.

5.0 Comparative Evaluation of Renewable Technologies: Solar, Wind with Piezoelectric Sensor Energy

A comparative analysis of solar, wind, and piezoelectric tiles was conducted based on key factors such as energy output, cost, land use, scalability, and environmental impact as shown in Table 4. While solar and wind energy proved to be more efficient and cost-effective, piezoelectric tiles stood out for their ability to integrate into existing urban infrastructure. However, their lower energy output and higher cost per kWh limit their large-scale feasibility.

Piezoelectric tiles generated significantly less energy (1.388 kWh/day for metro stations at Ghatkopar and Andheri) due to low energy harvesting per footstep (5J/step). This requires a high volume of foot traffic to produce meaningful energy. Additionally, installation costs (₹4.88 Cr for metro stations) were considerably higher compared to the energy output, making piezoelectric tiles less viable compared to solar and wind alternatives, which offer greater energy efficiency at a lower cost.

Table 4: Comparative Analysis between Renewable Alternatives

Aspect	Solar	Wind	Piezoelectric Tiles
Energy Output	150-200 kWh/m ² annually	6-8 million kWh/year (3 MW turbine)	5-20 kWh/day (1,825-7,300 kWh/year)
Carbon Footprint	20-70 grams CO ₂ /kWh	10-20 grams CO ₂ /kWh	20-30 grams CO ₂ /kWh
Land Use	50-100 acres per 1 MW	Requires spacing between turbines	Installed on existing sidewalks/floors
Cost	₹75000-85000 per kW	₹4 crore per MW	₹35,550 per tile
Maintenance	25+ years, minimal upkeep	Regular servicing needed	Prone to wear, especially in monsoons
Public Engagement	Invisible infrastructure	Invisible infrastructure	Visible, sparks curiosity and awareness
Ideal For	Large-scale adoption (rural, open land)	Coastal areas with consistent winds	Urban areas with high foot traffic
Energy Generation (Annual)	Dependent on area (e.g., 150-200 kWh/m ² annually)	6-8 million kWh per turbine/year	1,825 - 7,300 kWh/year (high-traffic areas)
Space Efficiency	Requires large land areas for solar farms	Takes up minimal ground area, but requires spacing	Installed in existing spaces (sidewalks, metro floors, etc.)
Environmental Impact	Requires significant raw materials like silicon	Low environmental impact due to simpler materials	Moderate impact due to polymers and metals used
Scalability	High scalability, especially in open land	Scalable in areas with enough wind resources	Limited scalability in low-traffic areas but feasible in urban settings
Installation Time	Relatively fast, but depends on the scale	It takes longer to install due to the turbine size	Quick installation in existing urban spaces
Noise	No noise generation	It can be noisy due to moving parts	No noise generation

Real-world challenges further limit the feasibility of piezoelectric tiles. High foot traffic leads to faster wear and tear, increasing maintenance costs. Energy storage remains a concern due to the small energy output, requiring advanced battery technology for effective utilization. Moreover, the high initial investment (₹35,550 per tile) makes large-scale adoption difficult. To

improve feasibility, research into better materials and alternative storage solutions is needed. A hybrid approach integrating solar panels with piezoelectric tiles could enhance efficiency, and field testing in urban areas should be conducted before broader implementation.

6.0 Conclusion

This research evaluates the feasibility of piezoelectric tiles as a renewable energy source for metro stations, comparing them with solar and wind energy alternatives. The findings indicate that piezoelectric tiles generate minimal energy (1.388 kWh/day for both stations) due to low energy harvesting per footstep, making them less efficient compared to solar and wind energy. Additionally, the high installation cost (₹4.88 Cr for Ghatkopar and Andheri stations) makes them economically unviable, as their energy output is too low to justify the investment. Wear-off issues, high maintenance needs, and energy storage challenges further limit their practicality. In contrast, solar energy proves to be more cost-effective and scalable, especially in urban environments with abundant sunlight. Wind energy also remains a steady alternative, provided suitable locations are available.

To explore the practical implementation of this technology, a prototype piezoelectric tile system was designed and tested. The modular triangular tile design, as shown in Figure X, enhances load distribution and optimizes energy harvesting by incorporating piezoelectric transducers in a structured grid pattern. While the prototype successfully demonstrated the feasibility of footstep-induced energy generation, the low power output per step and durability concerns remains key limitations.

Despite these challenges, piezoelectric tiles present an innovative approach to energy generation and could become more viable with technological advancements in material durability, energy storage, and hybrid integration with solar or kinetic energy systems. The study highlights the need for further research and field testing to optimize piezoelectric technology for practical use. While it is not currently a feasible large-scale energy solution for metro stations, hybrid approaches combining piezoelectric tiles with solar panels could enhance energy efficiency and sustainability in the future.

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CHAPTER 19

Assessing the Delay Analysis in Multi-storey Residential Project using Time Motion Study

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ABSTRACT

Delays are a common challenge in multi-storey residential construction projects, often leading to increased costs, extended timelines, and inefficiencies in resource utilization. This study aims to assess and analyse such delays using a Time Motion Study, with a focus on real-time tracking of construction activities. By identifying specific delays during project execution, comparing them with industry standards, and proposing mitigation strategies, the research offers practical insights into improving construction efficiency. To achieve this, the study employs the Continuous Timing Method, a real-time observation technique that records the start and end times of various activities without interruption. This method provides a precise and detailed account of productive work, idle time, and delays, offering a clear picture of on-site operations. The collected data is then analysed using the Method Productivity Delay Model (MPDM), which categorizes delays into key areas such as labor inefficiencies, equipment downtime, material shortages, and procedural bottlenecks. By integrating real-time observations with historical project performance trends, this research identifies the root causes of delays and their impact on overall productivity. The study goes a step further by offering targeted recommendations to mitigate these delays, ensuring better workflow management and timely project completion. The findings of this research can be valuable for project managers, contractors, and construction professionals seeking to enhance productivity, reduce inefficiencies, and optimize resource allocation. Ultimately, this study contributes to the broader goal of improving project execution strategies in the construction industry.

Keywords: Delay analysis; Time motion study; Continuous timing method; MPDM; Productivity delays.

1.0 Introduction

1.1 Background

Construction delays affect cost efficiency, project scheduling, and overall productivity. Various factors such as labor inefficiencies, material shortages, equipment breakdowns, and regulatory bottlenecks contribute to these delays.

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The Time-Motion Study (TMS) provides a structured approach to identifying and mitigating inefficiencies. To ensure precise data collection, this study employs the Continuous Timing Method, an observational technique that records activity durations without any interruptions. Borchert & Zellmer-Bruhn, 2010 assert that “work sampling is a reliable predictor of labor productivity, showing a close correlation between on-site observations and unit-rate productivity.” Similarly, Liou & John, 1986 demonstrate that “work sampling can reveal patterns of idle time, waiting periods, and other inefficiencies across multiple tasks or trades.” By capturing the exact time spent on each task, this method helps in identifying inefficiencies, tracking idle periods, and assessing overall productivity levels on-site. Once the data is gathered, it is analysed using the Method Productivity Delay Model (MPDM) — a framework that classifies delays into key categories such as labor inefficiencies, equipment downtime, material shortages, and procedural bottlenecks. By integrating real-time data with advanced analytical methods, this research aims to provide practical, data-driven insights that can enhance project performance, streamline workflows, and ensure timely project completion.

1.2 Objectives

- Identify the causes of delays in a multi-storey residential project, located in Pune.
- Compare observed delays with industry benchmarks and standards.
- Propose strategic solutions to enhance project efficiency.

1.3 Problem definition

Traditional delay analysis methods rely on historical data, making it difficult to implement real-time solutions. This study applies a data-driven approach using real-time tracking of construction activities and productivity analysis. Traditional methods of delay analysis often rely on historical data or subjective assessments, making it difficult to capture real-time inefficiencies and proactively implement corrective actions. This results in reactive problem-solving rather than preventive measures, further exacerbating project delays. To bridge this gap, this study employs Time Motion Study and Continuous Timing Method to record real-time data on construction activities and identify inefficiencies as they happen. The Method Productivity Delay Model (MPDM) will be used to systematically categorize and analyze these delays, providing insights into their root causes and impact on overall productivity.

1.4 Methodology overview

A case study approach was used, applying the Continuous Timing Method to observe and record construction cycles. In order to identify, assess, and minimize delays in multi-story residential construction projects, this study uses a data-driven methodology. With names removed for confidentiality, the study focuses on XYZ, a multi-story residential development in LMN Nagar in Pune, built by ABC Builders. For close examination, the concreting activity was chosen. A Time Motion Study was used to observe work duration in real time, and a Continuous Timing Method was used to continuously track activity start and end times, recording delays and

idle times. Procedure issues, equipment failure, labor inefficiencies, material unavailability, and external factors were the categories into which delays were divided for data analysis using the Method Productivity Delay Model (MPDM). Actual cycle times were compared to industry-standard benchmarks to determine productivity loss, and production delay sampling tables were used to spot trends. In order to determine acceptable productivity levels and determine critical delays through assessing variability limits, the recorded data was then compared with industry standards. Finally, mitigation techniques were suggested to improve material procurement procedures, equipment management, and workflow optimization. These strategies seek to boost productivity, enhance scheduling, and cut down on delays. The study offers useful insights to increase efficiency in multi-story residential construction projects by utilizing MPDM.

2.0 Literature Review

By following the PRISMA framework (Identification, Screening, Eligibility, Inclusion), the study ensured a structured and rigorous approach to selecting literature. The 17 included papers form a strong foundation for analyzing how MPDM and Time-Motion Studies can effectively address construction delays.

2.1 Time-motion studies in construction

In the construction industry, time and motion studies have long been recognized as essential tools for locating inefficiencies and boosting output. These studies assist in identifying ineffective times and possible areas for optimization by closely observing activity durations and workflows. Balar (2018) asserts in “Effective Time and Motion Study on Construction Project: A Case Study of Surat City” that these kinds of analyses can cut down on waste, optimize processes, and enhance project results in the end. The importance of examining labor productivity in residential construction was also emphasized by Chambrelin (2021) in “Application of Time and Motion Study for Brickwork Activity in Residential Building.” The study demonstrates how statistical analysis and structured observation can greatly increase productivity. Building on these foundational studies, accurate measurement is essential to identify delays, assess resource distribution, and prioritize tasks that need immediate attention.

2.2 Work sampling and relevance to MPDM

Work sampling predicts labor productivity and helps in categorizing delays into labor inefficiencies, equipment downtime, material shortages, and procedural delays.

2.3 Factors affecting productivity and delays

- *Material shortages:* Delays in procurement and supply chain inefficiencies.
- *Labor inefficiencies:* Workforce shortages and lack of coordination.
- *Equipment downtime:* Mechanical failures and poor maintenance.
- *Management and workflow:* Miscommunication and procedural bottlenecks.

2.4 Research gap

The Method Productivity Delay Model (MPDM) is effective for identifying and minimizing construction delays, but focusing on a single concreting activity reveals specific gaps. These include limited studies in the Indian context considering local labor practices and supply chains.

Key gaps are: Limited Task-Specific Analyses: Broader studies dilute insights; focusing on concreting can reveal overlooked inefficiencies. Overlooked Micro-Delays: Brief, repeated disruptions are often missed. Real-time tracking can capture these better. Inconsistent Data Quality: Multi-trade projects lead to fragmented data. Focusing on concreting ensures accuracy. Lack of Real-Time Observation: Many MPDM studies lack continuous monitoring, reducing data precision. Shallow Root Cause Analysis: General categories often miss specific sub-causes like truck scheduling vs. crew timing. Scalability Issues: Multi-task findings may not transfer well; single-activity benchmarks are more adaptable. Addressing these gaps can strengthen MPDM's application for managing delays in Indian construction projects.

3.0 Research Methodology

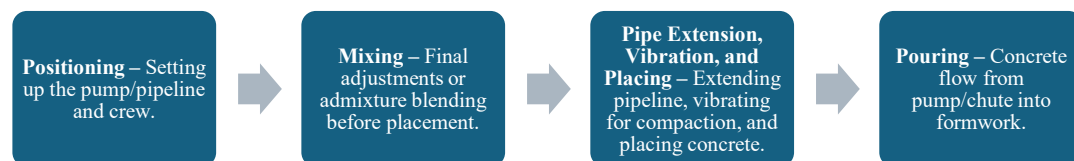
A common approach for carrying out Time-Motion Studies (TMS) on dynamic construction sites is observation. Despite being qualitative, it can provide quantifiable insights when methodically combined with quantitative analysis. Real-time insights into task completion, time spent, and inefficiencies can be obtained by classifying delays and recording precise time intervals using observational data and models such as the Method Productivity Delay Model (MPDM). By capturing start and stop times in real time, the Continuous Timing Method facilitates even more accurate tracking of productive versus non-productive time. In order to precisely identify delays in concreting activities, durations and idle periods were recorded using the continuous timing method.

3.1 Defining a concreting cycle

Cycle Determination by RMC Arrival: Each Ready-Mix Concrete (RMC) batch (5-6 m³) was treated as one cycle, starting from the truck/pump setup to the finishing step.

Total Number of Cycles: Over 3 days, 42 cycles (~14/day) were recorded.

3.2 Activities within each cycle



3.2.1 Continuous timing method, data recording and organization

The data collection process involved uninterrupted observation, where start and stop times were logged in real time to ensure accuracy. Time log sheets or digital timers, such as stopwatches, were used to monitor each phase of the concreting activity systematically. Additionally, any idle periods caused by waiting, equipment malfunctions, or realignments were carefully recorded, allowing for a comprehensive capture of real-time delays. The duration of each sub-activity was calculated by subtracting the start time from the end time. The overall cycle duration included the total of all sub-activities combined with idle time. Daily summaries were compiled to track productivity patterns, and all data were consolidated into a master spreadsheet for further analysis.

3.3 Identifying and categorizing delays along with outcome of continuous timing

Delays or idle time have been documented as a result of issues with management, labor, materials, equipment, or the environment. The Method Productivity Delay Model (MPDM) was used to group these delays into the following categories: management, environment, materials, labor, and equipment. The most important bottlenecks influencing productivity were then determined by quantifying the delays over 42 cycles. Precise timelines for each of the 42 cycles were provided by the creation of detailed cycle profiles. By using these profiles as the basis for MPDM analysis, inefficiencies in the concreting process were found. Both recurring and one-time delays were identified by comparing the cycles, providing useful information for resolving productivity problems.

3.4 Observer roles and data accuracy

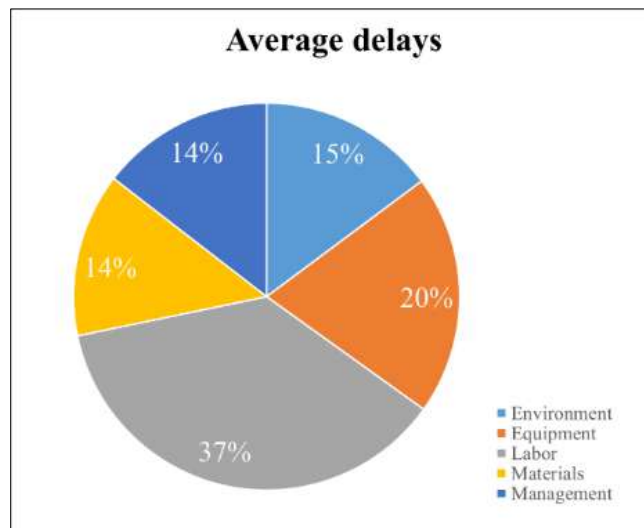
Observer roles were clearly defined, with two observers tracking RMC truck activities and two monitoring labor tasks, with periodic role rotation to maintain objectivity. Time measurement methods were improved using stopwatches, structured log sheets, and cross-verification for accuracy. Additionally, increasing the number of observations to 42 cycles, rotating observers, and rechecking entries helped reduce measurement errors and minimize inconsistencies.

4.0 Data Analysis and Findings

4.1 Delay categorization

- Labor Delays (37%): Workforce shortages, inefficient scheduling.
- Equipment Delays (20%): Pump failures, tower crane inefficiencies.
- Material Delays (14%): Late deliveries, inventory mismanagement.
- Environmental Delays (15%): Weather and regulatory issues.
- Management Delays (14%): Miscommunication and slow decision-making.

Figure 1: Average Delays in Pie Chart



4.2 MPDM processing

Table 1: MPDM Processing

	Total Production Time	Number of Cycles	Mean Cycle Time	Variance
(A) Non-Delay Production Cycles	33391	42	795	105
(B) Overall Production Cycles	58451	42	1392	229

Source: Compiled by authors

4.3 Delay information processing

Table 2: Delay Information Processing

	Delay				
	Environment	Equipment	Labor	Materials	Management
(C) Occurrences	9	8	40	13	11
(D) Total Added Time	1472	1836	18167	1753	1833
(E) Probability of Occurrence	0.2143	0.1905	0.9524	0.3095	0.2619
(F) Relative Severity	0.1175	0.1649	0.3263	0.0968	0.1197
(G) Expected % Delay Time per Production Cycle	2.5184	3.1412	31.0739	2.9977	3.1345

Source: Compiled by authors

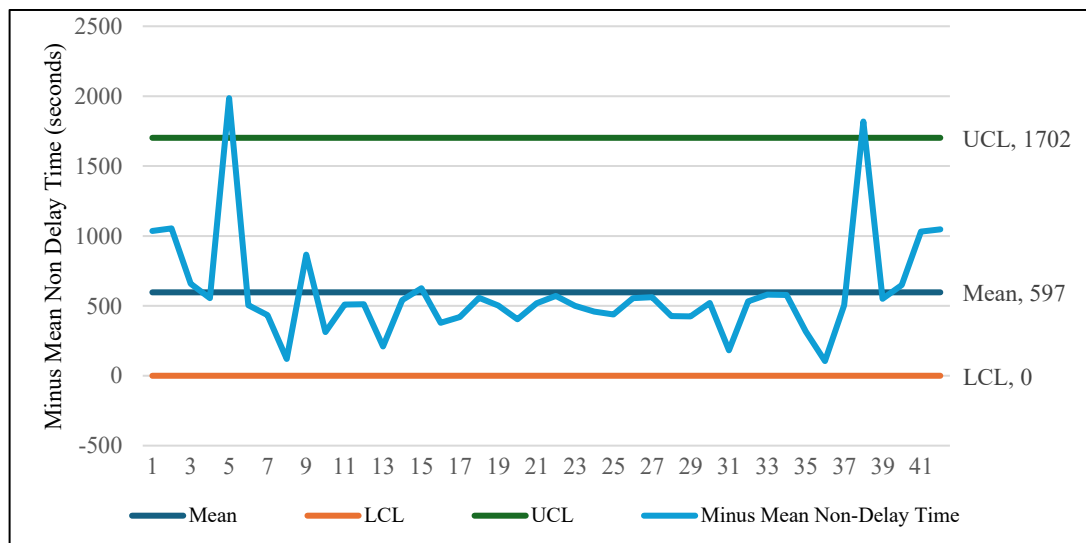
4.4 Productivity analysis

- Ideal Productivity: 4.5283 units/hr
- Actual Productivity: 2.5872 units/hr (Productivity loss: ~43%)
- Cycle Variability: 6.911, Higher fluctuations indicate process inefficiencies
- Productivity Efficiency: 57.13%

4.5 Statistical Insights

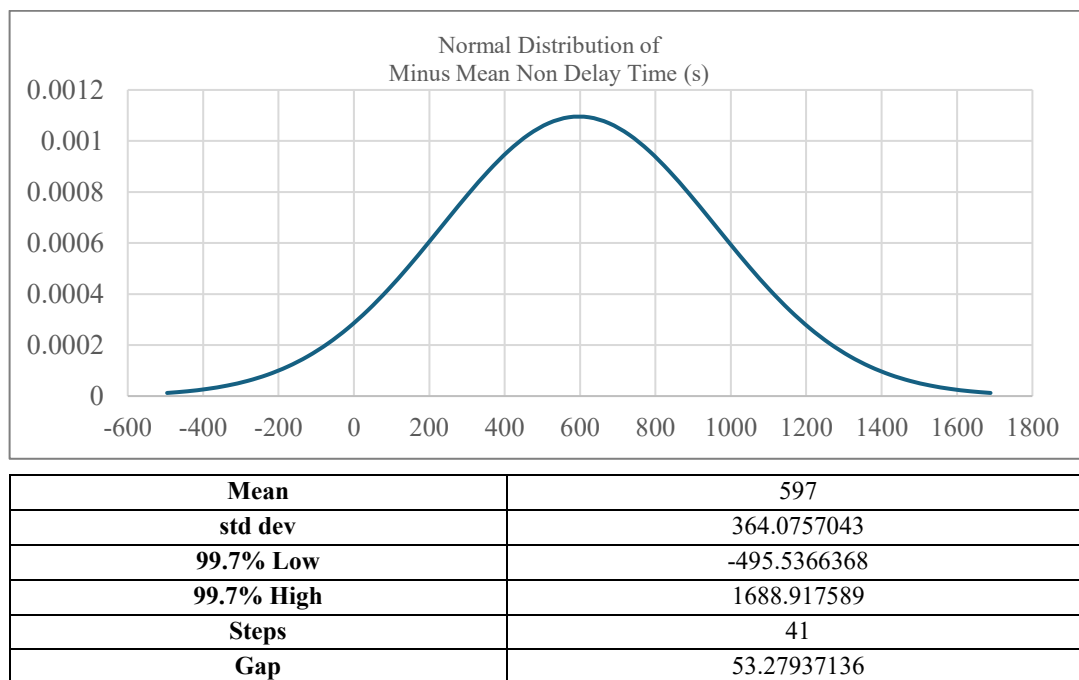
The control charts revealed deviations beyond acceptable limits, indicating irregular delays in certain cycles.

Figure 2: Control Chart



The normal distribution analysis confirmed that most delays fell within a predictable range; however, outliers significantly affected overall efficiency. This control chart visualizes the variation in Minus Mean Non-Delay Time (in seconds) across different cycles to assess the process stability and detect anomalies. A line showing actual cycle time variations – highlighting fluctuations over different cycles. Most the cycles remained within control limits, fluctuating between 0 and 1000 seconds, indicating that delays were within an acceptable range. This suggests a stable process with potential for improvement. However, two major outliers — Cycles 5 and 38 — exceeded the Upper Control Limit (UCL), indicating significant delays in these specific instances. Additionally, while several cycles hovered close to the mean line of 597 seconds, performing as expected, a few cycles approached the Lower Control Limit (LCL) of 0 seconds, suggesting minimal or no delays and indicating an optimized workflow.

Figure 3: Normal Distribution Curve



The normal distribution curve illustrates the spread of minus mean non-delay time (s) around the mean value of 597 seconds. The bell-shaped pattern suggests that most observations cluster around the mean, with a moderate spread indicated by a standard deviation of 364.08 seconds. This implies that while most values are close to the average, some show notable deviations. The 99.7% confidence range, spanning from -495.54 seconds to 1688.92 seconds, captures almost all data points, highlighting occasional extreme variations. The curve's symmetry shows that deviations on both lower and higher ends are balanced, ensuring a fair distribution. This visualization helps assess the reliability of measured times, predict future delays, establish acceptable time variation thresholds, and conduct risk assessments for the concreting process.

5.0 Conclusion, Limitations and Recommendations

Conclusion: The study used statistical tools like pie charts, bar charts, control charts, and normal distribution graphs to analyze delays in the Nayati Evoque residential project. Material shortages (14%) and labor inefficiencies (37%) were the primary delay factors. External issues like weather and regulatory approvals added 15% more delays. Concrete operations alone caused 25% of delays due to equipment issues and inconsistent cycles. Control

charts revealed significant variations, while the normal distribution showed an average delay of 597 seconds. Overall, better planning, real-time tracking, and advanced technologies like AI could reduce delays and enhance efficiency.

Limitations: The study's scope is limited to a single project, reducing the generalizability of its findings. Uncontrollable factors like strikes or weather and reliance on manual data collection can introduce errors. Short observation periods limit long-term insights, and the study relies heavily on industry benchmarks that may not apply everywhere. Despite these limitations, the study offers a foundation for future research with more extensive data and advanced technologies.

Recommendations: Future research should include multiple projects for broader insights. Automated data collection using AI, sensors, and IoT can reduce human errors. Advanced statistical tools like machine learning can improve analysis, while global standards can enhance relevance. Including stakeholder feedback can provide a deeper understanding of on-site challenges.

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CHAPTER 20

Assessing the Impact of Energy Projects in Meeting the Sustainable Development Goal 7 (SDG 7)

Priyanka Challapalli¹, Dheeraj Banda², Sathvika Bathoju² and Nishanth Ballur A.²

ABSTRACT

Achieving the Sustainable Development Goal 7 (SDG 7) universal access to affordable, reliable, sustainable and modern energy remains a challenge with implications on the global economic growth, social equity and environmental sustainability. This study explores how renewable energy projects contribute to sustainable development with an emphasis on the Indian context. The research examines the energy landscape in India, the progress towards SDG 7, and the barriers to the acquisition of clean energy. The paper utilizes the mixed method research technique by combining secondary literature reviews, policy analysis, and case studies with primary research using semi-structured interviews with industry experts from Thermax and Thyssenkrupp. The data is evaluated by comparing and analyzing and identifies patterns and challenges that are important in India's transition to energy. The findings indicate that while India has made significant strides in expanding its renewable energy capacity by undertaking solar, wind, and green hydrogen initiatives, there are still several challenges that continue to impede the large-scale adoption of renewable energy. These challenges include policy gaps, financial constraints, technological limitations, and energy storage inefficiencies. The case study research underscores the importance of public-private partnerships, decentralized energy solutions, and policy incentives in expediting the transition to renewable energy. By comparing Indian and global case studies, this research identifies best practices that can be adapted to strengthen India's renewable energy framework. The paper shows an evidence-based analysis of the progress India has made in clean energies. It identifies the major challenges and provides several policy recommendations on how to improve the accessibility, efficiency, and sustainability of energy.

Keywords: Clean energy transition; Sustainable Development Goal 7 (SDG 7); Renewable energy adoption; Energy efficiency; Green hydrogen; Decentralized energy systems; Climate policy and regulation; Public-private partnerships.

1.0 Introduction

Background: Energy is one of the most important drivers of economic growth, social development and environmental sustainability.

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It regulates the consumption of resources and is associated with all spheres of human life, from industrial production to housekeeping. It is one of the most crucial factors contributing to the development of the nation. To conclude, an increase in the demand for energy resources and the growth of concern about climate change, resource depletion and environmental degradation are the main reasons why a transition to renewable energy is happening (IEA, 2023). Energy is one of the most important drivers of economic growth, social development and environmental sustainability. It regulates the consumption of resources and is associated with all spheres of human life, from industrial production to housekeeping. It is one of the most crucial factors contributing to the development of the nation.

To conclude, an increase in the demand for energy resources and the growth of concern about climate change, resource depletion and environmental degradation are the main reasons why a transition to renewable energy is happening (IEA, 2023). The United Nations Sustainable Development Goals (SDGs) highlight energy as a transformative factor in development, especially in SDG 7. The goal of SDG 7 is to ensure access to affordable, reliable, and sustainable energy for all by the year 2030 (United Nations, 2022). Clean energy access is associated with SCG 13 (Climate Action) and SCG 9 (Industry, Innovation, and Infrastructure). Thus, this goal helps in enhancing economic resilience and decarbonization. However, even though there has been global progress, many developing countries are currently grappling with the issue of achieving SDG 7. In India, for example, demand for energy is on the increase (World Bank, 2023).

1.1 Aim and objectives

This study evaluates energy projects' business models, socio-economic outcomes, and environmental sustainability to determine their influence on SDG 7 and associated SDGs. It identifies obstacles, opportunities, and solutions to promote clean energy adoption in India for a sustainable and equitable energy transition.

Objectives:

- How do energy projects in India shape their business models to align with specific Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy)?
- What challenges do energy projects in India face in delivering sustainable solutions without compromising the achievement of SDGs, and what strategies are employed to address these challenges?

1.2 Scope

The study here deals with renewable energy projects and the contribution towards Sustainable Development Goal 7 (SDG 7) by studying major sources like solar, wind, bioenergy, and new renewable technologies for India. The study incorporates major components of SDG 7, such as energy access, adoption of renewable energy, and efficiency. It also assesses

the policy frameworks, financial mechanisms, and socio-economic impacts of clean energy programs. The research is limited to actual case studies in real life, policy measures, and investment patterns in India's renewable energy market, giving an exhaustive insight into the country's transition to clean energy.

2.0 Methodology

Energy projects and SDGs are assessed in four phases in this study. Renewable energy adoption and business model literature, case studies, and policies are examined in secondary research. Researchers interview and survey stakeholders for primary research. Comparative examination reveals large-scale, decentralised, and hybrid energy project patterns, successes, and obstacles. Synthesis and suggestions offer policy insights and roadmaps for clean energy adoption and sustainability.

Table 1: Methodology Chart

Step	Objective	Key Activities	Deliverables
Secondary Research	Build foundational knowledge	Data collection from academic papers, reports, and case studies	Database of sources, preliminary analysis
Primary Research	Gather first-hand stakeholder insights	Semi-structured interviews and surveys	Qualitative insights on projects and business models
Comparative Analysis	Identify themes and differences	Compare case studies, stakeholder data, and SDG 7 metrics	Comparative matrix summarizing outcomes and strategies
Synthesis & Conclusion	Integrate findings and propose solutions	SWOT analysis, policy gap identification, recommendations	Detailed conclusion with best practices and policy insights

Source: Compiled by authors

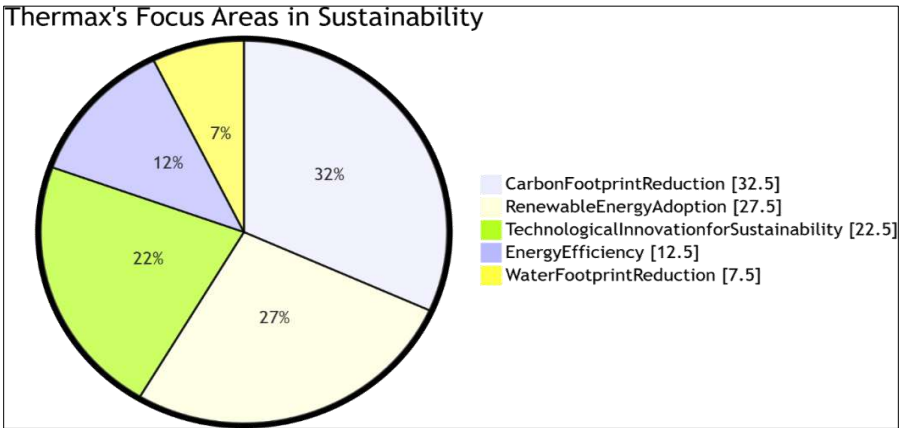
This study utilizes a mixed-method research methodology, combining secondary research (literature review, case study analysis, and policy evaluation) with primary research (stakeholder interviews and surveys). The technique employs a systematic, multi-phase approach, guaranteeing a comprehensive understanding of sustainable energy initiatives in India and their correspondence with Sustainable Development Goal 7 (SDG 7). The study is to examine diverse business models, evaluate policy efficacy, and measure socio-economic effects pertaining to energy access, efficiency, and sustainability. methods.

3.0 Data Analysis and Results

3.1 Stakeholder interview analysis

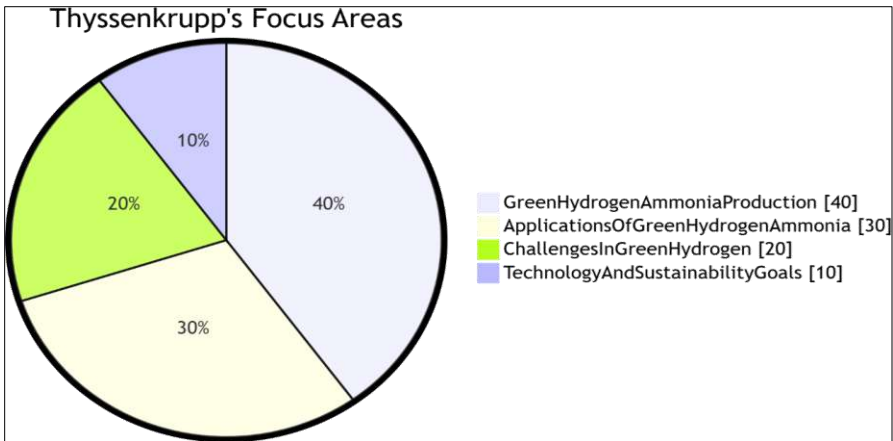
Figure 1 presents the main sustainability focus areas for Thermax, as indicated by the interview data. The size of each slice shows the relative proportion of attention given to each area during the interview. Thus, the focus areas for Thermax in terms of sustainability are Carbon Footprint Reduction and Renewable Energy Adoption since the slices representing these aspects are the largest on the diagram.

Figure 1: Thermax’s Focus Areas in Sustainability



Source: Compiled by authors

Figure 2: Thyssenkrupp’s Focus Areas



Source: Compiled by authors

This allows inferring that Thermax is actively engaged in reducing its carbon emissions and increasing the share of renewable energy sources in its operations. In a similar manner, it can be inferred that Technological Innovation for Sustainability is also a key focus area for Thermax since the corresponding slice is large. This implies that the company uses artificial intelligence (AI) and other technologies to improve its efficiency and other sustainability-related aspects. While Energy Efficiency is also a focus area for the company, it is discussed in terms of specific initiatives. In contrast, Water Footprint Reduction is only discussed in terms of the Net Zero water plant, which is why the respective slice is relatively small. Overall, the figure is based on the qualitative data from the interview and is intended to provide a visual representation of the sustainability priorities of Thermax.

Table 2: Comparative Analysis of the Interviews

Feature	Thermax	Thyssenkrupp
Core Focus	Reducing operational electricity consumption and carbon footprint.	Providing green hydrogen/ammonia technologies for industry.
Energy Saving	Implement LED lighting, motion sensors, timers.	Enables energy transition in other industries.
Carbon Footprint	Focuses on Scope 1, 2 (electricity), and 3 emissions.	Reduces CO ₂ by enabling green alternatives to carbon-heavy processes.
Renewable Energy	Uses solar power (rooftop, Open Access).	Uses renewables (solar, wind, hydro) for green hydrogen.
Key Projects	Solar project at Shirwal plant.	Green hydrogen plant; Saudi green ammonia project.
Technology	AI for boiler design, machine monitoring, remote performance.	Digital twins, AI tools.
Challenge	Regulatory delays and complex approval processes hinder green energy project implementation.	High green hydrogen cost.
Goal	Zero carbon by 2030; Net Zero water.	Net Zero emissions by 2045.
Application	NA	Steel, refineries, ammonia, power.

Source: Compiled by authors

In Figure 2, the primary areas of focus for Thyssenkrupp are outlined based on the interview data. The size of each slice shows how much relative emphasis the interviewee placed on each area of focus. Green Hydrogen/Ammonia Production is the largest focus area in the interview data, which relates to the company's focus on developing green hydrogen and ammonia technologies. Applications of Green Hydrogen/Ammonia are the next largest focus area, which suggests that the company is interested in other industries or areas that could use green hydrogen and ammonia. Challenges in Green Hydrogen is the next area of focus, as there are economic challenges to using green hydrogen. Technology and Sustainability Goals are of less focus in the interview data. The focus on each area is qualitatively determined from the interview and is shown for illustration purposes.

3.2 Case study analysis

Table 3: Summary of Indian Case Studies and their Alignment with Research Questions

Case Study	Business Model & Alignment with SDG 7	Challenges in Sustainable Implementation	Strategies for Overcoming Challenges
Kasai Village Biomass Project, Madhya Pradesh	Community-managed with government capital investment; SDG 7 achieved through biomass energy for off-grid areas.	Reliance on traditional biomass for cooking, potential indoor air pollution; need for biogas integration.	Integrating biogas for cooking, enhancing community awareness of clean energy benefits.
Gosaba Biomass Power Plant, West Bengal	Rural Energy Cooperative manages the plant, ensuring financial and operational sustainability; SDG 7 supported through biomass electrification.	Ensuring continuous biomass fuel supply, requiring dedicated energy plantations.	Developing dedicated agroforestry for sustained biomass supply.
Gramme Vikas Renewable Energy Projects, Odisha	Community-financed renewable energy solutions integrating solar, biodiesel, and water supply; aligns with SDG 7 and SDG 6.	Sustaining financial contributions from communities and addressing technical maintenance issues.	Expanding technical training programs and financial incentives for long-term community participation.
Ladakh Micro-Hydro and Solar PV Initiative	Community-operated micro- hydro plant, supplemented with solar PV for energy reliability; aligns with SDG 7 and SDG 9.	Seasonal variability in hydro energy output; need for energy storage solutions to improve reliability.	Hybrid energy model with solar PV as a backup; investment in battery storage solutions.
BERI Biomass Energy Project, Karnataka	Self-help groups involved in biomass fuel supply, ensuring sustainable energy access; aligns with SDG 7, SDG 13, and SDG 8.	Sustainable forestry practices needed to prevent biomass depletion and ensure long-term viability.	Implementing community-led reforestation programs and monitoring biomass usage.

Source: Compiled by authors

3.3 Summary of key findings and challenges in India's energy transition

This section synthesizes stakeholder interview insights, Indian and international case studies, and additional research to assess whether India's clean energy projects conform to SDG 7 while identifying major impediments to its clean energy transformation. Stakeholder interviews indicate that although Thermax's emphasis on energy efficiency and Open Access procurement of solar energy has resulted in substantial savings of electricity, bureaucratic delays and acquisition of land obstruct progress (MNRE, 2023).

Likewise, Thyssenkrupp's investment in green hydrogen and ammonia manufacturing is major steps towards industrial decarbonization, although economic feasibility issues, scarce hydrogen infrastructure, and expensive capital costs are principal challenges (MNRE, 2023). Both companies recognize the promise of AI and IoT technologies to maximize energy

efficiency but are hindered by fragmented policy frameworks and weak financial incentives for their wider use (IRENA, 2023).

Table 4: Summary of Global Case Studies and their Alignment with Research Questions

Country	Project Type	Key Features	Alignment with SDGs	Challenges
Germany	Wind Energy (Onshore & Offshore)	Feed-in Tariffs, Community Wind Ownership, Grid Integration	SDG 7, SDG 9, SDG 13	Grid congestion, Land acquisition opposition
Denmark	100% Renewable Transition	Offshore Wind, Community-Owned Projects, Energy Trading	SDG 7, SDG 12, SDG 17	Energy intermittency, Grid balancing
China	Large-Scale	Government-Supported Solar Farms, Storage	SDG 7, SDG 9, SDG 13	Grid integration, Remote location
	Solar Power	Investments	9, SDG 13	challenges
Bangladesh	Solar Home Systems	PAYG Financing, Microfinance Support, Rural Electrification	SDG 7, SDG 1, SDG 10	Maintenance costs, Donor dependence
Kenya	Solar Mini- Grids	Mobile-Based Payments, Off-Grid Energy Access, SME Support	SDG 7, SDG 8, SDG 11	Financing constraints, Regulatory challenges

Source: Compiled by authors

Indian case studies demonstrate that community-led renewable projects like biomass-based rural electrification and solar microgrids have successfully enhanced energy access and socio-economic conditions; however, these projects are plagued by financial sustainability concerns, maintenance issues, and resource constraints (World Bank, 2023). Government-backed initiatives, although enjoying state subsidies and funding mechanisms, are plagued by bureaucratic inefficiencies, policy lags, and uneven state-level policies that hinder their effectiveness (MNRE, 2023). International experiences in Germany, Denmark, China, Bangladesh, and Kenya highlight the need for sustained policy support, strong financing, and new models like state-led solar expansion, PAYG finance, and mobile-powered mini-grids, which may provide important lessons for India (German Federal Ministry for Economic Affairs and Energy, 2023; IEA, 2023; IRENA, 2021). In all, some of the key problems identified are regulatory gridlocks, significant initial capital expenditures on clean energy technologies, and infrastructural bottlenecks such as limited energy storage facilities and ageing grid infrastructure, all of which need to be redressed to stimulate India's clean energy revolution (World Bank, 2023; IEA, 2023).

4.0 Conclusion and Recommendations

4.1 Conclusion

This study evaluated the role of energy projects in helping achieve SDG 7 by examining business models, sustainability strategies, and challenges of implementation. Findings from stakeholder interviews with Thermax and Thyssenkrupp indicated that Thermax emphasizes energy efficiency and AI-driven solutions but are hindered by regulatory and infrastructure issues. Thyssenkrupp, a pioneer in green hydrogen and ammonia technologies, is limited by high costs and the lack of a robust hydrogen economy. Both firms placed a strong stress on the need for policy stability and funding to propel clean energy objectives (Stakeholder Interviews, 2023). Indian examples like the Kasai Village and Gosaba Biomass schemes highlighted the socio-economic advantages of decentralized renewable energy but indicated problems on issues of fuel sustainability and economic viability (IRENA, 2021). International case studies from Germany, Denmark, and China showed how long-term policy support, technological development, and financial assistance have facilitated the widespread implementation of renewable energy (IEA, 2023). Such cases offer replicable models that India can emulate.

The study identified that the convergence of energy projects with SDG 7 entails a mix of adoption of clean energy, energy efficiency, and policy-based financial incentives. But the major barriers persist, such as policy gridlock, finance, delays in land acquisition, and poor community engagement—highlighting the need for regulatory reforms and streamlined investment processes (World Bank, 2023). In summary, even with significant advancements, India needs to ramp up renewable energy projects, embrace new technologies such as AI, and attract sustained investment to achieve long-term success in its energy transition (UNDP, 2023).

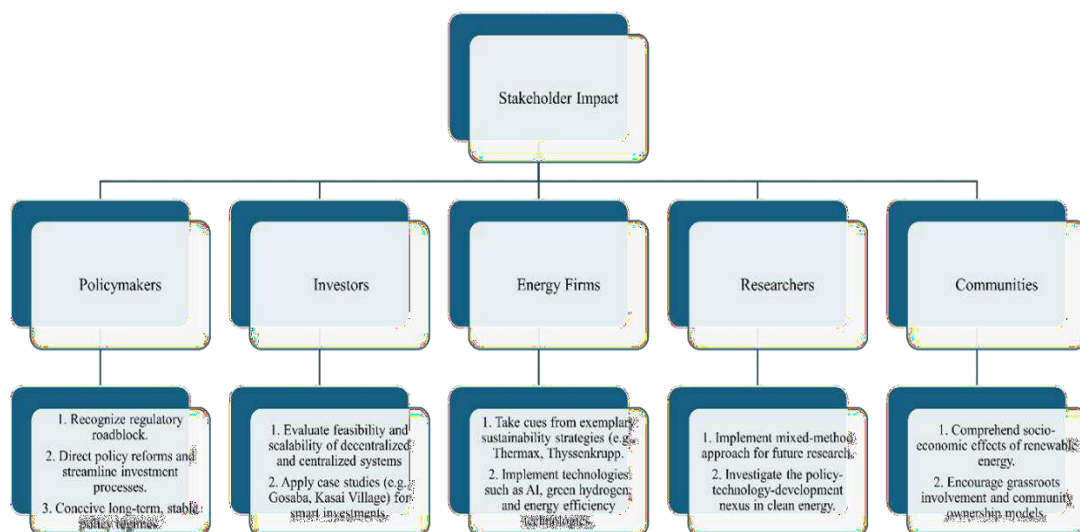
4.2 Stakeholder impact

This study presents valuable lessons for a broad range of stakeholders to undertake the clean energy transition. Policymakers can use the findings to identify regulatory roadblocks and prioritize reforms that ease investment and implementation processes (MNRE, 2023; World Bank, 2023). The emphasis on policy stability and economic incentives highlights the need for balanced, long-term policy frameworks to attract private sector participation (IEA, 2023).

Energy operators and industrial actors can benefit from insights into the best practices in sustainability—like Thermax and Thyssenkrupp’s—like the integration of AI, green hydrogen, and energy efficiency (Stakeholder Interviews, 2023; UNDP, 2023). Investors and renewable project developers can ascertain the scalability and feasibility of decentralized renewable projects, like the Kasai Village and Gosaba case studies, to guide future investment (IRENA, 2021; World Bank, 2023). Local communities and civil society organizations cultivate understanding of the socio-economic impacts of renewable energy initiatives and the way such initiatives can drive grassroots engagement as well as fuel sustainability (IRENA, 2023; UNDP,

2022). Scholars and academicians, finally, can capitalize on the analysis framework of the study in the sense of deeper exploration of relationship between sustainable development outcomes, policy paradigms, as well as technological innovation (IEA, 2023; UNDP, 2023).

Figure 3: Stakeholder Impact Map



Source: Compiled by authors

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CHAPTER 21

Assessing the Potential Lean in Megaprojects

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Krushnaji Kiran Shesharao¹ and Tushar Chandrakant Chaudhari¹*

ABSTRACT

Megaprojects are the economic drivers of infrastructure development. The megaproject delivery is often faced with Challenges in lean megaprojects, including complex coordination of stakeholders, logistical complexities, resistance to change, underutilization or overproduction of resources, inconsistencies in quality control, increased safety risks, and schedule. Also delays, data integration problems, environmental impact management, and cost overruns. Strong control over time management, costs, and optimizing available resources are, however, key to achieving mega-infrastructure success. The principles of Lean Construction approach these issues using tools such as Value Stream Mapping (VSM) to remove waste, standardize processes, and optimize the use of resources. Techniques like Kanban and focus on the Seven Wastes of Lean, including overproduction, waiting, transportation, overprocessing, inventory, motion, and defects improve operational efficiency. These practices also enhance stakeholder communication, impose structured workflows for safety, and clarify project scopes. Lean methodologies optimize the bidding process, reduce ambiguity in contracts, and align the goals of the stakeholders, resulting in cost savings, safety, and improved project collaboration. Navi Mumbai International Airport is where the Lean principle comes alive. This mega-project with over \$1 billion, having complex logistics and stakeholder coordination incorporates Lean to address NMIA's challenges. Designed for an initial capacity of 12 million passengers that can scale to 60 million passengers spread across 2,865 hectares, it uses meticulous planning and resource optimization to ensure efficient execution.

Keywords: Lean construction; Megaprojects; Navi Mumbai International Airport; Logistics complexities; Stakeholder coordination; Quality control; Resource optimization; Value stream mapping; Kanban; 7 wastes of lean; Safety management; Cost overruns.

1.0 Introduction

Megaprojects are the foundation of contemporary infrastructure, defining cities and economies. Yet, they tend to be plagued by cost overruns, delays, and inefficiencies because of their magnitude and complexity.

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To counter these issues, Lean Construction provides a more intelligent solution—eliminating waste, enhancing collaboration, and streamlining workflows to maximize overall efficiency. This research investigates the effects of Lean Construction in megaprojects based on a case study of the Navi Mumbai International Airport (NMIA). NMIA shows how lean methods such as Value Stream Mapping (VSM), Kanban, and the Last Planner System (LPS) make processes smooth, enhance decision-making, and foster sustainability. Through this observation, the research brings out how Lean Construction has the potential to transform big-ticket infrastructure projects so that they become more successful in the long term.

1.1 Research objectives

- To know the role of lean construction in megaprojects,
- To understand what are the benefits of Integrated Project Delivery (IPD)?
- To know how digital twins enhance decision-making in construction?
- To learn how does lean construction promote sustainability?
- To understand how the Last Planner System (LPS) improves workflow?

1.2 Scope of study

Lean construction maximizes project planning, supply chain, workflow, quality, and risk management by eliminating waste and enhancing efficiency. Collaboration with stakeholders earlier on reduces uncertainty, while lean supply chain minimizes material wastage and dependency. Non-value activities are removed to increase productivity, and a culture of improvement enhances quality control. Joint risk management responsibility fosters proactive solutions of issues. All these factors combined promote efficiency, cost savings, and sustainability in megaprojects.

1.3 Limitations of study

Although this study offers useful findings, it is mainly case studies and secondary data-based, thus being context-specific. The results, focused on the NMIA project, might not apply to all megaprojects. In addition, external variables like regulatory policies, economic environments, and unexpected risks might affect the efficacy of lean methodologies in practice. While these constraints exist, the research provides a good basis for understanding and applying Lean Construction principles across various project contexts.

2.0 Literature Review

Kemppainen *et al.* (2003) concluded that Lean principles for infrastructure projects minimized mass haul distances and material volume, and this produced cost savings and environmental advantages. Rad *et al.* (2010) discovered that Lean strategies such as JIT, VSM, and LPS enhanced disaster recovery by mitigating delays and improving stakeholder

coordination. Maraqa *et al.* (2011) noted that combining BIM and Lean Construction reduced waste and enhanced sustainability through optimized use of resources. Nowotarski *et al.* (2012) indicated that Lean implementations in construction projects improved cost management, labor productivity, and scheduling effectiveness. Solaimani & Sedighi (2010) pointed out that Lean initiatives harmonize economic, environmental, and social considerations, enhancing safety and minimizing carbon footprint.

Gaoa *et al.* (2015) discovered that Lean-based safety management systems, such as digital monitoring and 5S methodology, greatly minimized on-site risks. Jagannathan *et al.* (2013) recognized major hindrances to Lean implementation in India, highlighting policy reforms and training programs for successful implementation. Shaqour (2011) concluded that Lean initiatives such as LPS and 5S enhanced productivity and resource utilization in Egypt's construction sector. Singh *et al.* (2018) noted that developed economies have embraced Lean Construction extensively, while emerging economies require tailored Lean models for enhanced implementation.

Smalla *et al.* (2012) concluded that institutional resistance, absence of professional experts, and initial high costs were major deterrents to the adoption of Lean in Dubai, recommending policy incentives and training as remedies. According to the literature review carried out, it has been noted that a majority of studies on applying Lean Construction to transport infrastructure depend on surveys as opposed to live site applications, especially in India. This research will aim at addressing the site element, the application of Lean tools and techniques to overcome waste production, and comparison between traditional construction methods and Lean methods in Indian megaprojects.

3.0 Methodology

3.1 Data collection

Megaprojects are instrumental in designing contemporary cities and economies, yet they are frequently plagued by cost overruns, delays, and inefficiencies. Their enormity and complexity require creative solutions to guarantee successful implementation. Lean Construction provides the answer by reducing waste, promoting collaboration, and optimizing workflows to improve efficiency.

This research examines the influence of Lean Construction in megaprojects, using the Navi Mumbai International Airport (NMIA) as the subject of focus. Spread over 2,865 hectares, NMIA is planned to decongest Chhatrapati Shivaji Maharaj International Airport (CSMIA) in Mumbai. This \$5.63 billion PPP project incorporates Lean practices like Value Stream Mapping (VSM), Kanban, and the Last Planner System (LPS) to enhance efficiency and sustainability. Through the study of NMIA, this study illustrates how Lean Construction can transform mega-scale infrastructure projects to deliver improved results and long-term success.

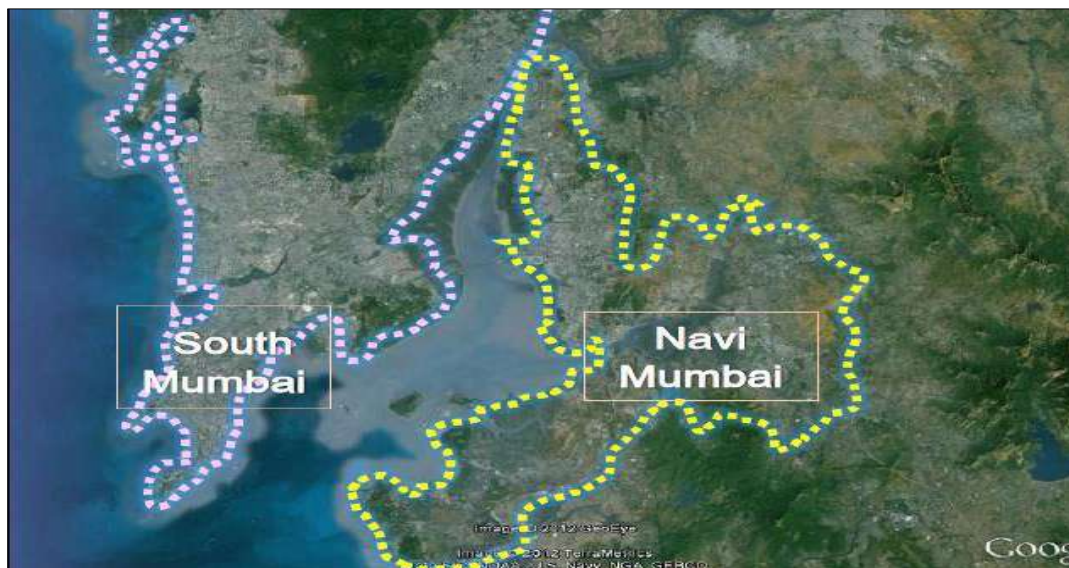
Table 1: Project Description

Project	Navi Mumbai International Airport
location	Panvel, Navi Mumbai, Maharashtra, India
Total area	~1,160 hectares (2,870 acres)
Estimated cost	₹16,000 crore (US\$1.9 billion)
Capacity	Initial Phase: 20 million passengers per annum (MPPA) Final Phase: 90 MPPA (by 2040)
Runways	Two parallel runways (3,700m & 3,800m)
Developer	City and Industrial Development Corporation (CIDCO) & Adani Group

Project execution and major contractors

- Design & Master Plan: Developed by Louis Berger-INECO-RITES consortium.
- Terminal Architecture: By Zaha Hadid Architects.
- EPC Contractor: Larsen & Toubro (L&T) Construction.
- Environmental Impact Study: Prepared by Bombay Natural History Society (BNHS).
- Financial and Legal Advisory: SBI Capital Markets and Cyril Amarchand Mangaldas.

Figure 1: Navi Mumbai International Airport Futuristic Planning

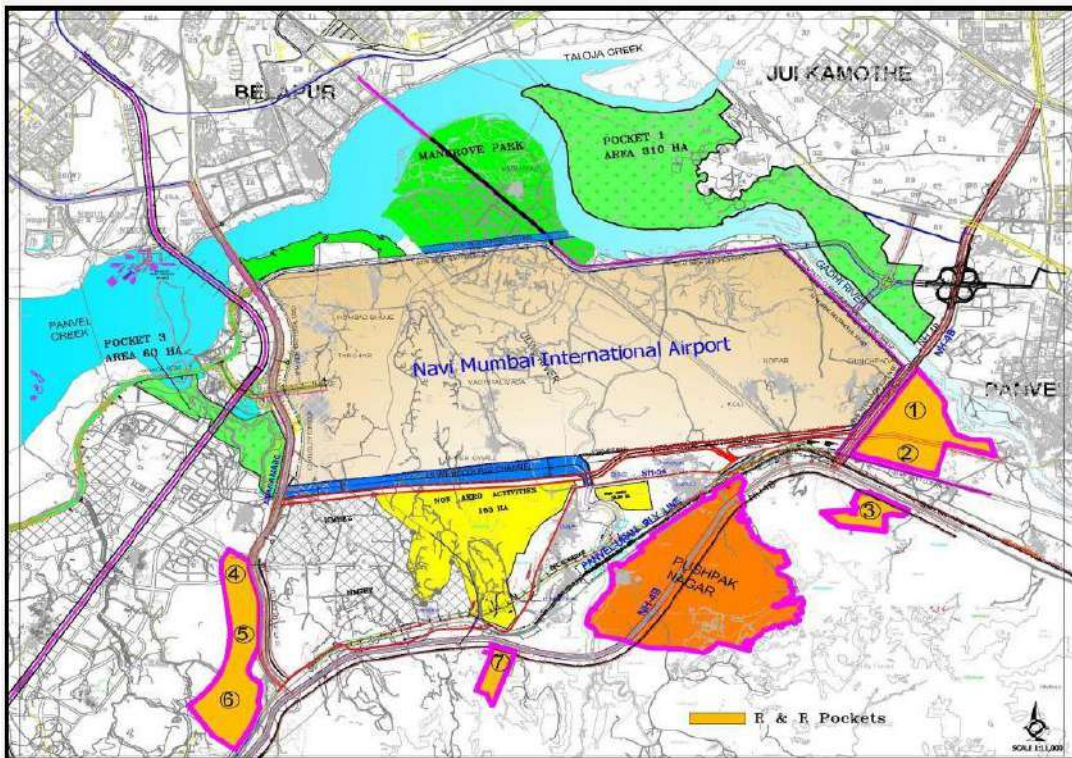


Source: Global Coastal Cities Summit 202, CIDCO

NMIA is planned to cater to the increasing air traffic needs of the Mumbai Metropolitan Region (MMR). Passenger capacity will be expanded in phases, beginning with 10

million passengers per year in 2024 and up to 60 million after 2032. The airport will have two parallel runways (3,700m each), three passenger terminals, and exclusive cargo terminals (23,700m² international, 33,000m² domestic). Further infrastructure consists of three aircraft hangars, a 151,000m² fuel farm, and 25,000m² for ground and catering services, providing smooth operations and future scalability. Sanctioned in 2008, NMIA is constructed in four phases on a DBFOT (Design-Build- Finance-Operate-Transfer) pattern with a concession period of 30 years. Although initially proposed to start operations in 2020, due to land acquisition problems, financial closures, and the COVID-19 pandemic, the schedule has been delayed. The first phase is now set to be completed by December 2024 with the help of a ₹127.7 billion (\$1.67 billion) debt facility guaranteed by SBI.

Figure 2: Environmental Sensitive Areas



Source: Global Coastal Cities Summit 2023, CIDCO)

Also, NMIA incorporates Lean Construction concepts to increase efficiency and sustainability. Major applications involve Value Stream Mapping (VSM) for logistics optimization, Just-in-Time (JIT) Delivery for lowered storage costs, and Prefabrication &

Modular Construction for quicker assembly. Digital Twin Technology & BIM facilitate real-time monitoring, while sustainable practices like green building certification, rainwater harvesting, and energy-efficient infrastructure minimize the carbon footprint. By embracing these practices, NMIA wants to provide a benchmark for efficient and sustainable megaproject development.

3.2 Data analysis

The Navi Mumbai International Airport (NMIA) encountered major challenges prior to breaking ground. Land acquisition and site clearing involved the relocation of 5.5 million cubic meters of soil, soil stabilization, and drainage planning because of soft clay and waterlogging close to Panvel Creek. Approvals from regulatory bodies were slow, especially because of environmental issues close to the Karnala Bird Sanctuary, necessitating clearances from several authorities. Financial issues were caused by changes in ownership from GVK to Adani Group, as well as increasing material prices impacting initial cost estimates.

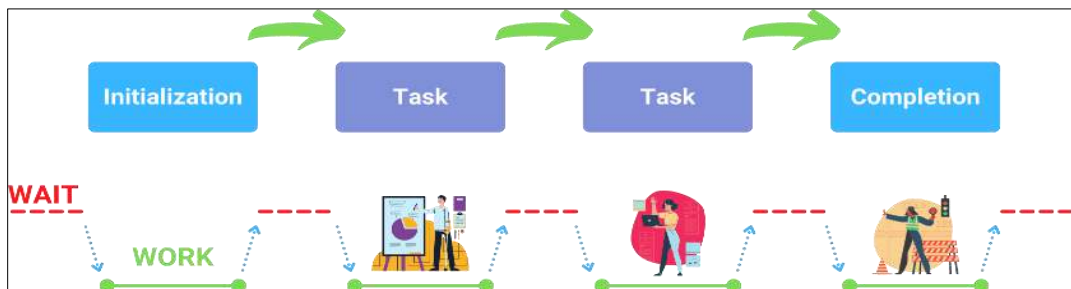
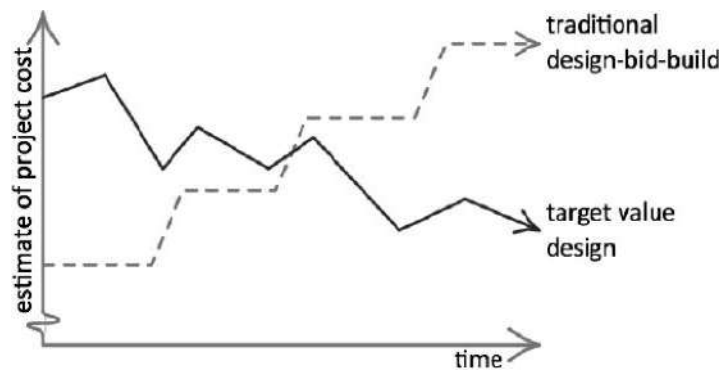
After the commencement of construction, runway and airside development needed high-load-bearing pavement and sophisticated navigation systems, but monsoons and unexpected delays hampered progress. The lotus-shaped terminal presented structural and engineering issues, while delays in importing major systems such as HVAC, baggage handling, and aerobridges further delayed completion. Issues related to utility, i.e., high water table levels, integration of solar power, and delayed waste management infrastructure, also affected timelines. Connectivity issues, including delays in projects like Mumbai Trans-Harbor Link, Sion-Panvel Expressway, and Metro Line 8, impacted access, while COVID-19 supply chain breakdowns delayed essential material and equipment. Shortages in labor in skilled fields such as BIM-based construction and AI-based airport systems further disrupted project advancement.

Even after initial build, testing and commissioning took longer because integration of ILS, radar, and ATC systems was delayed. Compliance with regulations also consumed more time and involved DGCA and AAI approvals, plus environmental audits to obtain green airport certification. Excess spending meant added financial burdens, with protracted timelines enhancing penalties and project costs overall.

4.0 Findings and Discussion

4.1 Pre-construction phase solutions

Even before construction had commenced, the Navi Mumbai International Airport had been through major hurdles, ranging from land acquisition through regulatory setbacks and financial uncertainty. In addressing these challenges, the team embraced Lean methods for better efficiency and coordination. The Last Planner System (LPS) ensured that all stakeholders were synchronized, minimizing miscommunication and maintaining site preparation on target. Value Stream Mapping (VSM) located inefficiencies in logistics so that operations could be smoother.

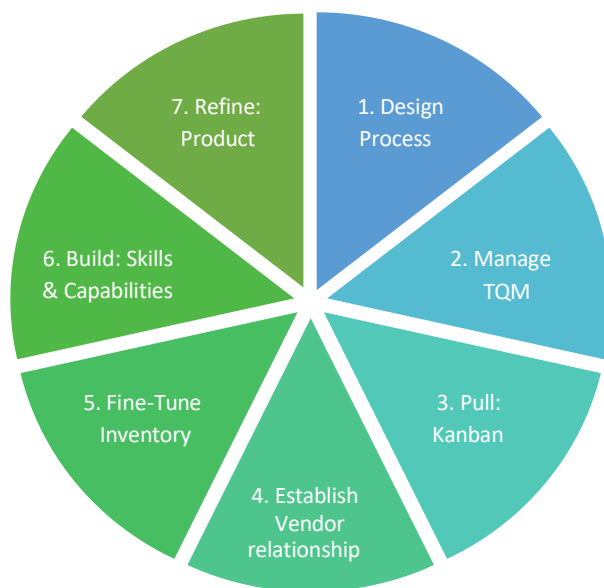
Figure 3: Value Stream Mapping**Figure 4: Target Value Design**

Regulatory approvals were another significant hurdle, particularly with stringent environmental regulations. Integrated Project Delivery (IPD) facilitated early interaction with authorities, accelerating permits and minimizing bureaucratic delays. Digital Twin Technology offered real-time environmental simulations, guaranteeing regulatory compliance and avoiding last-minute surprises. Financially, Target Value Design (TVD) facilitated cost-effective choices, while Lean Accounting allowed real-time budget monitoring, avoiding overruns and smooth financial handovers.

4.2 Construction phase solutions

Construction of NMIA was enormous, but Lean Construction ensured the job remained on course. Just-in-Time (JIT) Delivery allowed materials to reach the site precisely when required, minimizing waste and excess storage. 5S methodology ensured work areas remained tidy, while BIM technology enabled real-time monitoring of runway alignment and drainage systems, reducing mistakes and rework.

Figure 4: JIT Just-in-Time



Weather was another issue, particularly during monsoon months. Poka-Yoke (Error Proofing) and Lean Six Sigma maintained quality control to avoid material damage and construction flaws. To accelerate terminal construction, Prefabrication & Modular Construction facilitated large items such as HVAC equipment and baggage handling units to be constructed off-site and erected in a matter of weeks. Digital Twin Technology further improved scheduling and resource utilization.

Utility and infrastructure coordination was also intricate. Pull Planning coordinated utility work to correspond with other construction activities to prevent delays. Critical Chain Project Management (CCPM) coordinated dependent projects such as the Mumbai Trans-Harbor Link and Metro extensions to ensure airport connectivity readiness on schedule. In times of the COVID-19 pandemic that caused a global supply chain disruption, Lean Procurement Strategies and Multi-Sourcing allowed for alternative suppliers, avowing project delay.

4.3 Post-construction phase solutions

As NMIA approached completion, operationally smooth-running was a major priority. Standardized Work procedures optimized testing of navigation, security, and baggage systems, with Kaizen providing continuous improvement momentum. A3 Problem- Solving was used to speed up regulatory approvals, and Design for Maintainability (DfM) provided long-term reliability of essential systems. From a financial perspective, Earned Value Management (EVM) tracked costs, with TVD managing cost-effective facility upgrades so that the project remained financially viable.

5.0 Conclusion

This Lean Construction research for megaprojects, case-study NMIA, depicts how Lean fundamentals overcome most daunting issues such as delays in acquiring land, administrative issues, inefficiencies in logistics, and money crunches. Value Stream Mapping (VSM), Just-in-Time (JIT), Building Information Modelling (BIM), Digital Twin Technology, and Prefabrication minimized process fragmentation, increased efficiency, and lowered wastage. Lean Construction was successful in cost management, schedule optimization, and sustainability, reducing environmental footprints while optimizing the use of resources. NMIA shows that early participation by stakeholders, cutting-edge technology, and proactive risk management prevent significant cost overruns and delays. In summary, the implementation of Lean principles results in effective project delivery, cost reduction, improved safety, and timely delivery. Nonetheless, there is a need to overcome change resistance, unawareness, and training deficiencies. Megaprojects in the future must undertake systematic Lean adoption by policy assistance and a continuous improvement culture for ensuring efficiency, sustainability, and long-term success in mega- infrastructure development.

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CHAPTER 22

Assessment of Critical Success Factors for a Project Delivery

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ABSTRACT

A critical success factor (CSF) in construction projects refers to key elements, conditions, or activities that are essential for achieving the successful completion of a project. These factors directly influence the project's ability to meet its objectives, such as delivering on time, within budget, and to the required quality and safety standards, while satisfying stakeholder's expectations. In essence, CSFs are the core aspects that must be managed effectively to ensure a project success. The list of Critical Success Factors (CSFs) was determined through an extensive review of literature surveys. The most essential factors were identified based on their recurrence across multiple projects and their significant impact on success rates. These factors were then weighted accordingly. To validate the shortlisted CSFs, a questionnaire survey was designed, and inputs were collected from industrial experts, leveraging their experiences from current and past projects. The responses were analysed to confirm the prominence of the shortlisted CSFs. A school building project was selected as a case study to further verify these factors. The identified CSFs were found to align closely with those shortlisted earlier, reaffirming their relevance and importance.

Keywords: Critical success factors; Project delivery; School building project; Project success; Success rates.

1.0 Introduction

The critical success factors (CSFs) for construction projects in India have evolved over time, influenced by the nation's historical, cultural, and economic development. In the post-independence era, large-scale infrastructure projects like dams, roads, and urban development were driven by public sector initiatives, emphasizing government funding, skilled labor, and efficient planning. Over the decades, technological advancements, regulatory reforms, and global influences have shaped the construction industry, introducing modern management practices and sustainable approaches. Factors such as effective project planning, stakeholder coordination, adherence to timelines and budgets, quality control, risk management, and compliance with legal and environmental standards have become increasingly crucial.

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Additionally, the integration of technology, skilled workforce development, and robust supply chain management have gained prominence as India transitioned into a more urbanized and industrialized economy. Today, fostering innovation, addressing land acquisition challenges, and ensuring community engagement remain essential for the success of construction projects in the country. In the construction industry, the successful completion of a project is determined by a variety of factors, which must be carefully managed to ensure the project meets its objectives. Critical Success Factors (CSFs) refer to the essential areas of activity or elements that must be performed well to achieve the desired outcomes. Understanding these factors is crucial for project managers, contractors and other stakeholders involved in construction projects. Construction projects are complex endeavours, often involving multiple parties, tight budgets, strict timelines and a variety of technical and regulatory challenges. As such, the identification and management of CSFs help mitigate risks and increase the likelihood of project success. CSFs vary depending on the nature of the project, its size, location, and scope, but common factors are applicable across most construction endeavours.

2.0 Literature Review

Analyzed Critical success factors (CSFs) in building projects in India, emphasizing stakeholder interaction, planning, and efficient resource management. In order to increase project success, the study found that multi-stakeholder tactics were necessary (Kumar *et al.*, 2023). Practitioners suggest that, in addition to cost, time, and quality, elements such as risk management, environmental concerns, and client relationships are critical for construction management. (Kumar *et al.*, 2023). Project success is increased by planning, early standardization, and controlled execution, according to CSFs for facility design standardization in capital projects, especially in the oil and gas sector. (Choi *et al.*, 2020). Studied how capital project performance is enhanced by following design standardization CSFs. According to the study, stakeholder involvement and disciplined procedures lead to increased efficiency and cost savings (Shrestha *et al.*, 2020).

Developed key performance indicators (KPIs) for large-scale building projects, classifying success according to social effect, innovation, efficiency, stakeholder satisfaction, and strategic alignment (He *et al.*, 2020). Investigated project complexity in Chinese construction projects and came to the conclusion that high degrees of complexity have an adverse impact on project success, especially when it comes to information flow and goal alignment. (Negash *et al.*, 2020). Examined the effects of using big data in building projects and determined the elements that affect the utilization of it, including technological preparedness, management support, and team experience (Yu *et al.*, 2020).

Investigated how team behaviors affect client satisfaction in building projects, focusing the value of team empowerment, planning, coordination, and contractor assurance (Nguyen *et*

et al., 2019). In Public-Private Partnership (PPP) megaprojects, key elements influencing financial and completion risk include governance, risk allocation, and finance arrangements (Owolabi *et al.*, 2019). Determined the success criteria for Chinese construction projects, with a strong emphasis on social harmony, stakeholder management, and alignment with strategic goals (Yan *et al.*, 2019). Studied stakeholder management in long-term megaprojects, stressing proactive communication, adaptation, and strategic engagement to maintain project stability (Park *et al.*, 2017). Analyzed the elements that influence the effectiveness of modular construction projects in the industrial sector, highlighting vendor involvement, risk management, and early design alignment (Choi *et al.*, 2016). The study evaluated the relationship between project complexity and success in Chinese construction projects and concluded that controlling complexity through organized planning and clear communication enhances outcomes (Luo *et al.*, 2016). CSFs for Enterprise Resource Planning (ERP) implementation in Turkey's construction industry, with a focus on management support, clear goals, and team competence (Ozorhon *et al.*, 2015). Investigated Critical success factors for effective Building Information Modeling (BIM) implementation and discovered that interoperability, training, and trust are required for collaborative success (Shang *et al.* 2014).

Investigated CSFs in the construction project briefing process, emphasizing the significance of clear client needs, good stakeholder engagement, and structured communication (Yu *et al.*, 2013). Assessed the impact of Project Management Body of Knowledge (PMBOK) principles on construction success in Taiwan, Indonesia, and Vietnam, and found a positive relationship (Chou *et al.*, 2013). We compared two transportation megaprojects (in the United States and Mexico) and identified early planning, stakeholder alignment, and risk management as critical success factors (Lopez del Puerto *et al.*, 2013). The study examined the human factors in building performance and discovered that leadership, team dedication, and systematic project monitoring increase project outcomes (Tabish *et al.*, 2012).

The Analytical Hierarchy Process (AHP) was used to identify the most significant CSFs in construction, with the conclusion that project manager skill and comprehensive planning are important (Kog *et al.*, 2012). Investigated stakeholder management in construction projects, emphasizing the significance of social responsibility and proactive stakeholder participation (Yang *et al.*, 2010). The effects of construction project briefing on success, with the conclusion that excellent communication, documentation, and stakeholder involvement are critical (Yu *et al.*, 2006). Investigated success and failure variables in Web-based Project Management Systems (WPMSs), identifying project characteristics, system features, and team dynamics as significant effects. (Nitithamyong *et al.*, 2006). Factors influencing schedule performance in Indian construction, concluding that project management skill, owner involvement, and favourable conditions all effect completion times (Iyer *et al.*, 2006).

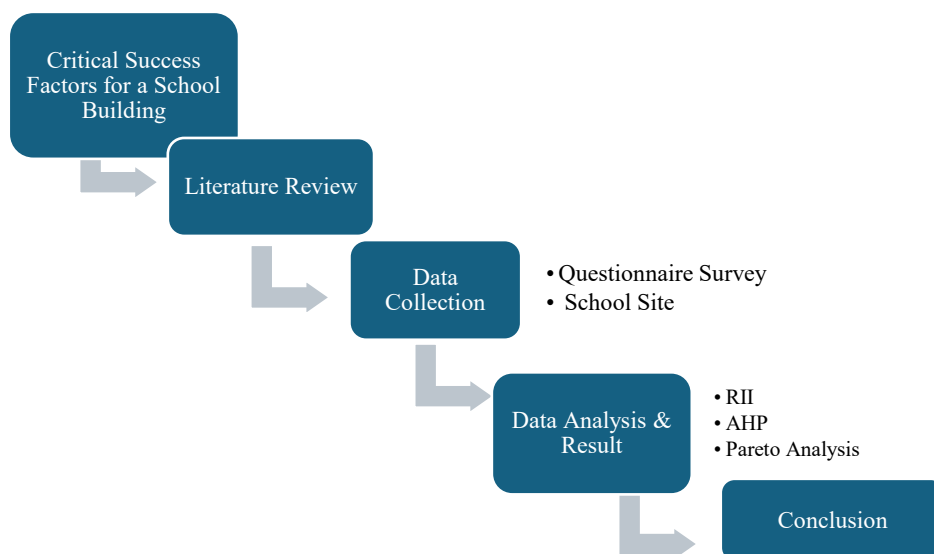
Established a conceptual framework for CSFs in construction, including project scope, procurement procedures, and human factors as main contributors (Chan *et al.*, 2004). Focused on value management in construction, with client support, clear objectives, and

multidisciplinary teamwork as critical success factors for optimizing project resources (Shen *et al.*, 2003). Developed a quantitative tool for quantifying construction success that includes cost growth, schedule adherence, quality, and safety indicators (Shields *et al.*, 2003). CSFs for building projects were identified using expert judgment, with economic risks, funding adequacy, and site limits being important issues (Chua *et al.*, 1999). Successful construction projects must integrate financial, managerial, and technical developments while maintaining good communication and risk mitigation.

3.0 Methodology

The primary objective of this study was to identify and prioritize the critical success factors (CSFs) that significantly influence the successful delivery of construction projects. Figure 1 shows methodology of study. Questionnaire is circulated among industry professionals, including project managers and engineers, to validate our findings and capture additional factors that reflect current practices and challenges in the field. The questionnaire was quantitative ratings on the importance of each identified factor. 5-point Likert scale, allowing respondents to indicate their perceptions, ranging from 1 (least important) to 5 (most important). Their feedback proved invaluable, enabling us to refine the questionnaire for clarity and effectiveness before finalizing it. Ultimately, we earned 44 completed surveys, which formed the basis of our analysis. Subsequently, we moved into the calculation of the RII for each factor. Employing the formula:

Figure 1: Methodology Flowchart



$$RII = \frac{\sum W}{A \times N} \quad \dots 1$$

Here, equation no (1) shows, $\sum W$ represents the total weight assigned by respondents, A is the maximum score possible on our scale (5 in this case), and N denotes the total number of respondents. Once the RII values were calculated, we ranked the factors in descending order to determine their relative importance to project success. In addition, the Analytic Hierarchy Process (AHP) was applied as a complementary analytical tool to validate the insights garnered from the RII calculations. AHP provides a structured framework for evaluating multiple factors and their interrelations. AHP Steps include:

1. *Define the goal*: Clearly state what decision you need to make.
2. *List criteria & alternatives*: List the factors (criteria) that affect the decision and the options (alternatives) to choose from.
3. *Pairwise comparisons*: Compare criteria and alternatives two at a time using 1–9 scale to judge importance.
4. *Calculate weights*: Normalize the comparisons to find priority values.
5. *Check consistency*: Ensure the comparisons are logically consistent ($CR < 0.1$).
6. *Find best option*: Multiply weights, rank alternatives, and pick the best one.

The integration of both RII and AHP fortified our findings and facilitated the development of actionable recommendations that project managers and organizations can implement to enhance project performance. In addition to this, Pareto Analysis was also done to get the most impactful Critical Success Factors.

4.0 Data Analysis and Result

A total of 44 people responded to the survey across various positions in the construction industry. The gathered data from the questionnaire survey was analysed using RII and the following results were obtained (see table no.1)

4.1 Relative importance index

The RII analysis revealed that strong communication and collaboration is the most critical factor for project success, followed by adequate budgeting and financial management and quality management and standards compliance. These findings align with the broader understanding in the construction industry that effective communication, financial control, and adherence to quality standards are foundational to achieving project objectives. Other factors, such as clear scope and objectives, risk management, and modern technology, also ranked highly, indicating their importance in ensuring project success.

4.2 Analytic hierarchy process

To further validate the findings, the Analytic Hierarchy Process (AHP) was applied. The AHP-based ranking confirmed the prominence of strong communication, budgeting, and

quality management, with these factors receiving the highest priority weights. This consistency between the RII and AHP results underscores the reliability of the findings and highlights the need to prioritize these factors in construction project management. Based on the AHP analysis using the RII rankings, Table no.2 shows the top-ranked CSFs with their respective priority weights are:

Table 1: Relative Importance Index

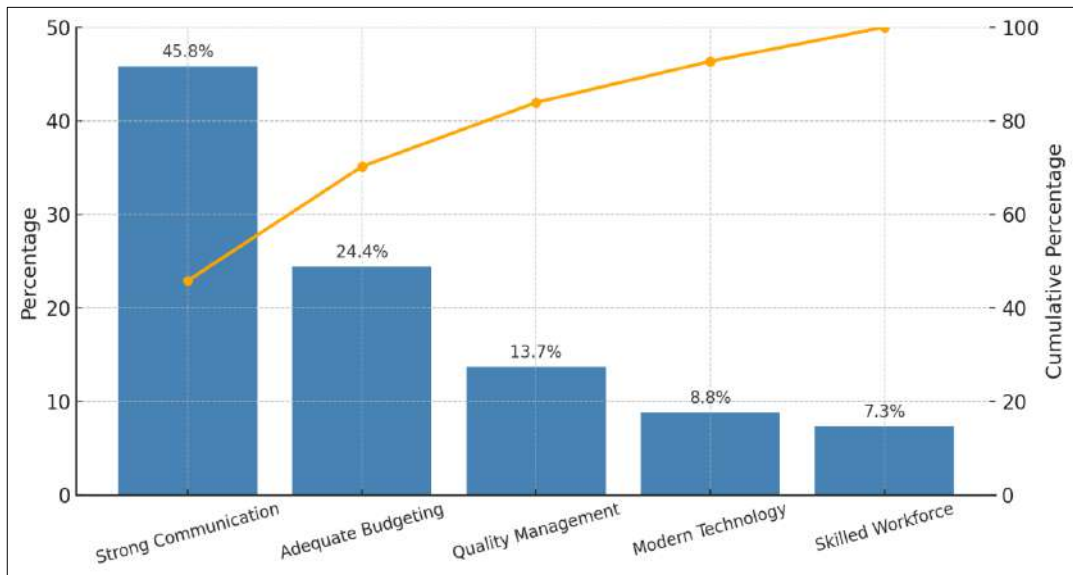
Factor	Ranking
Strong communication and collaboration	1
Adequate Budgeting and Financial Management	2
Quality Management and Standards Compliance	3
Modern Technology and Innovation	3
Skilled and Experienced Project Team	5
Client Satisfaction	6
Contractual Agreements and Legal Frameworks	7
Planning and Scheduling	8
Strict Compliance with HSE	9
Clear Scope and Objective	10
Risk Management and Contingency Planning	10
Supply Chain and Material Management	10
Site Management and Logistics	14
Effective Stakeholder Management and Engagement	15
Cultural and Organizational values	16

Table 2: AHP Weights for the Top 5 Critical Success Factors

Critical Success Factors	Priority Weights
Strong communication and collaboration	45.80%
Adequate Budgeting and Financial Management	24.40%
Quality Management and Standards Compliance	13.70%
Modern technology and innovation	8.80%
Skilled and experienced project team	7.30%

4.3 Pareto analysis

A Pareto analysis was also conducted to identify the most impactful CSFs. 80/20 rule, suggesting that focusing on the top 20% of CSFs such as communication, budgeting, and quality management can yield the most significant impact on project success. The orange line represents the cumulative percentage, while the 80% threshold helps identify the most impactful CSFs as shown in Figure 2.

Figure 2: Pareto Analysis**Table 3: Critical Success Factors Identified on Site**

Sr. No	Factors	Issues	Mitigation Measures
1	Project Planning	Cost overrun due to less anticipated quantity of work.	Worked out the total actual quantity of work and revised the estimate for future use.
		Schedule Overrun due to multiple revisions of drawings and causing reworks.	Effectively studying drawings and analysis it prior to any commencement of actual work.
2	Effective Communication	Delay in arranging samples for approval to client by management and also delay caused by client in the process of selecting the required materials.	Communicating with stakeholders and getting clarity about desired make and shade of materials.
3	Risk Management	Unforeseen site conditions leading to delays.	Conducting thorough site surveys and risk assessments before project initiation.
4	Supply Chain Management	Delays in material delivery affecting project timelines.	Establishing reliable supplier contracts and maintaining buffer stock for critical materials.
5	Stakeholder Engagement	Misalignment of expectations between stakeholders.	Regular stakeholder meetings and clear documentation of project goals and deliverables.
6	Skilled and experienced project team	Labour shortages or unskilled labour impacting productivity.	Implementing training programs and ensuring proper workforce planning and allocation.

4.4 Site data

A school building project was selected as a case study to further verify these Critical Success Factors gathered from Literature Review and Questionnaire survey. Table 3 shows the Factors affected the successful completion of the project with issues and their mitigation measures taken on site to overcome it. The site data highlights common challenges such as cost overruns, schedule delays, communication bottlenecks, and workforce issues, which are often encountered in construction projects. To address these issues, the study proposes practical mitigation measures, including revising estimates, conducting thorough risk assessments, improving stakeholder communication, ensuring efficient supply chain management, and investing in workforce training. These strategies aim to minimize risks and enhance project performance.

5.0 Conclusion and Recommendation

The analysis of Critical Success Factors (CSFs) in construction projects underscores the importance of strong communication, adequate budgeting, and quality management as the most critical drivers of project success. The findings, validated through both RII and AHP methods, emphasize the need to prioritize these factors to achieve project objectives efficiently. Additionally, the Pareto analysis highlights the 80/20 rule, suggesting that focusing on the top 20% of CSFs can yield the most significant impact on project outcomes. The site data further reinforces the practical relevance of these findings, identifying common issues such as cost overruns, schedule delays, communication challenges, and workforce management problems. By implementing the proposed mitigation measures—such as improved planning, risk management, stakeholder engagement, and workforce training—construction teams can address these challenges effectively and enhance project performance. The successful completion of construction projects is dependent on a careful balance of adequate budgeting, and quality management, technical expertise, effective communication, and adaptive management method. By prioritizing the identified CSFs and implementing the recommended mitigation strategies, construction teams can enhance project performance, minimize risks, and achieve stakeholder satisfaction. Future research should focus on developing context-specific CSF models and exploring the evolving role of sustainability, innovation, and technology in shaping the future of construction project management. This study serves as a valuable resource for project managers and construction professionals seeking to improve project delivery and achieve successful outcomes in an increasingly dynamic industry.

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CHAPTER 23

Asset Management Approach for Infrastructure Maintenance

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ABSTRACT

This study examines the role of Infrastructure Asset Management (IAM) in enhancing infrastructure service delivery, with a focus on identifying challenges, best practices, and opportunities for effective implementation, particularly in India. Using a case study approach, the research analyzes global and local examples to assess IAM's impact on infrastructure reliability, resource allocation, and cost reduction. Findings reveal that effective IAM significantly improves infrastructure performance but faces challenges such as inadequate funding, lack of technical expertise, and policy inefficiencies. Lessons from successful global implementations provide insights for developing nations like India. The study contributes to IAM knowledge by offering India-specific recommendations, including fostering public-private partnerships, investing in digital IAM tools, and strengthening institutional capacity. These insights are valuable for policymakers, infrastructure managers, and stakeholders, helping them develop sustainable, cost-effective asset management strategies that enhance infrastructure service delivery and economic growth.

Keywords: Infrastructure Asset Management (IAM); GDP growth; Best practices; Case studies.

1.0 Introduction

Infrastructure is the backbone of economic growth, public safety, and quality of life. Public utilities, water supply networks, roads, and railroads are vital resources that need to be managed well to maintain their functionality and durability. However, aged infrastructure, financial limitations, growing demand, and environmental issues make preserving these assets more difficult. Poor maintenance procedures can result in increased expenses, interrupted services, safety risks, and decreased asset effectiveness. Strong asset management techniques that maximize the lifecycle of infrastructure assets—from planning and purchase to operation, maintenance, and decommissioning—are therefore becoming more and more necessary. The methodical process of managing tangible assets to optimize their longevity, performance, and value is known as asset management (AM). The ISO 55000 standard defines asset management as an organization's coordinated activity to realize value from assets.

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This goes beyond simple upkeep to provide value for stakeholders by striking a balance between cost, risk, and performance over the course of an asset's existence. Despite its significance, many areas especially in developing nations—find it difficult to put into practice efficient asset management procedures because of tight finances, a dearth of data-driven decision-making, and ineffective maintenance techniques. For example, although industrialized regions like Spain and Germany have embraced cutting-edge technology and techniques to maximize asset performance, developing nations like India and Sri Lanka have substantial hurdles in sustaining their infrastructure.

2.0 Literature Review

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to guarantee a transparent and repeatable procedure, the research starts with a Systematic Literature Review (SLR) to find important studies, case studies, and best practices in asset management for infrastructure repair. The identification phase included a thorough literature search of scholarly databases such as Scopus, Web of Science, and Google Scholar using keywords such as “asset management,” “infrastructure maintenance,” “lifecycle management,” and “sustainability”. The search included both peer-reviewed literature and industry reports, and the results produced 60 documents. These papers were evaluated for relevance during the screening process, and research that were unrelated were disqualified. Based on the relevance and breadth of the insights into asset management methodologies, case studies, or frameworks, the eligibility stage further narrowed the selection to 25 articles. Relevant literature is presented in this section and select case studies.

Asset management research highlights data-driven decision-making, sustainability, and technological integration while facing challenges like budget constraints, stakeholder coordination, and regulatory hurdles. In addition to following papers were discussed, studies on road systems, including India's ARAMS (Kempriai & Goswami, 2022) and Madrid's ICARO (Nunez, 2019), emphasize predictive maintenance but struggle with funding and data accuracy. Water utilities research, such as Brighu's urban model in India and Bayliss's (2014) critique of financialization in England, raises affordability concerns. Railway and municipal infrastructure studies (Andrews & Rama, 2015; Harvey *et al.*, 2017) stress the need for robust Asset Management Plans despite financial and computational constraints. Research on London Underground's PPP (Adeney *et al.*, 2006) and U.S. EPA programs underscores regulatory challenges and high costs. Collectively, these studies reveal the ongoing evolution of asset management, balancing innovation with financial, technological, and governance complexities.

2.1 Gaps

Infrastructure maintenance varies across countries and industries due to the absence of standardized asset management frameworks, especially in India and developing nations, leading

to inefficiencies. Limited adoption of AI, IoT, and GIS hampers predictive maintenance, while poor real-time oversight weakens data-driven decision-making. Additionally, policy and execution are often misaligned, with strong regulations facing implementation challenges, resulting in inadequate maintenance plans. Financial constraints further hinder sustainability and long-term infrastructure upkeep in many developing countries.

2.2 Objectives

- To analyze the importance of asset management in infrastructure maintenance.
- To identify key challenges in maintaining infrastructure assets efficiently.
- To recommend strategies for improving asset management in infrastructure projects.
- To highlight best practices in asset management across different sectors.

3.0 Research Methodology

This study employs a qualitative approach that integrates Systematic Literature Review (SLR) and qualitative analysis to investigate asset management tactics for infrastructure upkeep. The research is organized using the TCCM framework (Theory, Context, Characteristics, Methodology), offering an organized approach to examine case studies. A SWOT analysis is used in the qualitative evaluation to evaluate the asset management techniques' possibilities, threats, weaknesses, and strengths. The PRISMA framework is employed to bring transparency and thoroughness in the literature review procedure. The goal of this thesis is to find best practices, obstacles, and creative solutions for asset management methods for infrastructure maintenance in the road, rail, and water sectors.

The study analyzes case studies from both developed and developing nations using a systematic literature review (SLR) that follows the PRISMA paradigm. The TCCM (Theory, Context, Characteristics, Methodology) framework is used to analyze these case studies. A qualitative SWOT analysis is then conducted to assess the case studies' opportunities, threats, weaknesses, and strengths. In order to give policymakers, asset managers, and urban planners responsible for maintaining and improving public infrastructure useful information, this study compares asset management techniques in various scenarios.

4.0 Qualitative Analysis with SWOT Analysis

This study examines ten case studies using the TCCM framework to assess asset management strategies. Strengths highlight effective technologies like GIS and IoT in Madrid, while weaknesses reveal gaps like Sri Lanka's National Water Supply and Drainage Board lack of criticality ratings. Opportunities explore innovations like AI-blockchain integration, while threats include budget constraints and climate change impacts.

4.1 Strength

This study's strength lies in its global and sectoral diversity, comparing asset management strategies across developed and developing nations in road, rail, and water sectors. It highlights cutting-edge technologies like GIS and IoT, along with sustainability efforts such as climate-resilient infrastructure. Practical recommendations, including PPPs and preventive maintenance, make the research highly relevant for policymakers and urban planners.

4.2 Weakness

This study has limitations, including shallow analysis in some case studies and a lack of comprehensive quantitative data, as seen in Indian Railways. Gaps like missing criticality ratings (e.g., National Water Supply and Drainage Board in Sri Lanka) hinder efficient asset renewal. Additionally, inconsistencies in financial management focus and limited stakeholder engagement analysis reduce insights into cooperative strategies.

4.3 Opportunities

This study presents opportunities for future research, including adopting new technologies to enhance predictive maintenance and data accuracy. Emphasizing climate resilience and cross-sector learning, such as adapting IoT from rail to water infrastructure, can improve asset management. Expanding case studies to underrepresented regions and providing policy recommendations would further strengthen its global relevance.

4.4 Threats

Key risks to asset management include budget constraints in developing nations, aging infrastructure requiring costly upkeep, and data inaccuracies affecting decision-making. Regulatory hurdles add complexity and expenses, while climate change intensifies threats like flooding and landslides, increasing maintenance costs and the need for resilient infrastructure.

5.0 Case Studies

The TCCM framework analyzes asset management through Theory, Context, Characteristics, and Methodology, assessing sustainability, financial oversight, stakeholder cooperation, and technological integration. This study examines both global and domestic case studies to identify best practices, challenges, and key insights.

5.1 Case study (international): Road asset management in Madrid region, Spain

Using GIS, IoT, and data analytics for real-time monitoring and predictive maintenance, Madrid's Road asset management plan places a strong emphasis on sustainable, economical maintenance. Following the financial crisis, priorities shifted from new construction to improving existing roads, guided by indices like the Structural Index and Road Safety Index.

Between 2018 and 2021, over €160 million was allocated for maintenance, with competitive bidding ensuring quality through KPIs. A shadow toll system optimized resource allocation, while PPPs and data-driven decisions enhanced efficiency. Despite challenges like budget constraints and climate effects, Madrid’s model serves as a benchmark for sustainable and innovative infrastructure management.

Table 1: Comparative Analysis of Asset Management in Water, Rail & Road

Parameter	Water Sector	Rail Sector	Road Sector
Nature of Assets	Pipelines, Reservoirs, Treatment plants	Tracks, Stations, Rolling Stock	Highways, Bridges, Tunnels
Investment Needs	High Initial Cost for Infrastructure	Capital Intensive for Maintenance	Requires Large Scale Investments
Asset Lifespan	20-100 Years	25-40 Years	10-30 Years
Technology Use	GIS Mapping, IOT Sensors	Predictive Maintenance	IOT Based Traffic Management
Revenue Models	Water Tariffs, PPP	Ticket Revenue, Freight Charges	Toll Collection, Fuel Taxes, PPP
Sustainability	Water Conservation, Recycling	Electrification, Hydrogen Powered Trains	Recycled Materials

5.2 Case study (domestic): Road asset management in Assam, India

Assam’s road asset management prioritizes sustainability, cost-effectiveness, and climate resilience using GIS, drone mapping, and data analytics for real-time monitoring. Programs like PMGSY focus on resource management and preventive maintenance, with PPPs ensuring performance-based contracts. Investments in flood-resistant infrastructure and digital tools enhance decision-making, despite challenges like funding shortages and environmental concerns. Hybrid financing models and rural connectivity initiatives support long-term sustainability. A comparative table summarizes key insights across road, rail, and water sectors, highlighting investment needs, technology use, sustainability efforts, and best practices.

6.0 Discussion

The case studies highlight common challenges, success factors, and key insights in asset management, offering valuable guidance for policymakers, asset managers, and urban planners.

6.1 Challenges

Financial constraints and aging infrastructure challenge asset maintenance in regions like Assam and Madrid, while data limitations hinder efficiency in Assam and Sri Lanka. Climate change and stakeholder coordination add complexity, requiring costly repairs and improved management strategies, as seen in Germany and Indian Railways.

6.2 Success factor

Effective asset management integrates technology, preventive maintenance, PPPs, sustainability, and data-driven decisions, enhancing efficiency and resource allocation. Examples include GIS in Madrid, preventive strategies in Deutsche Bahn, and sustainability efforts by Barwon Water, ensuring cost-effective and environmentally responsible infrastructure management.

6.3 Lesson learned

Technology, preventive maintenance, PPPs, sustainability, and data-driven decision-making enhance asset management efficiency, as seen in Deutsche Bahn, Madrid, and Barwon Water. These strategies optimize resource allocation, reduce costs, and improve sustainability through GIS, IoT, renewable energy, and predictive analytics.

6.4 Limitations

Financial constraints limit technology adoption in regions like Assam, while aging assets, as seen in Deutsche Bahn, strain maintenance efforts. Climate risks, stakeholder coordination issues, and high technology costs further hinder effective asset management, especially in emerging economies.

7.0 Conclusion

This research employs a qualitative approach to investigate asset management in road, rail, and water sectors using the TCCM framework and SWOT analysis. Findings highlight the role of advanced technologies like GIS, IoT, and predictive analytics in optimizing maintenance, as seen in Deutsche Bahn and Madrid's ICARO system. Preventive strategies, exemplified by Barwon Water and Assam, extend asset lifespans and reduce failures. However, financial constraints, outdated infrastructure, and data accuracy issues remain challenges, particularly in emerging regions. The study underscores the need for integrated technical, financial, and administrative approaches, emphasizing sustainability and stakeholder collaboration. Future research should explore cost-effective, climate-resilient solutions to enhance infrastructure reliability and efficiency.

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CHAPTER 24

Augmented Reality and Virtual Reality Applications for Enhanced Visualization and Decision-Making

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ABSTRACT

This study is built upon address construction project management with Augmented Reality (AR) and Virtual Reality (VR) technologies. Such promises come along with the work of enabling better visualization by decision-makers and collaboration among all stakeholders. These immersive virtual environments allow stakeholders to simulate the real-life scenarios of construction processes, predict problems, and optimize them before actual construction. A questionnaire survey was conducted to determine how the AR/VR tools are improving spatial understanding, enhancing planning accuracy, and boosting on-site performance. According to the findings, AR/VR technology to reduce mistakes, encourage green behaviors, and speed up decision-making are most valuable for the construction sector. The study further acknowledges limitations around small sample sizes, very short-term evaluations, and context-based designs, thus leading to restrictions on ascertainties. Therefore, it aligns technological innovations with real needs in the industry, which further contributes to developing better strategies for implementing AR/VR in construction workflows, such that project management would be more efficient, collaborative, and sustainable.

Keywords: Augmented reality; Virtual reality; Construction on management; Stakeholder engagement; Decision-making.

1.0 Introduction

Virtual Reality (VR) and Augmented Reality (AR) are new technologies in which people experience digital worlds in an entirely different way through first-class views and a first-class action in real time. People may practically work on hard data in these tools and make better decisions in space or on engineering works. Building, engineering, and business analysis are fields that benefit immensely from AR and VR because they enable teams to collaborate in real time, assess risks, and ultimately improve processes. Yet they have been largely unused to date, because of their high costs and complexity of learning them. Solving these issues could really help make better decisions in many areas.[Noghabaei, 2020] [Asadi, 2018]

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1.1 Background and context

AR and VR show data in three dimensions, which is better than old methods like CAD models. They are widely used in gaming and health care, but not much in building and city planning. Regardless of the useful application of AR and VR, there is a dismaying lack of evidence to suggest that they are better at decision-making. They can be very expensive and quite demanding of training, plus there are holes when it comes to understanding how to balance risk and work with others. This study looks at their effects using detailed checks and statistical tests.

2.0 Research Background

Though one of the biggest and most complex industries in the world, the construction sector has, in fact, suffered from age-old problems, with common issues such as cost overruns, delays, or rework. Inadequate visualization, poor decision-making, or inefficient collaboration between stakeholders (Noghabaei, 2020) normally account for these issues. Quite a few other project management practices, like 2D drawings, and even 3D Building Information Modeling (BIM), are limited in providing a broad comprehension of complex construction projects, especially for non-technical stakeholders (Asadi, 2018). Augmented Reality and Virtual Reality technologies have garnered the attention of many in this type of construction as transformation tools in the last few years. AR and VR technologies enable immersive virtual environments, allowing different stakeholders to visualize construction scenarios in order to identify possible issues as early as possible in the life cycle stage to improve the flows of work-from decision-making to collaboration (Du, 2018). The literature review that follows concentrates on the ways in which AR and VR are used in the management of construction projects and in enhancing visualization, decision-making, and stakeholder engagement.

2.1 AR/VR in construction visualization

Visualization is a core element of construction project management since it helps stakeholders understand design elements and identify their potential issues for further decisions. Conventional visualization methods like 2D drawings and 3D BIM models do not always capture the interest of stakeholders, especially when these latter are unfamiliar with technical drawings. AR and VR technologies help bridge that other between stakeholders and construction processes, since they provide interactive and immersive virtual environments to engage in real-time with 3D models. Among the major advantages of augmented and virtual realities in construction visualization are the simulation that they are capable of doing on real construction sites. In this context, [Balali *et al.*, 2018] developed a cloud\-based virtual reality platform called CoVR to allow multiple users to collaborate on BIM models in a shared virtual space. This platform takes a big step in improving communication among remote stakeholders by providing a common space for visualizing and commenting on project data. In the same stream of work,

[Sacks *et al.*, 2013] created a Mobile Augmented Reality (MAR) application to overlay BIM models on real-world environments. With such an application, construction technicians will be able to visualize and refine their designs right there on site, thus eliminating errors and rework. Further, AR and VR technologies allow for virtual site walkthroughs, whereby those concerned are able to literally walk through the site before any construction begins. Such a method is beneficial in making design clashes or conflicts more evident before actual construction starts, improving spatial comprehension and make construction planning more precise.

2.2 AR/VR in decision-making

The decisions made in any construction project will be one of the most important aspects for the success of that project. Traditional methods by which decisions are made are mostly based on incomplete or inaccurate information, which ultimately leads to suboptimal decisions. AR and VR types of technologies enhance decision-making capabilities with the ability to visualize and simulate aspects of a project so that stakeholders can make better-informed decisions. A critical application of AR and VR in decision-making is cost estimation. Balali *et al.* (2018) developed a VR-based cost estimation system that enables stakeholders to assess the financial impact of design modifications in real time. This method improves cost estimation accuracy and supports better decision-making in both design and construction phases. Also, with the aid of VR simulations, different construction sequences can be modeled, which allows project managers to check and eliminate all anticipated issues beforehand. Sacks *et al.* (2013) highlighted VR-based simulations as perceptive tools available for project managers to visualize construction processes and predict problems before they occur, thus preventing delays and extra costs from occurring. Equally critical is the risk management that can be accomplished using AR and VR. By simulating the risks and their repercussions, these technologies allow project managers to lay preemptive plans for the mitigation of such risks. Jeelani *et al.* (2017) designed a VR-based safety training program in which workers are placed in realistic construction accident scenarios that allow them to practice dealing with dangerous situations and do so without exposure to actual danger. This increases awareness of hazards and perception of risks, reducing accidents on the site.

2.3 AR/VR in stakeholder engagement

AR VR probably is one of the biggest leaps in stakeholder collaboration by allowing them to conduct virtual design meetings and reviews. Some other systems that have been mentioned in relation to digitized communication platforms are W. T. Du and coworkers' [Balali *et al.*, 2018] CoVR system for letting remote stakeholders into virtual meetings. The embedded AR VR spaces allow stakeholders to review project information without physical proximity. This is extremely critical especially for vast projects with geographically dispersed stakeholders [Wei *et al.*, 2015]. It also allows AR VR to further coordinate between architects, engineers, and construction workers. Williams and coworkers [Sacks *et al.*, 2013] built a mobile

AR assistant for performing BIM on-the-job in case of overlays onto a real-world setting so that the field technicians could visualize and correct their work on the fly. Errors would be reduced, and rework will eventually improve the efficiency of the project.

2.4 Limitations and challenges

While various advantages exist for the introduction of AR and VR technologies in the construction industry, their widespread acceptance has been rather sluggish mostly due to several obstacles. One major wall would be the high cost of implementation, including hardware, software, and personnel training [Goulding *et al.*, 2012]. Besides, the lack of awareness and knowledge about the advantages associated with AR and VR among construction professionals, especially at the management level [Ergan *et al.*, 2019], leads to resistance to adopting these new technologies. One more important problem is integration of AR and VR into existing construction activities. Numerous firms have been employing BIM and other digital devices, while the combined application of AR and VR with such systems can become both furthermore complex and time-consuming [li, 2018]. Also, the power of AR and VR management depends on the information and modes upon which it is developed. Suboptimal, incomplete BIM models will likely obscure accurate visualization further rendering a decision-making process inefficient [Pelargos *et al.*, 2017].

2.5 Research gap

Even though the short-term advantages of AR and VR in building are notable, their long-term advantages still require an evaluation. Present literature focuses largely on real-time visualization and decision-making enhancements of AR and VR applications, however, little has been done to understand their impacts on more chronic success indicators, such as cost savings, schedule adherence, or final project quality [Danylec *et al.*, 2022] [Zheng *et al.*, 2021]. Another gap in research relates to the technical skills needed to implement AR and VR. Many construction companies lack construction decision-making expertise or technical skill within their organizations to integrate these new technologies among their workflows. Thus, they partly rely on consultants [Beh *et al.*, 2022]. Nevertheless, with recent developments in AR and VR platforming, implementation is anticipated to be made easier and will have fewer barriers financially, thus having these technologies become user-friendly in the construction industry [Aguilar *et al.*, 2024].

3.0 Research Methodology

This study adopts a quantitative research approach to analyse the trends and adoption of AR/VR technologies in the construction industry. The research is based on survey responses collected from professionals in the construction sector to understand their familiarity with AR/VR, adoption barriers, and the impact of these technologies on decision-making and project efficiency. The Flowchart of the methodology is depicted in Figure 1.

Figure 1: Research Methodology Flow Chart



3.1 Questionnaire survey

A structured survey was carried out to assess awareness, use, and attitude towards Augmented Reality (AR) and Virtual Reality (VR) technologies in construction. The aim was to determine challenges, advantages, and how AR/VR can be incorporated into construction processes. A structured survey is conducted amongst the constructional professionals focusing mainly on AR\VR users.

The survey focused on:

- Industry Experience & Technology Adoption.
- Usage & Understanding of AR/VR.
- Benefits & Challenges.
- Future Adoption & Suggestions.

Data Collection process: Online survey with Construction professionals.

3.2 T tests analysis

A t test is a statistical test that is used to compare the means of two groups. This method will be helpful for assessing different factors that will be affecting adoption of AR\VR in the

construction industry. The t test is a parametric test of difference, meaning that it makes the same assumptions about the available data as other parametric tests. The t test assumes our data:

1. are independent
2. are (approximately) normally distributed
3. have a similar amount of variance within each group being compared (a.k.a. homogeneity of variance)

4.0 Data Collection

Data was collected using an online questionnaire survey. At first, a sampling method was used, and a specific formula was utilized to calculate the sample size. The sampling process was conducted, and data was collected through Google Forms. The respondents primarily consisted of professionals from the construction industry, including architects, civil engineers, project managers, and construction site supervisors. The responses were then processed and analysed with the help of Microsoft Excel after data collection. We applied statistical methods such as t test analysis to find whether their differences are statistically significant or not. t-test was appropriate in the study as it statistically confirms participants are utilizing AR/VR applications. Significant results allow further study on the aspect of AR/VR enhancing visualization and efficiency of decision-making. The use of statistics helps to derive conclusions from accurate data, hence its importance in maximizing AR/VR systems and user experience.

4.1 Questionnaire survey

In this study, data collection was conducted using online as well as offline methods including a structured questionnaire in excel sent using Google Forms. Since the minimum sample size for calculating t test is not universally defined, most researchers recommend collecting a sample of at least 30 responses to make it statistically significant for analysis. A pilot study with 30 responses was first conducted to determine the appropriate sample size. Thus, a formal sampling nature was employed, obtaining a total of 40 responses from the construction professionals.

4.2 Data analysis

Comparing the graphs clearly illustrates trends in the adoption of AR/VR, users' experience, and challenges. Analysing usage patterns, user characteristics, motivations for the adoption of AR/VR technology, and adoption challenges can provide valuable information on how the industry is evolving. It reflects the rising perception of its use in more detailed visualization and decision-making within sectors. Better project productivity enhanced spatial perception, and training in immersion are the main impulses of AR/VR use, justifying enhanced utility of the technology in the modern working scenario.

The Analysis from the online questionnaire are as follows.

Figure 2: Classification According to Experience

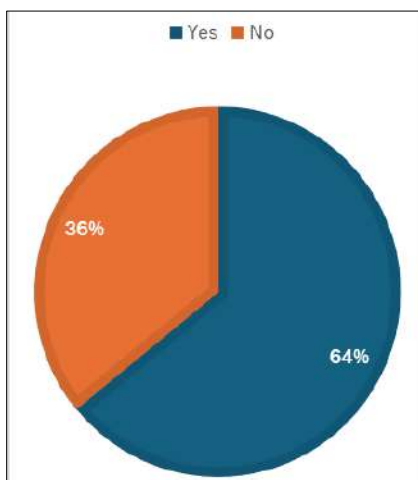
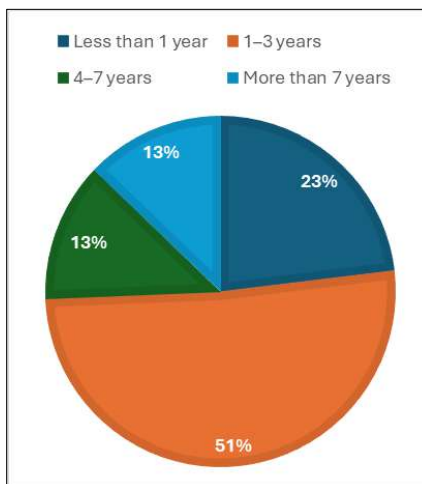


Figure 3: Classification According to Usage



4.3 t test result

Table 1: t Test Result

Variable	t-value	df	p-value
Experience	14.417	38	<.001
Usage	19.923	38	<.001

5.0 Results and Discussions

- Since $p < 0.001$ for experience and usage, the mean of these variables significantly differs from zero.
- Higher t-values (14.417 and 19.923) indicate greater deviation from zero and verifies participants are well versed and use AR/VR applications.
- Degrees of freedom ($df = 38$) indicate that 39 participants were analysed.

As per current Study:

- Verifies that AR/VR applications are used actively for visualization and decision-making.
- Is equipped with statistical evidence supporting participants having meaningful interaction with AR/VR.
- Justifies continuing research in understanding how AR/VR affects cognitive processes and decision efficiency.

Figure 4: t Test Result

One Sample T-Test			
	t	df	p
Experience	14.417	38	< .001
Usage	19.923	38	< .001

Note. For the Student t-test, the alternative hypothesis specifies that the mean is different from 0.

Note. Student's t-test.

5.1 Q-Q plots interpretation (normality check)

Q-Q plots are used to determine if residuals (errors) are normally distributed. Points should align along the red diagonal line.

5.1.1 Experience Q-Q plot

- There is a general tendency of most of the residuals to follow the red line apart from in extreme regions (outliers). Q-Q plots are used to determine if residuals (errors) are normally distributed. Points should align along the red diagonal line.
- It points towards moderate normality, but some deviations exist.

Figure 5: Q-Q Plots of Experience

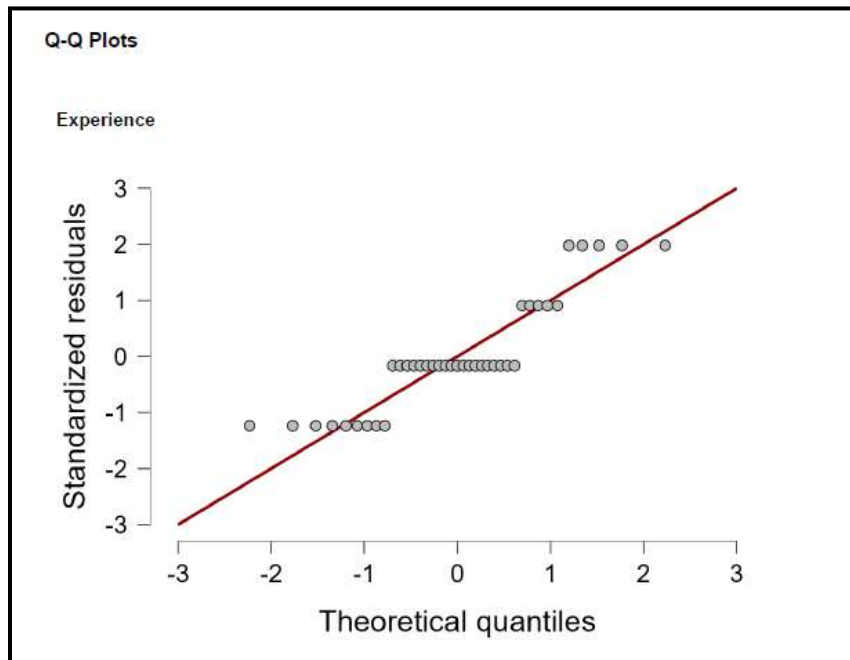
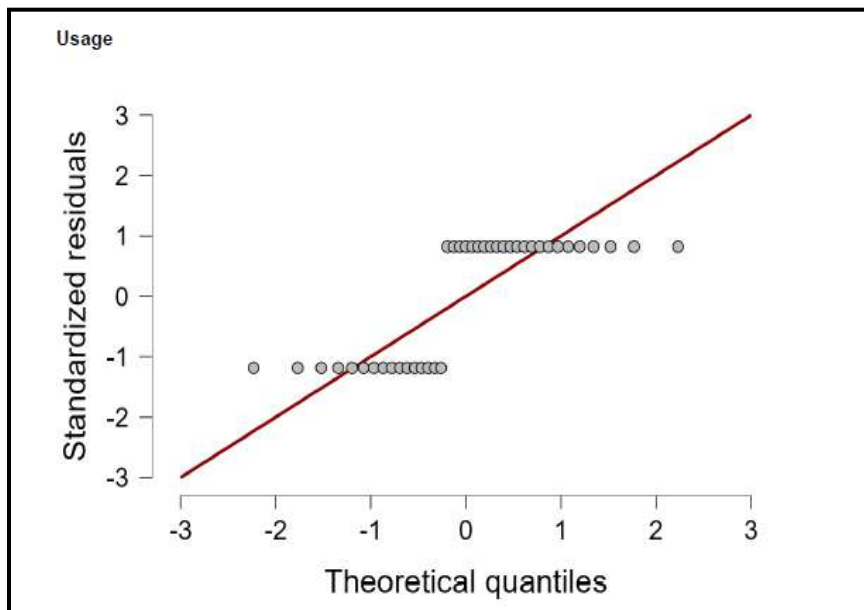


Figure 6: Q-Q Plots of Usage



5.1.2 Usage Q-Q plot

- Same pattern—data clings to the line but with variation at extremes.
- Suggesting almost normal distribution, though it is slightly skewed.

5.2 Relevance to our current study

- Since normality is approximately met, parametric tests (ANOVA, regression) are applicable for examining AR/VR effect.
- The slight deviations suggest that a few users of outstandingly high or low experience exist, and they might be investigated in a qualitative follow-up study.
- This supports the use of predictive modelling to examine the effect of AR/VR use on decision-making.

5.3 Result

The research tested the effect of Augmented Reality (AR) and Virtual Reality (VR) apps on improved visualization and decision-making. One-sample t-test was used to check if participants' experience and use of AR/VR apps were significantly different from zero. The findings were as below:

- Experience: $t(38) = 14.417, p < 0.001$
- Usage: $t(38) = 19.923, p < 0.001$

Both p-values were extremely significant, which shows that participants do use and have experience with AR/VR applications. The high t-values suggest high levels of evidence that AR/VR applications are widely used and provide high levels of engagement for users. In addition, Q-Q plots were examined to assess residual normality. It was noted that points were mostly consistent with the normality line but slightly diverged at extremes, reflecting little skewness but generally moderate normality. This opens a door for additional parametric testing, e.g., regression or ANOVA, to ascertain how AR/VR apps enhance cognitive ability and decision-making.

6.0 Conclusion

The findings validate that AR/VR applications are utilized for visualization and decision-making in active forms. The high t-test values support the hypothesis that AR/VR technologies play a crucial role in enabling users' ability to dissect intricate information and make sound decisions. Although usage and experience levels are high, more research is required to identify how particular AR/VR features (e.g., interaction level, 3D visualization, real-time data integration) help to achieve better decision-making outcomes. Additionally, the minimal departures from normality in Q-Q plots indicate that although AR/VR applications are, in general, advantageous, user experience is variable based on familiarity, training, or application type. Future research must investigate the variations to maximize AR/VR use in decision-making contexts.

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CHAPTER 25

Automated Construction Safety Inspection System Leveraging Computer Vision

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ABSTRACT

The construction industry stands as one of the most hazardous sectors globally, accounting for over 60,000 fatalities annually. According to Heinrich, a significant portion of accidents (88%) are attributed to unsafe acts, while 10% result from unsafe conditions, and 2% arise from uncontrollable factors. Of these, 98% of accidents can potentially be mitigated through the implementation of safe practices and ensuring proper site conditions. Despite this, past examinations have indicated a deficiency in manual safety compliance mechanisms for enforcing safety protocols on construction sites. The advent of deep learning algorithms and advanced image-capturing technologies has offered safety professionals valuable tools to bolster safety management strategies. However, a comprehensive understanding of these advancements remains lacking within the existing body of knowledge. Therefore, conducting a systematic literature review on this subject is imperative. This study employed various pertinent keywords to explore literature within the Scopus database. Utilizing the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach, relevant literature was identified and analyzed. The findings of this review shed light on prominent researchers, institutions, and countries engaged in this domain. Furthermore, it pinpointed both highly focused and overlooked research themes, extracting future research directions from top-tier investigations. This study serves as a foundational resource for future inquiries in this field, offering safety professionals insights into automated methods for ensuring safety compliance on construction projects.

Keywords: Computer Vision; Safety management; Automation; Construction Hazards; Construction safety.

1.0 Introduction

1.1 Background

Construction ranks among the most hazardous industries worldwide, comprising about 7% of the workforce while being responsible for nearly 30% of work-related fatalities (Fang *et al.*, 2020).

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In India, the risk increases because of rapid infrastructure development. The NCRB reports that more than 10,000 workers die each year due to occupational hazards, with construction sites being a significant factor. Traditionally, in India, site safety relies on inconsistent human oversight. With the help of real-time video analytics, computer vision provides a proactive alternative for identifying hazards and guaranteeing PPE compliance. Firms employing this technology have experienced a reduction in accidents by 20–30%, along with decreased medical, legal, and insurance expenses, as well as productivity improvements of up to 15%. The eventual incorporation of IoT and predictive analytics may enhance outcomes even more. Implementation encompasses the preparation of datasets, training of models, and deployment in real-world scenarios. The YOLOv5 algorithm (Li *et al.*, 2023) can accurately identify compliant and non-compliant workers using annotated images of PPE violations

1.2 Need for study

Unlike the automotive or manufacturing sectors, construction contends with distinct safety challenges arising from its ever-evolving work environments and lack of standardized procedures. Real-time monitoring and early hazard detection are made possible by computer vision technology (Li *et al.*, 2023), which greatly enhances site safety and lowers the incidence of accidents (Yang *et al.*, 2022).

1.3 Research objectives

This research article aims to achieve the following objective: (Yang *et al.*, 2022)

- Examine how widely Computer Vision is currently being implemented in construction safety.
- Develop an object recognition model using CCTV footage, trained with the YOLOv5 algorithm, capable of identifying construction workers along with their safety vests and helmets.

2.0 Literature Review

2.1 Computer vision

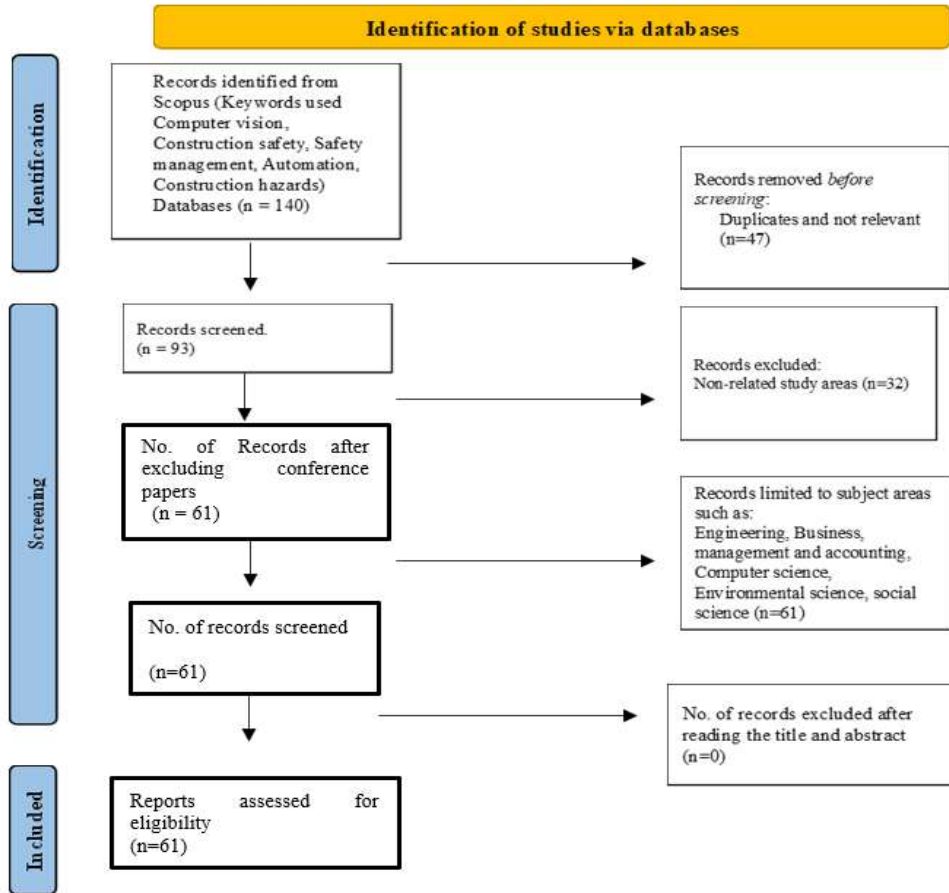
Computer vision, a branch of computer science, has extensive applications in speech recognition, natural language processing, and robot control. Traditional machine learning techniques cannot process data in its raw state. (Fang *et al.*, 2020) In the realm of AI and deep learning, (Kompare *et al.*, 1994) characterizes computer vision as “a technology that enables machines to interpret and understand the content of digital images and video.” This description emphasizes the development of computer vision, particularly through deep learning methods, which have significantly enhanced the field’s capabilities.

2.2 Construction safety

Construction safety, as outlined by (Zhang *et al.*, 2019), refers to “the identification, assessment, and management of risks linked to construction activities in order to safeguard

workers and reduce incidents.” As stated by OSHA (2021), it encompasses “policies and procedures to reduce injury risks and ensure workers have access to safety training and equipment.”

Figure 1: Identification of Relevant Papers using PRISMA



2.3 Systematic Literature Review (SLR) using “PRISMA”

This study investigates the relationship between Construction Safety and Computer Vision through the use of CNN and the PRISMA methodology (Sharma & Laishram, 2024). *Stage I* delineates the SLR process, which includes identifying keywords and selecting databases with Boolean operators to establish the review scope.

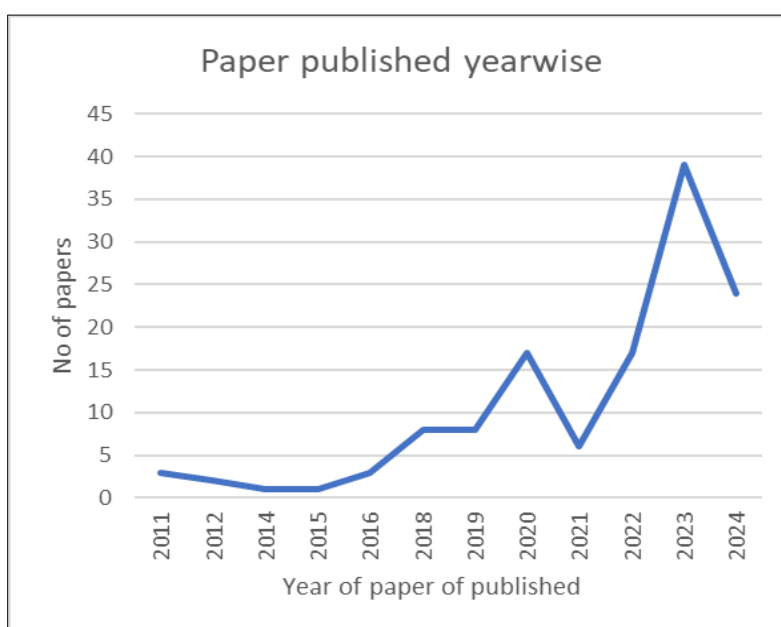
Stage II encompasses the identification, screening, and selection of pertinent studies.

Stage III encompasses the analysis and reporting of findings, with an emphasis on theory, methods, and study locations to identify research gaps and future directions in construction safety.

Table 1: Paper Published Year-wise

Year	No. of Paper	Year	No. of Paper	Year	No. of Paper
2010	0	2015	1	2020	17
2011	3	2016	3	2021	6
2012	2	2017	0	2022	17
2013	0	2018	8	2023	39
2014	1	2019	8	2024	24

Figure 2: Analysis of Papers Published



2.4 Literature review using the “TCCM” method

Theories-characteristics-contexts-methods (TCCM) framework for a systematic search and analysis of articles, with the goal of addressing the following questions: Which theories, variables, and contexts are being applied by researchers? What are the options and future pathways? (Ip & Chark, 2025)

Technology (T): Employ computer vision grounded in YOLOv5 for the real-time identification of personnel and PPE in CCTV footage, ensuring compliance with safety regulations and detection of risks.

Context (C): Focus on Indian construction sites, addressing safety oversights, human errors, and delays in hazard identification due to environmental factors.

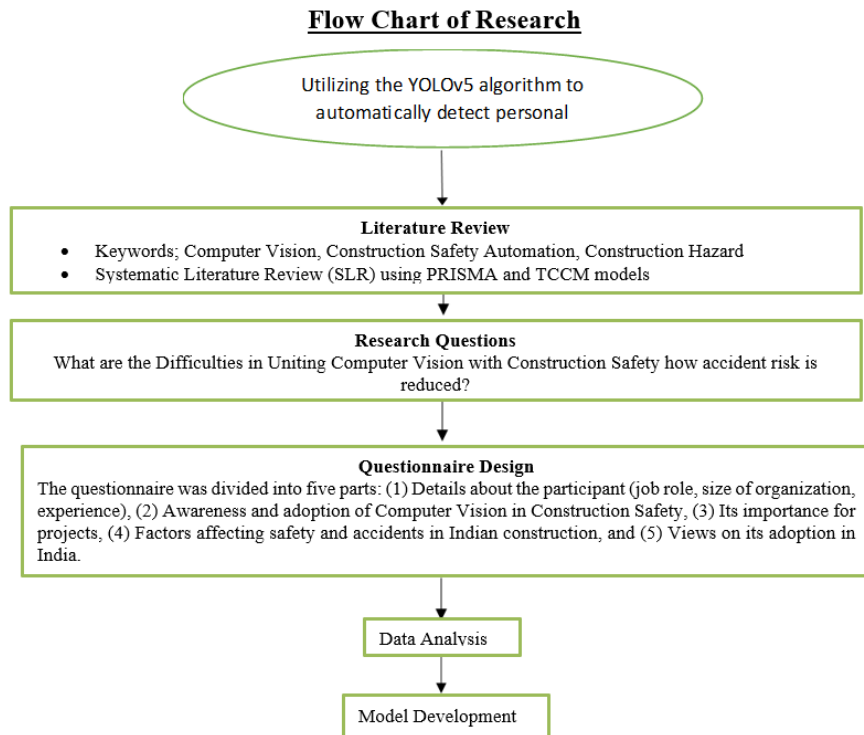
Content (C): Utilize computer vision alongside safety measures to automate hazard identification and notifications, improving reaction times and site safety.

Methodology (M): Train YOLOv5 using current and historical CCTV footage. Evaluate performance by comparing detection accuracy, accident rates, and response efficiency with traditional methods

2.5 Research gap

Lack of Comprehensive Studies: While many studies explore the use of computer vision in construction, most focus on aspects like object detection, PPE compliance, or hazard recognition. No comprehensive study exists that brings together various applications and evaluates their effectiveness in real-world scenarios.

Figure 3: Flow Chart of Research



3.0 Methodology

Literature review & industry analysis: Examination of scholarly articles, case studies, and industry reports to assess the role of computer vision in construction safety in India concerning implementation levels, challenges, and benefits.

Survey for identifying crucial parameters: Questionnaire survey targeting site managers and safety officers to identify critical activities and primary focus on PPE monitoring. This will establish the focus of the object recognition model.

Baseline safety assessment: Collection of pre-implementation data through CCTV surveillance to investigate adherence to PPE and unsafe actions, establishing a reference point for comparison. YOLOv5 Object Recognition Model Development – Creating a computer vision model to detect workers and PPE using labeled data, iterative refinements, and accuracy checks.

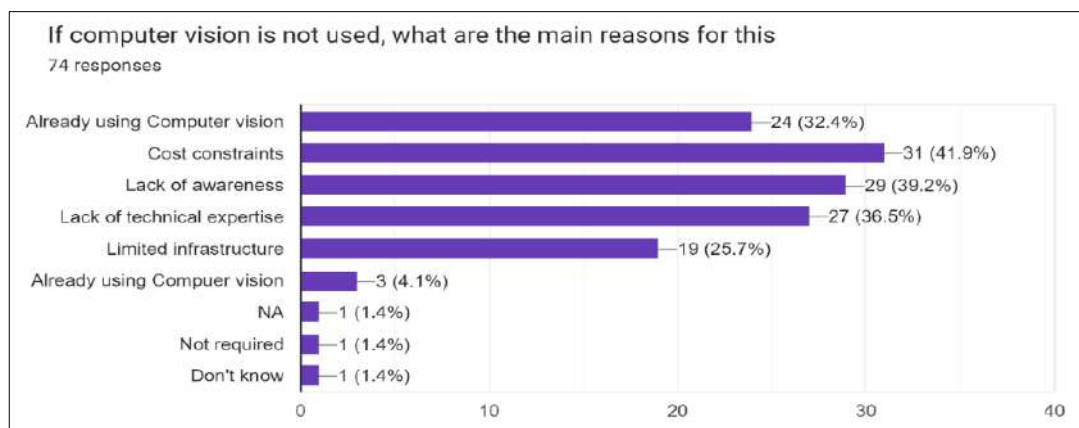
4.0 Data Analysis

This study analyzes responses from 74 construction professionals to assess key factors affecting Computer Vision (CV) and Construction Safety (CS) integration.

Table 2: Data Analysis

Category	Details	Number of Respondents	Percentage (%)
Gender	Male	60	81.08%
	Female	14	18.91%
Work Experience	1-3 years	56	75.67%
	3-6 years	11	14.86%
	6-9 years	5	6.75%
	More than 9 years	2	2.70%
Company Size	1-50 employees	30	37.80%
	51-200 employees	8	10.80%
	201-500 employee	7	9.50%
	500+ employees	31	41.90%

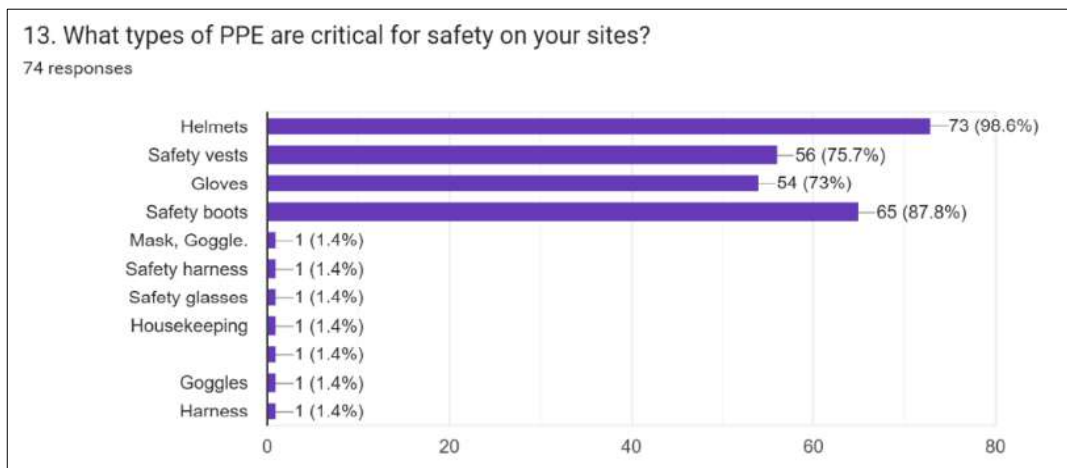
Figure 4: Response for ‘Key Reasons for not Utilizing Computer Vision’



4.1 Inference from survey

According to the survey, the primary obstacles to adopting computer vision in construction are a lack of awareness and technical expertise, with cost concerns following closely behind. All respondents, however, indicated a readiness to embrace the technology after successful pilot tests, acknowledging its potential to improve site safety. In light of these findings, our model based on YOLO will zero in on identifying whether helmets and safety vests—designated as the most vital PPE—are present or absent. An alert system that operates in real-time will be incorporated to inform site managers of any instances of safety non-compliance.

Figure 5: Response for ‘Which kind of PPE is Crucial’



5.0 Model Development

5.1 Overview of YOLOv5

YOLOv5s is a fast and efficient deep-learning (Ngoc-Thoan *et al.*, 2023) model capable of quickly recognizing multiple objects within an image. The “s” stands for “small,” suggesting that it requires less computational resources while still being equally effective.

5.2 The architecture of YOLOv5

- Backbone employs Cross Stage Partial Network (CSPNet) to reduce processing load and improve learning. Employs convolutional and bottleneck layers to derive fundamental visual traits.

- Neck uses Path Aggregation Network (PANet) for the combination of features from different scales. Assists in recognizing items of different sizes, useful for construction locations where laborers are positioned at varying distances.
- Head Utilizes anchor boxes and bounding box regression for precise object detection. Items are classified and assigned confidence scores (e.g., Helmet, Safety Vest, No-Helmet, No-Vest).

The integration of CSPNet, PANet, and the YOLO head enhances YOLOv5 speed, accuracy, and efficiency.

Table 3: YOLOv5 Performance

Metric	YOLOv5s Performance
Input Resolution	600 × 640 pixels
Inferences Speed	~ 140 FPS (Tesla V100 GPU)
mAP (mean Avg. Precision)	~ 45% - 50% (varies with dataset)
Model Size	~ 14 MB
Training Time	Faster than other YOLO version

5.3 Processes involved

Data Collection and Preparation: Acquire images/videos of employees, both with and without PPE. Augment, preprocess, and label data to improve model training.

Training and Selection of Model: Train the YOLOv5 model for PPE detection using annotated data. Make use of transfer learning to improve precision and efficacy. Utilize metrics like mAP and recall validating performance.

Integration and Implementation: Employ OpenCV for real-time video processing. Enhance detection in diverse lighting situations.

Detection and Alert System: Utilize bounding boxes to pinpoint workers who are not compliant. Deliver immediate alerts via text messages, e-mails, or alarms. Provide a dashboard for monitoring compliance.

Testing and Optimization: Evaluate accuracy based on real site measurements. Modify thresholds to reduce the occurrence of false positives. Comparison with SSD and Faster R-CNN models.

5.4 Deployment and monitoring

Integrate with CCTV for instant use. Enable remote monitoring via the cloud.

6.0 Discussion and Results

6.1 Utilized dataset

Images in the dataset show employees with Safety vests and helmets. Among the data

sources are Open-source datasets, such as the COCO, Kaggle, and PPE Detection datasets. Actual photos were taken on building sites in a variety of lighting and environmental settings.

Figure 6: Some of the Pictures used to Train the Model



6.2 Detection of helmet and safety vest through YOLO V5 model with co-authors

Figure 7: Before the Application of YOLO



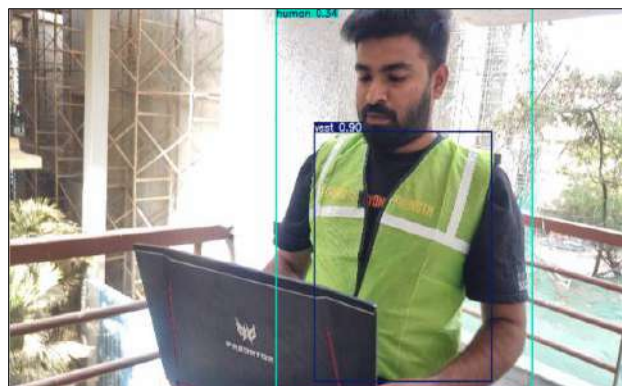
Figure 8: After the Application of YOLO



Figure 9: Without Helmet and Safety Vest



Figure 10: With Safety Vest and no Helmet



6.3 Testing of YOLO V5 with a group of workers on site

Figure 11: Testing of YOLO V5 with a Group of Workers on Site



Figure 12: Alert Notification Through Telegram of a Missing Element with Picture



7.0 Conclusion

Construction is one of the most hazardous industries, where frequent accidents arise from human limitations and delays in recognizing risks. As conventional safety measures often fail, there is a need for advanced solutions. Computer vision, and intense learning models like YOLOv5, have proven effective in bolstering safety monitoring by identifying PPE such as helmets and vests in real-time, thus reducing workplace hazards. A literature review highlighted the global efficacy of AI-driven safety solutions but pointed out their slow adoption in India due to factors like high costs, limited awareness, and insufficient regulations.

To address this problem, a model based on YOLOv5 was developed and trained with images of construction workers. When integrated with CCTV systems for real-time monitoring, it demonstrated a high level of accuracy. This model generated automatic alerts for violations, resulting in a marked enhancement of compliance enforcement. A survey of 74 industry professionals identified critical challenges, including a lack of technical expertise, budget constraints, and resistance to change. Nevertheless, the respondents acknowledged that effective pilot projects could ease broader implementation.

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CHAPTER 26

Automated Pavement Distress Detection using YOLOv8 with Augmentation Techniques

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ABSTRACT

Roadways are pivotal in transportation infrastructure, serving as essential pathways for travel and connectivity. Well-maintained highways significantly contribute to a nation's economic growth. Highways are essentially pavement structures with three to four layers designed to provide structural strength and endure repetitive traffic loads. However, over time, the continuous impact of heavy traffic and adverse weather conditions leads to a gradual loss of structural integrity. This deterioration results in various distresses on the pavement surface, such as cracks, potholes, and ravelling. The durability and functionality of pavements are critical to ensuring safe and efficient transportation. This study focuses on implementing artificial intelligence to enhance the assessment of pavement conditions, addressing limitations in traditional manual methods. This research employs Convolutional Neural Networks (CNN) and the You Only Look Once (YOLO) model to detect, classify, and quantify pavement distresses such as cracks, potholes, and rutting, by training it on the open-source database which has around 14,000 images. The YOLOv8 architecture was selected for its superior performance in object detection tasks. The models were evaluated using metrics like Mean Average Precision (mAP), precision, and recall, achieving promising results for certain distress types. From the results, it was observed that the YOLOv8 model gives around 25% precision and after the data augmentation, the results improved to 37%. Also from this trained model, the website developed for automated pavement distress detection using video. The findings demonstrate the potential of AI-driven approaches to automate pavement condition assessments while highlighting challenges, including dataset imbalances and variability in distress detection accuracy.

Keywords: Pavement distress; Deep learning; Convolutional Neural Network (CNN); YOLOv8; Pavement Condition Index (PCI).

1.0 Introduction

For connecting villages, cities, districts, states, production lines, and even countries, roads are considered one of the most important elements in civilized communities (Shatnawi, 2018).

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Roads or Pavement is a smooth finished surface, which helps it be durable and should withstand the designed traffic and other environmental conditions, for a life span of 20-30 years. A pavement is a structure, whose primary function is to distribute the designed traffic loads among the pavement layers. Due to material deterioration brought on by excessive traffic, unfavourable weather, aging, or improper maintenance, pavement loses its structural strength (Jianqing WU, 2022; Walaa *et al.*, 2019). Improving the structural strength of pavement, will increase riding quality and enhance travellers' comfort levels, so for improving structural strength there is a need for pavement distress data (Deluka-Tibljaš *et al.*, 2013). Still, the timely detection of distress and the application of appropriate treatment methods are most important for treating the pavement (Chan *et al.*, 2011). Researchers and transportation agencies are attracted by the importance of a timely manner of detecting distress and so many researchers have started working on pavement inspection technologies, which can accurately assess pavement distress and its severity (Zhu *et al.*, 2022).

Pavement functional evaluation is used to evaluate the condition but is mostly done by manual method and visual observation to identify the pavement distress and its severity, based on which Pavement Condition Index (PCI) is calculated. Based on the calculated PCI value, road condition was graded from poor to good, and according to IRC:82 for Indian conditions and ASTM D6433 as international standards treatment methods are suggested for repairing roads. Moreover, while conducting manual inspection tasks, there exists the potential for human visual mistakes, as well as safety concerns due to the proximity of passing motor vehicles.

Additionally, these operations have the potential to disrupt the flow of traffic. To overcome the limitation of manual methods for evaluating conditions, there is a need for automated distress detection method, which can be used to create to assess, track, and chart the progression of both the surface and subsurface structure of the pavement, along with the profile of any distress. In an endeavor to reduce expenses and expedite maintenance activities, transportation departments are emphasizing the advancement of automated profiling systems for evaluating pavement distress. While automated data collection methods offer numerous advantages, they also result in a substantial volume of raw pavement data. Analyzing and making decisions based on this raw data necessitates the expertise of human professionals.

From literature review, it was observed that most of research is focused on crack and pothole type of distress, but for calculating PCI value, other type of distress data and its severity is needed. So, this research mostly focuses on identifying the distress type from images, where the training of model will be done on the open-source datasets and based on that distress identification of raw images which are collected from the field, will be done using trained model and based on the condition of pavement will be evaluated.

2.0 Literature Review

For knowing the potential research gap, a comprehensive literature review was performed to know how the researchers are using machine learning for the detection of distress

in pavements, and which extra techniques need to be employed for extracting the features from images. (Astor *et al.*, 2022) used Agisoft Metashape Professional Software and Build Dense Cloud process for obtaining a 3-Dimensional (3D) model, from which the type and dimensions of the image are observed. For this 2388 photos were captured using drones and processed for producing an orthophoto as a 3D model. The observed results were validated with actual field measurements. From the study, it was observed that when the obtained depth of pavement obtained compared with the real figures, it was obtained as 0.3 to 3 cm. (Shatnawi, 2018) detects the cracks in place north of Jordan through four processes namely Image Enhancement and Pre-processing, Feature Extraction, Neural Network Modelling, and Validation. For this researcher used 800 images which include cracked and crack-free pavement by cropping the original image. For the detection of distress, ANN modelling was used with variable learning backpropagation function to train the network. The method detected distress with 90% Sensitivity, 60% Specificity, 82.5% Accuracy, and 87% Precision.

(Pauly *et al.*, 2017) concluded that a deeper CNN network would provide a better result for pavement crack detection. CNN was developed using Keras by TensorFlow as a backend, which consists of four convolutional, pooling layers and two connected layers. From the results, it was observed that it detects successfully pavement distress, but fails for the new locations. (Walaa *et al.*, 2019) used the MATLAB toolbox CrackIT and DeepCNN approach for pavement distress detection in Massachusetts. Unmanned Aerial Systems (UAS) with thermal and visual cameras are used for the collection of images for predicting pavement distress. From the study, it was found that CrackIT was found inaccurate, and also some false detections were observed.

Single Shot Detector (SSD) MobileNetV1 network was found accurate for distress prediction and for determining the width of cracks, the U-Net model was used. Crack 5000 database and other various open-source datasets were used for enhancing the performance of the model and which will lead to better detection of distress. (Ali *et al.*, 2019) for detecting cracks proposed a CNN model for which a dataset of 4000 patches was created using images captured from various road sections in the UAE. For the detection and localization of cracks, the sliding window technique is combined with the CNN model. With different epochs of training, it was observed that the 20th epoch had the greatest training and validation accuracy, 92% and 90%, respectively.

From the literature review, it was observed that most researchers have used machine learning models for the identification of distress and image processing techniques for distress feature identification from images and around 500 to 28000 images were used for training with the pixel size of 900x1000 to 150x150, also maximum the sample size for training more will be the accuracy. For measuring performance of models, researchers have calculated recall, True Positive Rate (TPR), Precision, Mean Average Precision (MAP), F1 Score, Mean Intersection Over Union (MioU) and Accuracy. Studies have made use of different neural networks and different image processing processes for distress feature identification as presented in Table 1.

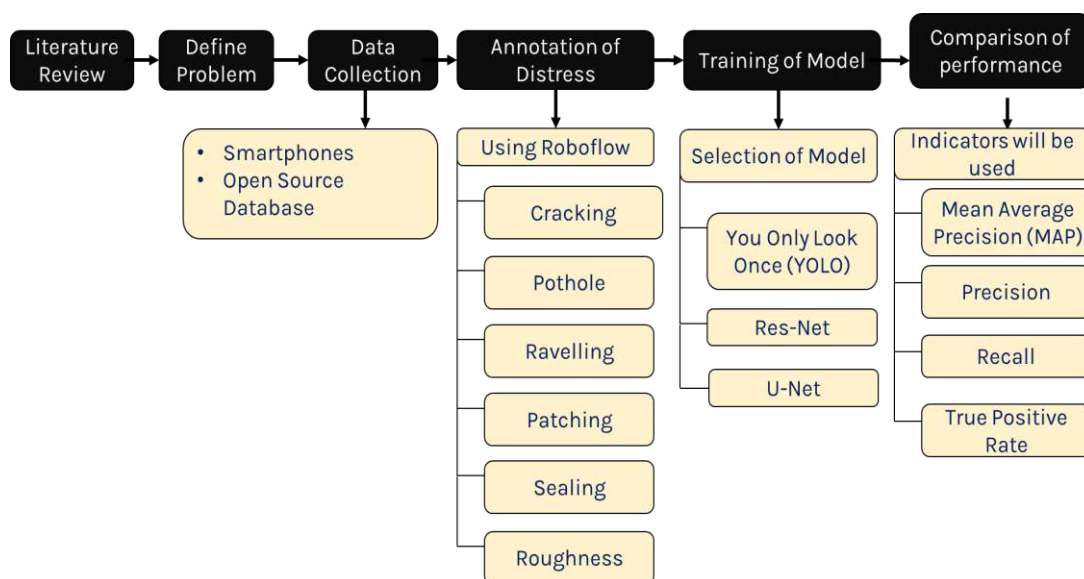
Table 1: Summary of Literature Review

Sr. No.	Type of Distress	Data Collection Method	Feature Identification Method	Network for Detection
1	Cracking	- Thermal & Visual Cameras (Ranyal <i>et al.</i>, 2022) - Open Source - Microsoft Kinect (Zhang <i>et al.</i>, 2018) - BaidueMap (Lei <i>et al.</i>, 2020) - UAV Images (Outay <i>et al.</i>, 2020; Romero-Chambi <i>et al.</i>, 2020; Shaghlil & Khalafallah, 2018) - Drone Video (Astor <i>et al.</i>, 2022) - CCD Cameras (Zhou <i>et al.</i>, 2022)	- Image Processing (Liu <i>et al.</i>, 2021; Zakeri <i>et al.</i>, 2017) - Colour Image Processing - Image Thresholding - Image Smoothing - Image Denoising - Feature Extraction Filter Kinect Algorithm (Zhang <i>et al.</i>, 2018)	- SSDMobileNet (Qurishee, 2019) - U-Net (Li <i>et al.</i>, 2021) - AlexNet (Li & Zhao, 2019) - GoogleNet (Tang <i>et al.</i>, 2021) - SqueezeNet - ResNet (Li <i>et al.</i>, 2021; Samma <i>et al.</i>, 2021) - DenseNet (Ranjbar <i>et al.</i>, 2021) - YOLO (Majidifard <i>et al.</i>, 2020; Zhu <i>et al.</i>, 2022) - CNN (Abdeljaber <i>et al.</i>, 2018; Ali <i>et al.</i>, 2019) - Random Forest (Pan <i>et al.</i>, 2018)
2	Pothole	- UAV images (Outay <i>et al.</i>, 2020; Romero-Chambi <i>et al.</i>, 2020; Shaghlil & Khalafallah, 2018) - BaidueMap (Lei <i>et al.</i>, 2020)	- Conversion into 3D - The same Image Processing Method was Used as above.	- YOLO (Lei <i>et al.</i>, 2020) - Random Forest (Pan <i>et al.</i>, 2017) - Faster R-CNN (Wang <i>et al.</i>, 2019)
3	Patching	- UAV Images (Outay <i>et al.</i>, 2020; Romero-Chambi <i>et al.</i>, 2020; Shaghlil & Khalafallah, 2018) - BaidueMap (Lei <i>et al.</i>, 2020)	The same Image Processing Method was Used as above.	YOLO (Lei <i>et al.</i>, 2020)
4	Rutting	UAV Images (Outay <i>et al.</i>, 2020; Romero-Chambi <i>et al.</i>, 2020; Shaghlil & Khalafallah, 2018)	Digital Elevation Method	

3.0 Methodology

For Data Collection, pavement images can be captured using UAV cameras, Smartphone cameras, or using open-source databases of pavement images.

Figure 1: Methodology Followed



After data collection, Convolutional Neural Network (CNN) model is made for the detection and classification of distress. After classification, Image processing techniques like Standardization of Images, Image Enhancement, Colour Image Processing, Image Denoising, Image Thresholding, Morphological Processing, and others can be used for distress identification. After the identification of distresses, for quantification of distresses each distress dimension needs to be measured & by that the severity level of distresses to be measured according to ASTM D6433.

The methodology discussed for determining severity level was followed earlier, but quantifying distress dimensions pixels per metric value is needed, which is a challenging task, and also this CNN model can only detect one type of distress from one image. So, for the detection of multiple distress in one image, we used the YOLO model and by using this model, quantifying the distress severity with help of the image processing process is eliminated.

Reframed Methodology is like a collection of data (pavement images), categorization of distress and its severity using the YOLO model, and then calculating PCI values, which is presented in Figure 1. The function of the YOLO model like training and testing of images is explained in the section. By knowing the severity level, for each distress type Pavement Condition Index (PCI) value is measured and the total PCI value is calculated for the whole pavement section. Based on PCI value, the overall condition of the pavement section can be known, and based on that appropriate treatment method can be recommended.

4.0 Model Analysis and Results

For model training, 14,953 total images were collected from the open-source database, which was distributed into the training set, validation set, and test set with a percentage of 75%, 15%, and 10% respectively. The object's class number and the locations of the bounding box's edges are labelled on each image. With an average of 1.1 annotated objects per image, 17,182 annotations overall, and a median image ratio of 1280x1080, an image may contain several objects and classes. Auto-orientation pre-processing was used in the photos; no augmentations were used. Dataset represents different types of distresses like Cracking (5614), Alligator Cracking (4464), Pothole (2660), Sealing (1331), Shoving (1069), Patching (921), and Ravelling (568), suffering from a class imbalance. The model was trained on a dataset focused on identifying various pavement distress types, such as alligator cracking, potholes, patching, and other related issues. The dataset was split into three parts:

- *Training Set:* 11,215 images, used to train the model by adjusting weights through backpropagation and minimizing the loss functions.
- *Validation Set:* 2,243 images, used to tune model hyperparameters and prevent overfitting by monitoring performance on unseen data during training.
- *Test Set:* 1,495 images, used to evaluate the model's effectiveness on new, unseen data after training.

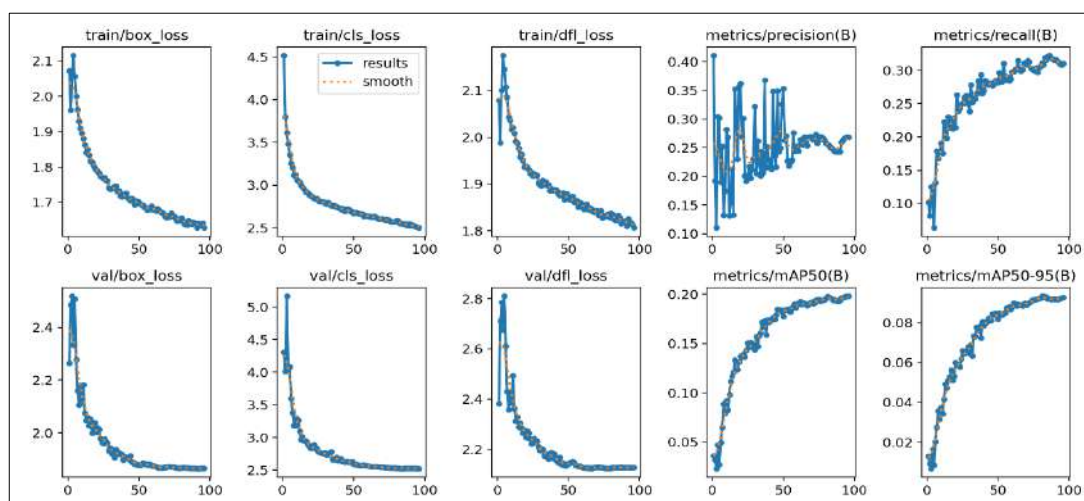
Figure 2: Annotated Images: Cracking (Red), Alligator (SkyBlue), Pothole (Orange), Patching (Violet), Ravelling (Yellow), Sealing (Light Green)



4.1 Model results

The overall performance of the model on the test set was evaluated using several key metrics, including Mean Average Precision (MAP), Precision, and Recall. The MAP (Mean Average Precision) observed 19.7%. This value provides an overall indication of the model's accuracy in predicting bounding boxes and correctly identifying the class of pavement distress. MAP of 19.7% suggests that while the model can detect objects and predict bounding boxes, there is room for improvement in achieving higher accuracy. The precision observed 25.4%, which measures the ratio of true positive predictions to the total positive predictions made by the model. In this case, a precision of 25.4% indicates that the model produces a moderate number of accurate predictions but also has false positives, meaning it sometimes predicts distress where there is none. Recall value was observed as 31.2%. Recall measures the proportion of actual positives that were correctly identified by the model. A recall of 31.2% suggests the model captures a reasonable portion of actual pavement distress cases, although some cases remain undetected.

Figure 3: Model Results



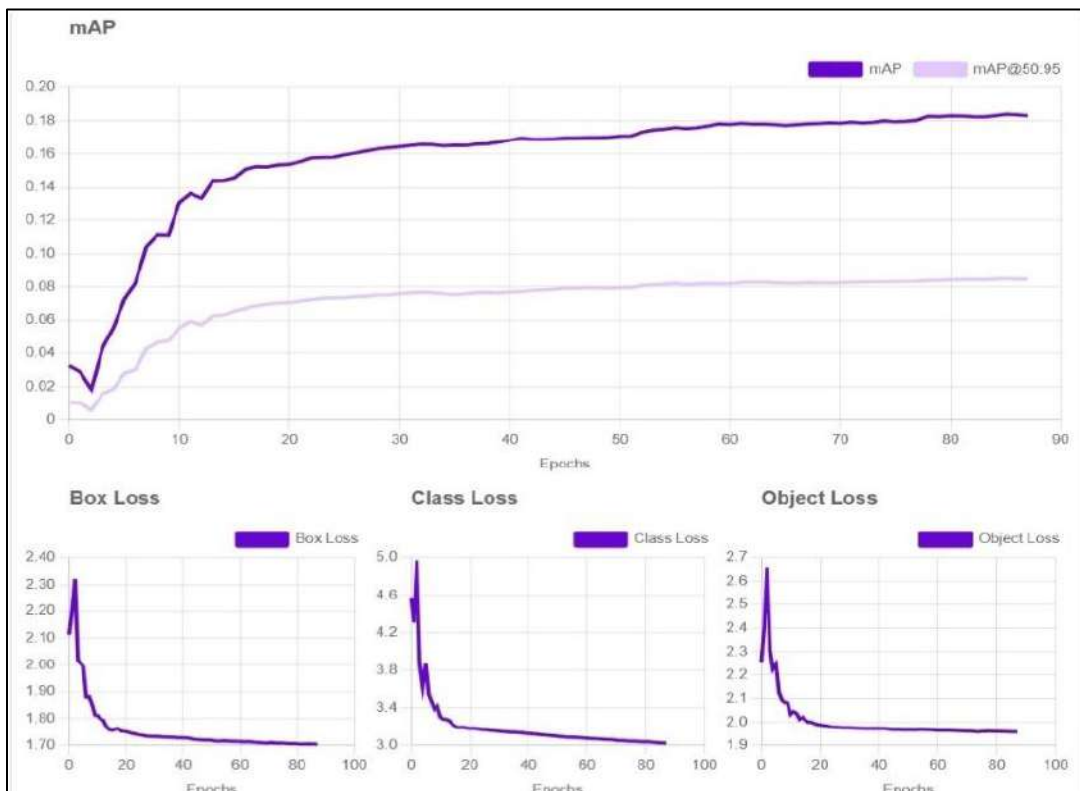
The Average Precision (AP) per class, as displayed in the horizontal bar graph, provides insight into how well the model performed on each distress type. Specific classes like “Alligator Cracking” and “Pothole” had relatively higher precision, while others like “Shoving” and “Ravelling” had lower precision. This variation might indicate an imbalance in the dataset or certain classes being more challenging to detect due to visual similarities with other classes.

4.2 Improvements in model

The model demonstrates a promising starting point, particularly in recall and class-specific accuracy for certain distress types. However, improvements in precision and MAP are

needed to make the model more reliable. Some recommendations for further enhancement include data augmentation, hyperparameter tuning, balancing classes and fine-tuning the model. Data augmentation helps to increase the dataset size or using techniques such as rotation, flipping, and contrast adjustment were done to help the model generalize better, especially on distress types with lower precision. Hyperparameter tuning and further experimentation with learning rates, batch sizes, and regularization methods could enhance model stability and performance. With more fine-tuning of the model, the precision is increased from 25.1% to 34.1%, which shows the better results for detection of raw pavement images.

Figure 4: Model Improvement Results



5.0 Conclusions

Pavement Asset Management System (PAMS) is a tool used for maintaining the deterioration of the pavement, by assessing the actual condition of the pavement which helps to allocate the budget for repairing the pavement. For assessing the pavement, the Pavement Condition Index (PCI) is one of the parameters for which functional evaluation of the pavement

needs to be done, where the distress types and severity is measured. For automation of distress detection, many machine learning models are been used, but most of them are used for only crack detection, still, there are many other distress data needed for the calculation of PCI values as per IRC:82. Therefore, in this study, all other types of distress are also considered and the model is developed to classify the distresses.

Cracking, Alligator Cracking, Pothole, Sealing, Shoving, Patching, and Raveling are the seven types of distresses that are considered for model development, where a total of 14,953 images were obtained from different open-source databases. These images were annotated in the Roboflow platform and were trained first with the YOLOv5 model with no tuning, results obtained were MAP as 19.7%, Precision as 25.4%, and recall as 31.2%. For the further improvement of the model, hyperparameter tuning, data tuning and also while detection some thresholds were changed, by which Precision increased to 34.1%.

YOLOv5 model was trained using open-source database, which are mostly developed from developed countries, so in future these models should be trained using real collected images for Indian field conditions and based on that model further detection of distresses could be done for Indian conditions. Also, the YOLO trained model was able to detect only the surface distresses, which are visible, but there are other distresses like rutting which is due to deformation, depth of crack and potholes for knowing severity level of distress and also to calculate PCI value, so that pavement conditions can be evaluated. After this detection of distress types and their severity, one can also detect the amount required for repairing and maintaining the whole pavement.

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CHAPTER 27

Balancing Spatial Expansion and Socio-Economic Inclusion in Peri-Urban Area: A Case Study of Nashik

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ABSTRACT

Spatial expansion of cities exerts a lot of pressure on natural resources and socio-economic development in peri-urban areas. Now addressing these issues in planning process by result in unsustainable and exclusive development. Nashik has come a long way with rapid urbanization driving its spatial expansion while increasing the peri-urban area, witnessing great socio-economic and environmental challenges. This research discusses the fast-changing nature of spatial growth and socio-economic changes while investigating issues of socio-economic disparity and sustainable development in the peri-urban areas of Nashik. The paper analyzes spatial trends of growth, demographic change, infrastructural deficiencies, and socio-economic inequalities therein and comes out with issues impacting peri-urban transitioning areas. The research employed mixed-method strategies i.e quantitative and qualitative methodologies: spatial analysis through GIS and socioeconomic assessments through household surveys and interviews. It contains structured household surveys that indicate demographic trends, standard of living, and access to basic needs while at the same time holding interviews with town planners and city officials to learn how governance and policy frameworks deliver. The results expose the adverse impacts of uncontrolled urban expansion, which include the loss of agricultural land, lack of infrastructure, housing affordability problems, and socioeconomic isolation of poorer citizens. The study finally links best practices and case studies to develop an integrated planning framework that places spatial development strategies in focus with socioeconomic responses, particularly concerning equal access to resources, infrastructure, and opportunity.

Keywords: Peri-urban development; Spatial expansion; Socio-economic inclusion; Urban-rural linkages; GIS.

1.0 Introduction

1.1 Background

In fast-developing urban areas such as Nashik, urban sprawl has drastically altered peri-urban regions, which are transitional zones between rural and urban environments.

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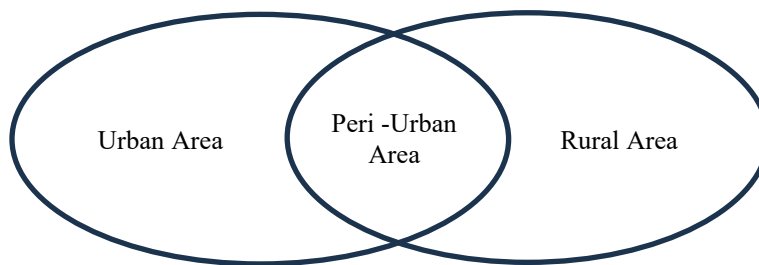
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Triggered by population growth, migration, and industrialization, these regions have quickly transformed from agricultural to urban land use. Informal in nature, with mixed-use development and inadequate connectivity, unplanned expansion has caused socio-economic and spatial inequalities, limiting access to basic services, housing, and employment for poorer segments of the population (Chhangani, 2023).

1.2 Definition

The terms of the Peri- Urban have evolved from the word ‘peripheral’ (Janakarajan, 2010). Peri- urban regions are a phase of an area which falls between rural and urban; that is, they afford features of both classes of grounds. The general meaning of the peri-urban area refers to a dynamic zone that is presumed to be more than the peripheral or the edge separating an urban centre from a non-urban centre (Ravetz, 2013).

Figure 1: Peri -Urban Area



Source: Compiled by authors

1.3 Aim

To investigate and propose integrated planning strategies for achieving sustainable development in the peri-urban areas by balancing spatial expansion with socio-economic inclusion.

1.4 Objective

- *To analyze the current state of peri-urban development:* Explore spatial scale and distribution, populational changes, infrastructural gaps and socio- economic inequalities in the peri-urban Nashik.
- *To examine the adequacy of physical infrastructure and land use:* Examine the challenges faced regarding the role of infrastructure provision and land use planning for socio economic inclusion of peri-urban areas.
- *To identify successful case studies and best practices:* Examine and critique different experiences of integrated planning to enable sustainable peri-urban development from around the world.

- *To evaluate obstacles and challenges:* Determine what concerns the planning of physical infrastructure and socioeconomic inclusion in peri-urban areas.
- *To develop a conceptual framework for integrated planning:* Suggest an intervention strategy that combines the provision of structural physical infrastructure with socio economic interventions especially for peri urban areas.

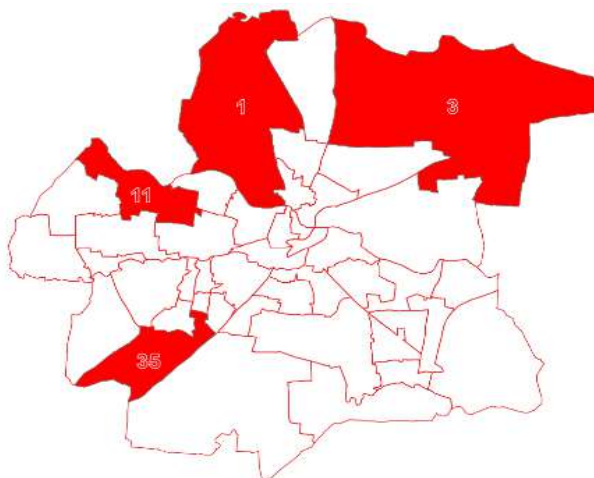
1.5 Scope of work

Urban land use expansion in peri-urban areas is an important challenge to expanding cities, both as an opportunity and threat for sustainable development. It usually occurs through rapid expansion of urban land uses, contributing to displacement, increased socio-economic disparities, and environmental degradation (Salem, 2024). Though peri-urban regions are becoming increasingly prominent in urban planning, they have limited research attention. The majority of studies are concentrated on metropolitan cities, leaving the smaller urban peripheries and their distinct issues unexplored. Many reviews also have a narrow spatial focus, prioritizing land use or infrastructure over socio-economic interactions. This study attempts to fill this gap by formulating a comprehensive framework for peri-urban Nashik, tackling urban sprawl, socio-economic requirements, and environmental sustainability.

1.6 Site overview

As one of the growing urban centers in Maharashtra state, peri-urban landscapes of Nashik are undergoing rapid urbanisation. Nashik has a geographic area of about 264.23 km² wide and is located on the Mumbai-Agra National Highway – NH 3 and within the Mumbai-Pune-Nashik industrial triangle.

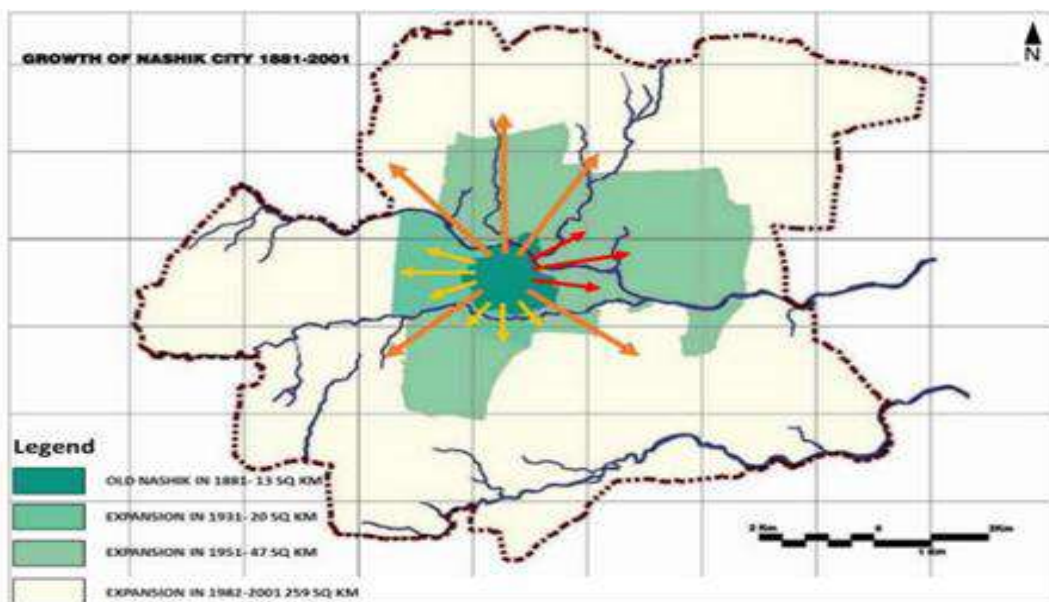
Figure 2: Growth of Nashik City 1881 -2001



Source: DP Report of Nashik 2016 -36

This positioning has triggered tremendous growth of the urban area, the city's population is now over 1.8 million as of 2021 (Nashik Municipal Corporation, 2021). Adgaon, Ambad, Makhmalabad and Gangapur localities in the peri-urban areas of the city continue to undergo lot of land-use changes where agricultural lands are being converted to residential and industrial use to cater for the increasing population density and industries in the city. Peri-urban Nashik is marked by stark socio-economic inequalities, with marginalized groups such as migrants and low-paid workers being deprived of basic amenities like water, healthcare, and education. Increased luxury gated community development in juxtaposition with informal settlements has widened inequality, and socio-economic zones are clearly delineated. The affordability of housing is still a big challenge, with real estate development leading to the displacement of slum dwellers. Although Nashik is under the Smart City Mission, its services and infrastructure are not able to cope with the needs of the fast-growing peri-urban population (Smart City Nashik, 2022).

Figure 3: Key Focus Area (Ward Wise)



Source: Compiled by authors

3.0 Literature Review

3.1 Peri-urban development

Peri-urban regions are defined as areas between the conventional urban and rural regions and is therefore an area of high spatial growth and land use dualism. When cities and

towns expand, their hinterland comes under increasing social, economic and physical pressures due to conversion for real estate, infrastructural requirements and the demographic reshuffle. These areas usually undergo unregulated growth, which leads to socioeconomic difficulties like inequality, marginalization, and land-use conflicts (Allen, 2003). Sustainable peri-urban development therefore requires a symbiotic planning approach to both spatial and social-economic growth and developments that allows for infrastructure amidst the denial of agricultural land (Simon, 2008).

3.2 Spatial expansion and its impacts

The Causes of urban sprawl; population pressure, job opportunities, speculation on real property and availability of sizable tracts of land for development. In India, the peri-urban contexts are usually vulnerable to the speculation and the duality of rural land for residential or commercial purposes results in an unplanned growth (Pradhan, 2013). Researchers have established that this expansion occurs without infrastructure services hence putting pressure on smaller local governments to provide infrastructure services (Shaw, 2007).

3.2.1 Impact on land use and agriculture

The growth of cities such as Nashik toward their surrounding peri-urban zones leads to change of land use from agriculture to urban. This not only makes fragmentation of agriculturally rich land but also decreases the food security factor (Satterthwaite, 2010).

3.2.2 Challenges in infrastructure provision

When the cities grow the provision of the necessary amenities for the public such as roads, sewer systems, water supply and several others are very daunting. The findings also show that in many cases, peri-urban areas are poorly serviced in terms of physical infrastructure relative to central business districts (Allen, 2003). This leads to an unequal distribution of services, and most people living in peri-urban areas will at times do without some basic services (Narain, 2009). Proper planning strategies are required in order to supply infrastructure as a support structure of spatial growth, as well as developmental lines that are relevant to the populations found within the peri-urban territories (Narain, 2010).

3.3 Socio-economic inclusion

Population in peri-urban areas is a mixed population that comprises of the old rural dwellers, the new settlers from core urban areas and squatters. This diversity poses a problem for social integration because these groups require different successful integration solutions.

3.3.1 Employment and livelihoods

Employment was found easily in peri-urban areas employing sectors that include construction, manufacturing and services. However, the migration from rural to urban areas is

characterised by some form of tension because the change from farming to taking up non-farming employment is occasioned by the growth of urban areas. It is thus essential for integrated planning to factor how it can establish new employment that can effectively accord the peri-urban society, especially women and the urban poor a chance (Mondal, 2021).

3.3.2 Housing and informal settlements

Housing in peri-urban areas is mainly regarded as being of an informal nature, for a sizable percentage of the population lives in slums or other forms of informal shelters (Shaw, 2007). Due to high costs of houses, people are forced to construct their own houses in an improper way hence leading to increase in number of people being evicted from their houses or compounds and lacking in basic facilities (Dupont, 2008). Any plan designed towards sustainable peri-urban development should therefore incorporate issues of housing and tenure security to improve people's position in the economic sphere of the society (Fox, 2014).

4.0 Results and Discussions

4.1 Integrated planning approaches for peri-urban development

The tension between spatial growth and economic-social equity can only be well managed through integrated planning solutions. Use of conventional sectoral strategies for planning that either promotes urban expansion or protects the rural areas fail to capture peri urban dynamics (Narain, 2009). As a result, more comprehensive and spatial, environment and socio-economic strategies are important for sustainable development (Kim, 2014).

4.2 Strategies for managing spatial expansion

With regard to physical planning several policies have been advanced to control spatial expansion in the peri-urban areas such as the use of the green belt policies, the land pooling policies, and the use of zoning. These strategies seek to check the undesirable urban development but encourage efficient compact utilization of resources in the provision of urban areas (Allen, 2003). In Indian scenario more specifically, the policy tool of land pooling schemes has indicated significant effectiveness in including rural land in urban development plans besides paying a fair price to the rural landowners.

4.3 Promoting socio-economic inclusion

Policies aimed at promoting socio economic equity in Peri urban areas need to consider spatial and social aspects of the urban transition. This encompasses housing accessibility, increased access to services and equal employment opportunities (Fox, 2014). Therefore, in line with this study decision-making process that involves peri-urban communities is important so that development reflects the needs of the people.

5.0 Conclusions

In conclusion, as Nashik's population increases, well-coordinated land planning and management are necessary in order to meet rural and urban demands sustainably. Through combining inclusive planning, employment, and housing, peri-urban development can benefit all the residents and not only the elite. The study analyzes new issues in service delivery, land utilization, and socio-economic integration in Nashik's peri-urban zones. Following the analysis, it will set out a policy framework to connect spatial planning and socio-economic objectives for sustainability. The suggestions shall be based on accessibility, infrastructure, public involvement, and proactive land utilization policies to ensure these issues are effectively addressed.

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CHAPTER 28

Balancing Urbanization and Cultural Preservation in Construction Practices in Northeast India

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ABSTRACT

Urbanization in Northeast India is speeding up with the growth in population, economy, and infrastructure development, posing a significant impact on the area's rich cultural heritage. The present study discusses the equilibrium between modernization and culture conservation through the investigation of traditional architectural strategies, native values, and the socio-economic context of urbanization. Based on a quantitative survey-based methodology, information was gathered from 74 stakeholders, i.e., urban planners, architects, policymakers, and local community members. Statistical analysis using SPSS resulted in a high Relative Importance Index (RII) of 0.851 for preserving culture, showing strong support from the populace. It is seen that 74.3% of the respondents answered that cultural preservation was "Important" or "Very Important," and this indicates broad concern about the disappearance of traditional architecture. The research also shows that the preservation of culture increases economic advantages, like tourism and traditional crafts, with 82.4% of the respondents agreeing on it. The study calls for participatory urban planning, adaptive reuse policies, and financial incentives for promoting sustainable growth and conserving cultural heritage. The study suggests integrated policies, which harmonize modernity with heritage conservation, and promotes inclusive and sustainable development in Northeast India based on global models such as Kyoto and Bhutan.

Keywords: Cultural preservation; Urbanization; Traditional architecture; Economic benefits; Sustainable development.

1.0 Introduction

Northeast India, renowned for its breathtaking landscapes and rich biodiversity, is experiencing rapid urbanization driven by population growth, economic expansion, and improved connectivity. Cities like Guwahati, Shillong, and Imphal are transforming with infrastructure projects such as highways, airports, and smart city initiatives. While urbanization promises economic growth and improved living standards, it also poses significant challenges, including environmental degradation, loss of cultural identity, and socio-economic disparities.

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Unplanned urban sprawl threatens ecosystems, traditional livelihoods, and regional sustainability, particularly as modern construction practices often overlook local cultural and environmental contexts (Pautunthang & Institute for Social and Economic Change, 2018; Mandal *et al.*, 2022). The region is a cultural mosaic, home to over 200 indigenous communities, each with unique languages, traditions, and architectural practices. These traditions, such as the stilt houses of the Mishing tribe and the bamboo structures of the Khasi people, are deeply intertwined with the natural environment and reflect cultural identity and communal values. However, rapid modernization and globalization risk erasing this heritage, replacing it with generic urban landscapes devoid of historical significance. Preserving this cultural wealth is essential not only for honoring the past but also for fostering a sense of identity and pride among future generations (Pandiya, 2024).

Balancing modernization with cultural preservation is a critical challenge in Northeast India. While infrastructure development is vital for economic progress, it often comes at the cost of environmental and cultural integrity. Large-scale projects like highways and dams have displaced indigenous communities and destroyed sacred sites, while Western-style architecture has marginalized traditional building practices. Addressing this tension requires participatory planning that integrates local cultural and environmental aspirations. By incorporating traditional knowledge and sustainable practices, such as flood-resistant stilt houses and living root bridges, urban development can achieve a harmonious blend of modernity and cultural preservation, ensuring inclusive and sustainable growth (O'Connor, 2024; Sharma *et al.*, 2024).

1.1 Objectives

- To identify the Perception of Urbanization and Cultural Heritage.
- To recognise the Attitudes toward Cultural Preservation.
- To understand the Preferences for Construction Practices.
- To find the Barriers to Using Traditional Practices in Urban Development.
- To identify the Policy and Community Recommendations

2.0 Literature Reviews

Kiruthiga & Thirumaran (2019) explored the impact of urbanization on heritage buildings in Kumbakonam, Tamil Nadu, emphasizing how rapid urban growth threatens the integrity of historical sites. Their study focused on the physical, socioeconomic, and sociocultural influences that affect the preservation of heritage characteristics, particularly in temple towns facing modern urban pressures. Similarly, Chandra & Sinha (2023) examined the role of urban planning in preserving cultural heritage while boosting tourism, using Gwalior as a case study. They highlighted the importance of integrating heritage conservation into urban planning to enhance tourism without compromising cultural identity, stressing the need for a collaborative approach involving government bodies, local communities, and tourism

stakeholders. Pokhriyal & Kawatra (2024) discussed the role of tourism in cultural heritage conservation in India, specifically at UNESCO-designated heritage sites. While tourism promotes awareness and economic benefits, they noted it also leads to overcrowding and ecological degradation. They recommended a balanced approach that integrates sustainable tourism with heritage conservation, a principle that could be applied to Northeast India, where urbanization is rapidly altering traditional landscapes. Roy *et al.*, (2023) emphasized the need for documentation and cultural preservation of indigenous technical knowledge in Northeast India, focusing on local construction techniques and traditional ecological knowledge at risk due to urbanization and modern construction practices. They stressed integrating indigenous knowledge into contemporary planning systems to maintain cultural continuity and support sustainable development.

Bhardwaj (2024) analyzed shifting cultivation practices in Northeast India, discussing how traditional agricultural methods, such as the jhum system, contribute to biodiversity conservation. While urbanization and policy changes have led to the decline of these practices, the study suggests maintaining a balance between modern agricultural methods and traditional practices to ensure environmental sustainability. Sharma *et al.* (2024) investigated the integration of traditional knowledge and modern planning practices in cultural heritage conservation, arguing that urbanization and development pose significant challenges to preserving cultural heritage in cities.

They proposed fostering communication between stakeholders and incorporating traditional knowledge into urban planning to create a more resilient and culturally sensitive framework for heritage conservation. Sahu & Ahirwar (2024) examined the balance between urbanization and heritage preservation in Jaipur, India, focusing on integrating heritage sites into urban development plans. Their findings emphasized the importance of a holistic urban planning approach that includes heritage preservation without hindering urban growth. This insight is relevant for heritage cities in Northeast India, where rapid urban expansion threatens both tangible and intangible cultural heritage. Doley (2014) studied the changing cultural practices among the Missing tribe of Assam, particularly in the context of rural-urban migration. His research highlighted how modern urbanization is influencing traditional practices, including construction techniques and social structures, stressing the need to preserve cultural identity while adapting to urban lifestyles.

Riganti (2017) discussed the pressures of rapid urbanization on cultural heritage in Indian cities, noting the increasing challenge of preserving historic sites amid unplanned urban growth. He called for a “smartheritage” approach, where smart technologies are applied in conservation practices to improve decision-making and sustainability, aligning with modern urban development. Guerrieri (2022) highlighted the evolving field of heritage conservation in postcolonial India, emphasizing the importance of local perspectives that differ from colonial legacies. He pointed out the role of institutions like INTACH in advocating community-based preservation and integrating traditional knowledge with modern planning systems.

Meitei & Das (2024) analyzed urbanization patterns in Northeast India, focusing on urban population growth and its impact on infrastructure and cultural landscapes. They noted that urban growth, particularly in Assam, has strained both the environment and traditional cultural practices. The study suggested that a comprehensive urban planning framework, which incorporates environmental and cultural heritage protection, is essential for sustainable development in the region. Khakha (2019) explored urbanization challenges in tribal areas, particularly in Shillong, Meghalaya, and how it has affected tribal populations and their cultural identity. The research emphasized the importance of understanding tribal governance and land tenure systems to integrate heritage conservation with urban growth effectively.

Vinutha (2023) studied Kanchipuram, Tamil Nadu, to illustrate how urban development and heritage conservation can coexist. The research emphasized sustainability in balancing urbanization with cultural preservation, advocating for adaptive reuse of historic buildings and creating heritage zones. This study stresses the importance of integrated planning approaches that recognize both modern needs and the significance of preserving cultural and historical assets. Overall, the literature on Northeast Indian urbanization and cultural conservation underscores the challenges posed by unplanned urban expansion to cultural heritage. The degradation of tangible and intangible heritage, compromising cultural identity, is evident. To reverse this, there is an increasing demand for incorporating heritage conservation into urban planning through sustainable strategies. Several studies stress the need to apply smart technologies and holistic urban planning frameworks to balance infrastructure development with the conservation of cultural and environmental resources.

3.0 Research Methodology

This research adopts a quantitative, survey-based research approach to examine the equilibrium between urbanization and culture conservation in Northeast India. A standardized questionnaire was administered to 74 stakeholders consisting of urban planners, architects, policymakers, and local people via online and face-to-face surveys. The data were examined with SPSS to test reliability (Cronbach's Alpha), descriptive statistics, and Relative Importance Index (RII) for ranking influencing factors.

The results present major trends and essential drivers influencing the interaction between modernization and cultural heritage, maintaining data integrity through extensive cleaning, coding, and management of missing values. Comparative analysis with international heritage conservation models—Kyoto, European cities, Bhutan, and Singapore—unveils strategies for sustainable urbanization. Kyoto's zoning regulations and economic incentives, Europe's adaptive reuse policies, Bhutan's traditional architecture requirements, and Singapore's tax remission schemes provide useful lessons. Conversely, Northeast India is saddled with issues of insufficient heritage zoning, absence of financial incentives, and loss of traditional crafts. The research stresses the implementation of integrated policies that harmonize

contemporary development with cultural conservation and promotes community participation, regulatory instruments, and economic inducement to foster sustainable and culturally responsive urban development.

4.0 Data Analysis

Table 1: Heritage Mapping of North-East India

State	Traditional Architecture Style	Key Features	Cultural Significance	Threats Due to Urbanization
Assam	Chang Ghar (Saikia, J., Hazarika, M., Singha, K. D., Paul, M., & Talukdar, F. 2016)	Stilted bamboo houses with thatched roofs	Protects from floods, sustainable & climate-responsive	Concrete buildings replacing bamboo houses
Nagaland	Naga Longhouses (Sharma, A., Pawar, T., & Ji, S. 2023)	Large communal wooden houses with tribal carvings	Symbol of community bonding and tribal identity	Rapid urban migration, decline in wood availability
Meghalaya	Khasi & Jaintia Houses (Sharma, A., Pawar, T., & Ji, S. 2023)	Bamboo & wooden houses with steep roofs for high rainfall	Efficient drainage system & eco-friendly	Modern steel structures replacing traditional homes
Manipur	Meitei Houses (Saikia, J., Hazarika, M., Singha, K. D., Paul, M., & Talukdar, F. 2016)	Bamboo-mud hybrid structures, earthquake-resistant	Adapted to seismic activity	Cement-based housing replacing vernacular styles
Arunachal Pradesh	Monpa & Apatani Houses (Chhipa, N. & L.J. 2017).	Stone-wood houses reinforced with beams	High-altitude weather adaptation	Traditional techniques being lost due to modern urban expansion
Mizoram	Lushai Stilt Houses (Saikia, J., Hazarika, M., Singha, K. D., Paul, M., & Talukdar, F. 2016)	Elevated bamboo & hardwood houses	Ventilation & humidity control	Preference for concrete houses
Sikkim	Buddhist Monasteries (Saikia, J., Hazarika, M., Singha, K. D., Paul, M., & Talukdar, F. 2016)	Tibetan-influenced colorful wooden structures	Religious and cultural hub	Lack of restoration, modern modifications
Tripura	Risa-Rignai Houses (Saikia, J., Hazarika, M., Singha, K. D., Paul, 2016)	Compact homes using clay & bamboo	Traditional community housing	Loss of artisans skilled in bamboo construction

Source: Compiled by author

4.1 Geographic mapping of heritage sites

4.1.1 Regions with high density of traditional architecture

- Majuli, Assam – Home to traditional Chang Ghar houses and unique Satras (monastic institutions)
- Kohima, Nagaland – Naga longhouses showcasing intricate tribal carvings
- Shillong, Meghalaya – Khasi traditional homes and heritage buildings
- Loktak Lake, Manipur – Phumdis (floating islands) with stilt houses
- Lunglei, Mizoram – Stilted houses adapted for hilly terrain

4.1.2 At-risk heritage sites

- Chang Ghar settlements in Assam (facing floods & modernization)
- Naga heritage villages (being abandoned for urban housing)
- Ziro Valley traditional homes (decline in traditional wood craftsmanship)
- Shillong’s colonial-era Khasi architecture (being replaced by concrete buildings)
- Monasteries in Sikkim & Arunachal Pradesh (modern modifications diluting traditional styles)

4.2 Survey and analysis

With the help of descriptive statistics, you can find the frequency of the responses given. The Likert scale consists of 1-5 number each having its own meaning they are as follows

- 1 = Not Important/Strongly Disagree/Very Low
- 2 = Slightly Important/Disagree/Low
- 3 = Moderately Important/Neutral
- 4 = Important/Agree/High
- 5 = Very Important/Strongly Agree/Very High

4.2.1. Perception of urbanization and cultural heritage

- *Gender distribution:* The sample comprised 74 valid responses, with 47.3% male and 52.7% female participants. The gender distribution is nearly even, with a mean value of 1.5270, indicating a balanced representation. The Relative Importance Index (RII) for gender was 0.7635, suggesting a slightly higher number of female respondents.
- *Importance of urbanization:* The majority of respondents considered urbanization in Northeast India to be important, with 43.2% rating it as “Very Important” and 62.1% combining “Very Important” and “Important.” The RII value was 0.792, indicating strong support for urbanization’s role in development.
- *Cultural preservation and urbanization:* Cultural preservation amidst urbanization was highly valued, with 55.4% rating it “Very Important.” The RII of 0.851 reflects widespread agreement on the need to preserve culture in urban development.

- *Urbanization as a threat to cultural heritage:* Respondents showed varied opinions on urbanization's threat to cultural heritage. However, 55.4% considered it a significant concern, with an RII of 0.7135, highlighting moderate concern about this threat.

4.2.2 Attitudes toward cultural preservation

- *Risk to traditional architecture and landscapes:* A majority of respondents (64.8%) rated the risk of losing traditional architecture due to urbanization as "Important" or "Very Important." The RII of 0.7676 underscores the importance placed on preserving these elements.
- *Incorporating cultural heritage in urban development:* A significant majority (77%) viewed the incorporation of cultural heritage elements in urban projects as "Important" or "Very Important." The RII value was 0.8378, indicating strong support for this idea.
- *Cultural heritage and economic benefits:* The idea that cultural heritage preservation can contribute to economic benefits, such as tourism, was widely endorsed. 50% of respondents considered it "Very Important," and the RII of 0.8514 highlights the importance placed on this aspect.
- *Community-centered spaces reflecting local culture:* The importance of community-centered spaces reflecting local culture was widely recognized, with 48.6% rating them "Very Important." The RII of 0.846 suggests strong support for culturally inclusive urban planning.

4.2.3 Preferences for construction practices

- *Traditional construction practices for environmental sustainability:* Traditional construction practices were seen as important for environmental sustainability, with 36.5% rating them "Very Important." The RII was 0.7946, showing a consensus on their environmental value.
- *Integration of traditional and modern practices:* Respondents strongly supported the integration of traditional and modern practices, with an RII of 0.7946, indicating that most consider it essential to balance heritage and innovation in urban development.
- *Bamboo as a building material:* Bamboo was highly regarded as a building material, with 48.6% rating it "Very Important." The RII of 0.8351 reflects its strong cultural, environmental, and economic significance in the region.
- *Timber as a building material:* Timber was considered moderately important, with an RII of 0.7703. While some respondents saw it as "Very Important" (35.1%), others expressed more mixed views, likely due to sustainability concerns.
- *Stone as a building material:* Stone was similarly valued, with 37.8% rating it "Very Important" and an RII of 0.795, indicating its significance due to its durability and cultural importance in traditional construction.

- *Locally sourced brick or clay:* Locally sourced materials like brick or clay were regarded as important, with 41.9% rating them “Very Important” and an RII of 0.816, emphasizing sustainability and regional economic benefits.
- *Modern materials (Concrete, Steel, Glass):* Modern materials were viewed positively, with 35.1% rating them “Very Important.” The RII of 0.743 suggests that while they are acknowledged, opinions on their use vary, balancing innovation and preservation concerns.
- *Hybrid construction (modern structures with traditional elements):* Hybrid construction that blends modern designs with traditional aesthetics received strong backing, with 54.1% considering it “Very Important.” The RII of 0.862 demonstrates a high preference for this approach.

4.2.4 Barriers to using traditional practices in urban development

- *Higher costs of traditional materials and techniques:* Concerns about the higher costs of traditional materials and techniques were acknowledged, with 31.1% rating it “Important.” The RII of 0.738 shows a moderate level of concern regarding this issue.
- *Lack of skilled labor in traditional techniques:* The lack of skilled labor in traditional techniques was seen as an important issue, with 36.5% rating it “Important.” The RII of 0.762 indicates a significant challenge for preserving traditional methods.
- *Low demand or awareness among developers and planners:* Low demand and awareness among developers was recognized as a key issue, with an RII of 0.814, suggesting that many feel a need for greater awareness to support traditional practices.
- *Regulatory or policy limitations:* Regulatory and policy limitations were considered significant, with an RII of 0.781, indicating that respondents view policies as influencing the adoption of traditional building practices.

4.2.5 Policy and community recommendations

- *Construction policies mandating cultural preservation:* There was strong support for construction policies enforcing cultural preservation, with an RII of 0.8270, suggesting that most respondents favor policies ensuring cultural heritage is maintained in urban projects.
- *Providing subsidies for traditional building materials:* Providing subsidies for traditional materials was seen as crucial by many respondents, with an RII of 0.824, reflecting strong support for financial incentives to encourage the use of traditional building materials.
- *Establishing heritage conservation zones:* Establishing heritage conservation zones was viewed as important, with 43.2% rating it “Very Important.” The RII of 0.838 indicates strong support for protected areas to preserve cultural heritage.
- *Supporting education and training in traditional skills:* Education and training in traditional skills was considered essential, with 52.7% rating it “Very Important.” The RII of 0.803 highlights the need for educational initiatives to promote traditional craftsmanship.

- *Raising community awareness and engagement in cultural preservation:* Raising community awareness about cultural preservation was highly valued, with 50% marking it “Very Important.” The RII of 0.835 emphasizes the need for community involvement in heritage conservation.
- *Effectiveness of community programs in heritage preservation:* Community programs focused on heritage preservation were deemed effective by 36.5% of respondents, with an RII of 0.803, indicating strong support for grassroots efforts to preserve cultural heritage.
- *Integrating traditional practices for sustainable urban development:* The integration of traditional practices for sustainable urban development was strongly supported, with 36.5% rating it “Very Important.” The RII of 0.805 reflects the importance of combining traditional knowledge with sustainable development goals.
- *Reliability analysis:* The reliability analysis showed excellent internal consistency, with a Cronbach’s Alpha of 0.949 across all 34 items, suggesting that the measurement scale is reliable and the responses are highly correlated across the various factors. All 74 respondents were included in the analysis, ensuring a robust dataset.

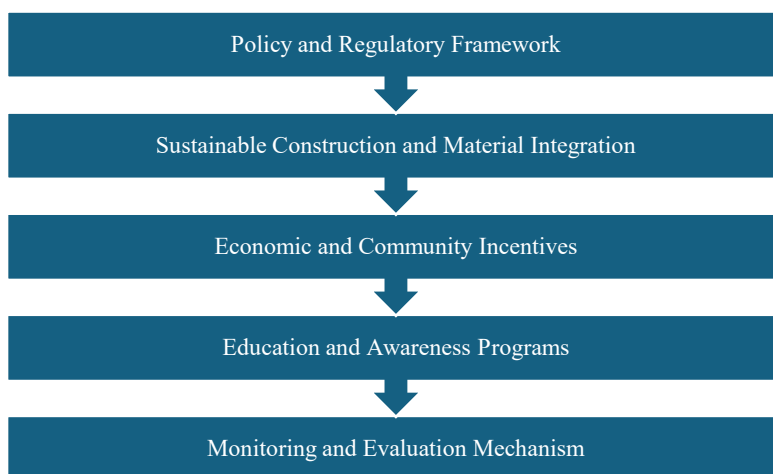
5.0 Discussion

The proposed framework for balancing sustainable urban development with the preservation of cultural and architectural heritage in Northeast India encompasses five key dimensions. The Policy and Regulatory Framework emphasizes enacting heritage zoning laws, adaptive reuse policies, architectural guidelines, financial incentives, and empowering heritage protection agencies to safeguard historically significant areas while supporting sustainable growth. Sustainable Construction and Material Integration promotes the fusion of traditional materials like bamboo and timber with modern engineering, sustainable supply chains, technical workshops, mandatory local material usage, and R&D for climate-resilient designs.

The Economic and Community Incentives component focuses on promoting heritage-based tourism, artisan training programs, cultural conservation funds, public-private partnerships, and community engagement to create economic opportunities and foster local ownership. Education and Awareness Programs aim to instill appreciation for traditional architecture through heritage education, cultural festivals, media campaigns, advocacy efforts, and university partnerships.

Finally, the Monitoring and Evaluation Mechanism ensures effective implementation through heritage conservation committees, key performance indicators (KPIs), annual audits, community feedback, and sustainability reports to track progress and maintain accountability. Together, these interconnected strategies create a holistic approach to preserving Northeast India’s rich cultural heritage while supporting sustainable urban development.

Figure 1: Flow Chart of Framework



6.0 Conclusion

The research “Balancing Urbanisation and Cultural Preservation in Construction Practices in Northeast India” sheds light on how current construction techniques affect cultural heritage and urban growth. Most categories scored over 0.75 in the Relative Importance Index (RII) research, indicating that respondents value cultural preservation alongside urban expansion. Although urbanisation is inevitable, research shows substantial support for indigenous architectural characteristics, green materials, and local building processes in new infrastructure. Low “Not Important” and “Slightly Important” grades emphasise the necessity for a development strategy that safeguards the region’s cultural heritage. High RII scores (0.80 and above) for priority variables suggest a need for policy that promotes eco-friendly city development without compromising cultural heritage. The study shows a growing tendency towards green construction, public engagement in decision-making, and protecting historic sites.

However, modest RII values for certain components suggest that urban expansion must be in harmony with traditional methods and demand more awareness and government intervention. The findings suggest that policymakers and developers should use a hybrid approach that blends contemporary efficiency with traditional authenticity to provide Northeast India a unique architectural character. The study emphasises the necessity for a careful balance between modernisation and culture to support urbanisation in Northeast India. Economic progress demands urban expansion, but unplanned urbanisation undermines the country’s rich architectural traditions and national knowledge systems. Participatory urban policy, stakeholder participation, and adaptive building approaches that respect progress and tradition are highlighted by the findings. Future study must develop region-specific case studies and frameworks to find sustainable and culturally relevant urbanisation solutions in Northeast India.

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CHAPTER 29

Case Analysis of Price Movements and Absorption Rates in Real Estate

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ABSTRACT

The purpose of this study to examine the price movements and absorption rates in real estate markets of Hyderabad and Bangalore, two key technology hubs in India. The research gathers quarterly property price data from Tier 1 cities like Hyderabad and Bangalore micro - markets over the period. By using statistical Analysis to examine price differences among flat typologies between Hyderabad and Bangalore. The findings reveal that significant differences in pricing and absorption rates exist between property types and cities. Factors like IT development and infrastructure projects have substantial impacts on market performance. This study provides an in-depth analysis of real estate price movements and absorption rates in mid-range properties in Hyderabad and Bangalore, addressing gaps in current literature regarding localized demand and market dynamics. The analysis is limited to mid-range flats and does not cover other property types. Developers can use absorption rate trends to decide on property types to build and provides insights for investment decisions.

Keywords: Indian Real estate market; Price movements in real estate; Absorption rate in real estate; Housing market trends in Tier 1 cities; Real estate market segmentation.

1.0 Introduction

Real estate is one of the most well-known and desired industries in the world. The four subsectors of Real Estate are – housing, commercial, retail and hospitality. Urbanization and infrastructure development continue to be growth drivers for Real Estate. The prolonged mobilization of citizens to urban centers has fueled calls for housing and commercial properties. Smart city and transit-oriented development projects are restructuring cityscapes, with green infrastructure planning taking center stage. Absorption rate is not the same throughout India it varies depending on several reasons. The absorption rates required in establishing whether the real estate market is seller friendly or buyer friendly. High absorption rate reflects a seller's market, with high demand and low inventory fueling competition. Conversely, a low absorption rate indicates a buyer's market, where there are surplus supply grants consumers greater bargaining power.

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Also, it helps to determine how quickly properties are being sold in some areas or industries, providing helpful information on market activity. The absorption rate directly influences property prices. High absorption rates often lead to price increases, as demand outpaces supply. Conversely, low absorption rates suggest a surplus of homes, which can lead to price adjustments. By monitoring such trends, stakeholders can make informed decisions and better interpret price movements.

To investors and contractors, absorption rate is a valuable tool to understand where, when, and what to invest in. It also helps determine the most appropriate time to invest and the form properties to target, such as luxury, middle-range, or low-cost housing, depending on market demand. The present research is centred on Hyderabad and Bangalore as main research locations for examining price movements and absorption levels in the Indian real estate market. These cities are perfect research subjects due to their position as premier technology hubs that top significant economic development in South India.

Bangalore has been referred to as India's Silicon Valley, has witnessed radical population changes with its population of migrants increasing 300% during 2001-2021. The boom is because the city is the leader in information technology and its successful startup economy, which has spurred raised both house values and overall cost of living. Hyderabad, on the other hand, is currently a major challenger, especially as Telangana became a standalone state in 2014. The city has seen a 40% increase in IT professionals moving in there, attracted by its enhanced infrastructure, more affordable housing options, and government policies that favour business development. Bangalore still retains very serious traffic issues and expensive property; Hyderabad has an affordable option with rent levels averaging 35-40% lower.

2.0 Literature Review

Studies on housing markets highlight the complex interactions between psychological factors, economic fundamentals, and market conditions that drive price movements and absorption rates. Shiller (2007) illustrated how market sentiment can affect price variations independently of economic fundamentals, while Genesove & Mayer (2001) discovered that sellers who are averse to losses tend to set higher asking prices. DiPasquale and Wheaton (1994) noted that markets with inelastic supply absorb new units more rapidly, whereas Saiz (2010) found that cities with geographic limitations experience absorption rates that are 30-45% higher. Quigley & Raphael (2005) determined that cities with stringent regulations have absorption levels up to 40% greater, and Ellen *et al.* (2018) reported significant variations at the neighbourhood level based on local amenities and access to transportation.

The COVID-19 pandemic accelerated pre-existing trends in the housing market rather than creating entirely new dynamics, as observed by Delventhal *et al.* (2022). Their study identified a significant shift in housing demand as remote workers left costly urban centers, leading to unprecedented demand in suburban and secondary markets. Ramani & Bloom (2021)

corroborated this trend, noting increased absorption rates in smaller cities due to pandemic-driven migration from metropolitan areas. Liu & Su (2021) highlighted a notable reassessment of location characteristics, with changing priorities affecting absorption across different submarkets. Delventhal & Parkhomenko (2020) anticipated that these pandemic-induced trends would have a lasting impact, permanently altering spatial demand patterns and the connection between home and workplace locations.

3.0 Research Methodology

3.1 Determining a null and alternative hypothesis

The typology comparison between Bangalore and Hyderabad:

- *Null Hypothesis (H_0):* There is no significant difference in absorption rates for 2BHK units between Bangalore and Hyderabad.
- *Alternative Hypothesis (H_1):* There is a significant difference in absorption rates for 2BHK units between Bangalore and Hyderabad.

3.2 Determine the appropriate statistical test

A two-tailed paired t-test was selected for this analysis. The t-test is used to determine whether there is a significant difference between the means of two groups, especially with small sample sizes.

The formula for the paired t-test is:

$$t = \frac{\bar{x} - \mu}{s / \sqrt{n}}$$

Where:

- $\bar{x}$ is the mean difference between paired observations
- s is the standard deviation of the differences
- n is the number of pairs
- $\sqrt{n}$ is the square root of the sample size

This paired t-test was appropriate because the analysis involved comparing related data points cross different housing configurations and cities, with potentially small sample sizes.

3.3 Set the value of alpha, the type I error rate

The conventional significance level of $\alpha = 0.05$ (5%) has been employed, i.e., we have a 5% probability of rejecting a true null hypothesis. We have also employed this 5% significance level as the cut-off point for identifying statistical significance in our work.

3.4 Establish the decision rule

If the p-value is less than 0.05, reject the null hypothesis and conclude there is a statistically significant difference between the groups.

3.5 Gather sample data

The data set consists of 57 points from 2008 to 2022, which gives 56 degrees of freedom ($n-1$) for statistical analysis. The data set allows for a detailed analysis of the residential real estate market in two leading Tier-1 cities of India, Bangalore and Hyderabad, with a focus on the inventory of unsold houses, the segmentation by BHK configurations, and supply trends over a few quarters. The most significant component of the dataset is the segmentation of unsold housing inventory by the number of bedrooms, i.e., 1BHK, 2BHK, 3BHK, and 4BHK apartments. The dataset offers complete quarterly information on unsold stock, both units and the corresponding area in million square feet, thus facilitating the proper comparison of absorption by housing type and city location. The period between 2008 and 2022 was selected based on its incorporation of the crucial stages associated with real estate expansion, infrastructure expansion, policy reforms, and economic shocks that significantly influenced the housing markets of Bangalore and Hyderabad. This period covers:

- Mega-infrastructure projects like Hyderabad's Outer Ring Road, Metro Rail, and T-Hub, and Bangalore's Namma Metro, IT corridor development, and Peripheral Ring Road.
- Seasonal variations in housing demand across quarters, including:
 - Q1 (Jan-Mar): Lower sales due to financial year closure
 - Q2 (April-June): Higher capital expenditures because of tax incentive advantages and yearly salary increases.
 - Q3 (July-September): Strong property sales during festive seasons like Diwali and Dussehra
 - Q4 (Oct-Dec): Builders' end-of-year sales and promotional discounts

Demand patterns have been greatly influenced by the COVID-19 pandemic, as evident from a discernible trend towards larger homes in suburban locations. This big data is especially valuable for research papers on urban residential development, real estate investment patterns, cross-regional market comparisons, and the impact of economic cycles and infrastructure projects on residential property absorption rates.

3.6 Analyse the data

The paired t-tests were conducted, yielding p-values for different comparisons:

- 1BHK vs 2BHK: $p = 0.0324$
- 2BHK vs 3BHK: $p = 0.0084$
- 3BHK vs 4BHK: $p = 0.0000097$
- 2BHK in Bangalore vs 2BHK in Hyderabad: $p = 0.9186$

3.7 Reach a statistical conclusion

- For comparisons within Hyderabad (1BHK vs 2BHK, 2BHK vs 3BHK, and 3BHK vs 4BHK), all p-values are below 0.05, so we reject the null hypothesis. This indicates statistically significant differences in absorption rates between these housing configurations.

- For 2BHK comparison between Bangalore and Hyderabad, $p = 0.9186 > 0.05$, so we fail to reject the null hypothesis. This indicates no statistically significant difference in 2BHK absorption rates between the two cities.

Figure 1: Statistical Comparison of Housing Typologies in Hyderabad

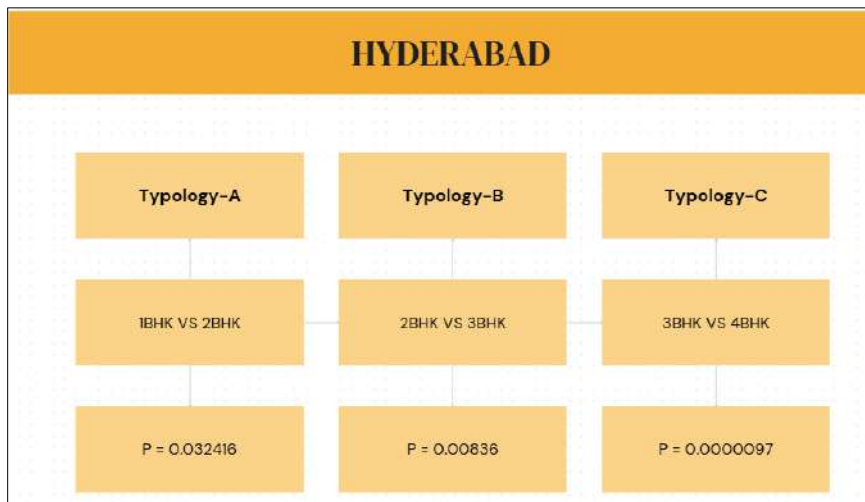
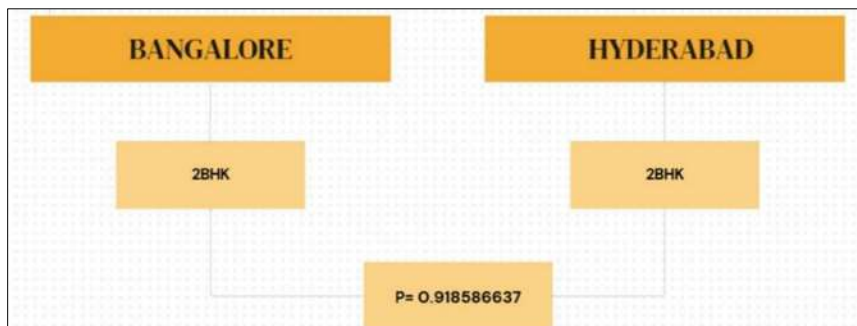


Figure 2: Statistical Comparison of 2BHK Housing between Bangalore and Hyderabad



3.8 Make a business decision

Based on the statistical conclusions:

- Developers in Hyderabad should recognize that buyer preferences vary significantly across different unit configurations (1BHK, 2BHK, 3BHK, 4BHK).

- The significant differences in absorption rates suggest that certain configurations are more in demand than others in Hyderabad.
- For 2BHK units, developers can use similar marketing and pricing strategies in both Bangalore and Hyderabad, as the absorption rates are not significantly different between the two cities.
- Investment decisions should consider these configuration-specific trends rather than treating all unit types as having equal market performance.

Table 1: Hypothesis Testing Results: Significant Absorption Rate Variations across Residential Unit categories in Hyderabad

Typology Comparison	Null Hypothesis (H ₀)	Alternative Hypothesis (H _a)	P-Value
1BHK vs 2BHK	There is no significant difference in absorption rates. between 1BHK and 2BHK units.	There is a significant difference in absorption rates between 1BHK and 2BHK units.	0.0324
2BHK vs 3BHK	There is no significant difference in absorption rates between 2BHK and 3BHK units.	There is a significant difference in absorption rates Between 2BHK and 3BHK units.	0.0084
3BHK vs 4BHK	There is no significant difference in absorption rates between 3BHK and 4BHK units.	There is a significant difference in absorption rates between 3BHK and 4BHK units.	0.0000097

Table 2: Hypothesis Testing Results: Absorption Rate Variations across 2BHK Apartments in Bangalore vs. Hyderabad

Typology Comparison	Null Hypothesis (H ₀)	Alternative Hypothesis (H ₁)	p-value
2BHK Apartments: Bangalore vs. - Hyderabad	There is no significant difference in absorption rates for 2BHK apartments between Bangalore and Hyderabad	There is a significant difference in absorption rates for 2BHK apartments between Bangalore and Hyderabad	0.9186

4.0 Conclusion

The results from the two-tailed t-tests show key differences in housing demand across BHK categories in Hyderabad. Mid-sized units like 2BHK and 3BHK have higher absorption rates, while larger units (4BHK and above) have lower demand. This information helps real estate developers, investors, and policymakers make smart decisions about housing supply, pricing, and future projects. Meanwhile, another t-test comparing 2BHK absorption rates in

Bangalore and Hyderabad shows no significant difference, with a high p-value (0.9186). This means demand for 2BHK apartments is stable in both cities, making them a safe investment. Developers can focus on pricing, location, and affordability, knowing that 2BHK units remain popular regardless of regional differences.

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CHAPTER 30

Case Study on 84.400km Single Lane Bituminous Concrete Road Paved between Amravati and Akola District on NH53

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ABSTRACT

This case study examines the construction of an 84.4 km single-lane bituminous road between Amravati and Akola on NH-53, completed by Rajpath Infracon Pvt. Ltd. in 105 hours and 33 minutes. Initiated by the National Highways Authority of India (NHAI), this project demonstrates India's growing infrastructure capabilities and commitment to rapid highway development. The project involved a workforce of 720 workers, advanced machinery, and innovative project management strategies to ensure continuous and efficient progress despite challenges. Preparation for the record attempt spanned six months, encompassing feasibility studies, mock drills, and a detailed project roadmap. Robust safety measures, environmental considerations, and disaster preparedness systems underscored the project's holistic approach. The meticulous planning phase involved multiple departments collaborating through deliberations, site surveys, and testing to eliminate ambiguities. The milestone moments of the project highlighted the team's resilience, from enduring extreme heat to overcoming logistical challenges. The paving operation crossed the existing world record by Day 4 and concluded with the completion of 84.4 kilometers, including a 42.2-kilometer double-lane stretch, on Day 5. Additionally, the initiative aligned with environmental sustainability goals by planting over 98,000 saplings along NH-53. This record-breaking project is a testament to the transformative potential of infrastructure development, emphasizing technical expertise, efficient execution, effective planning strategy and a commitment to quality. It demonstrates how innovative approaches and meticulous planning can drive rapid advancements in national infrastructure, contributing to economic growth and improved quality of life.

Keywords: Infrastructure development; Project management; Guinness world record; Sustainability practices.

1.0 Introduction

Rajpath Infracon Pvt. Ltd laid the longest continuous asphalt concrete on NH53, India, from June 3 to 7, 2022, between Amravati and Akola district. The Amravati-Akola Expressway construction started at 6 a.m. on Saturday and finished on Tuesday.

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The Amravati to Akola section in Maharashtra was laid in 105 hours and 33 minutes. The news was posted by the Honourable Shri Nitin Gadkari on his Twitter handle and also uploaded the photo of the expressway with the Guinness World Record certificate. As per the past record, the record was previously held by ASHGHAL of Qatar on February 27, 2019. The highway was a part of the Al-Khor Expressway and it took 10 days to finish the project. Previously, Rajpath Infracon had also created a world record by constructing a road from Sangli to Satara within 24 hours. This record was set on one of the longest national highways linking eastern and western India under the prestigious national project of 'Bharat Mala Pariyojana'.

2.0 Objective and Scope of the Study

This research investigates highway construction methods applied in mega projects, emphasizing sophisticated equipment and innovative project management techniques to maximize efficiency and quality. The research specifically reviews the Amravati-Akola Highway construction project, assessing planning approaches, stakeholder management, conflict resolution mechanisms, quality and safety practices, and risk management practices. It also investigates combined technological innovations to enhance efficiency and productivity. The research involves a thorough analysis of planning, coordination, and execution-based project management methods. It also analyzes strategies to overcome challenges, maximize the utilization of resources, and achieve deadlines. New-age technologies like drone surveying and Jawli Sutra software will be analyzed to determine their ability to enhance precision and efficiency. Lastly, the research analyzes logistics planning and management strategies that maintain a steady flow of resources.

3.0 Methodology

Since this is a finished data collection project, we have an interviewee and data list prepared to know more about the project. Following are the questions asked to Dr. Trupti Nayak (Chief Operating Officer) and Mr. Surya (Head of Planning), and their respective answers:

Table 1: Questionnaire Table

Questions	Answers
Vision behind this project.	Building confidence in India's infrastructure segment and projecting Indian infrastructure at an international level to support its development.
What Planning was done before executing project?	Five months in advance with a mock drill, specialists arranged with checked technical assistance for proper 24/7 functioning.

Who is the client for this project?	National Highway Authority of India (NHAI)
Was this a Greenfield or Brownfield project?	A brownfield project was initially granted to two companies (8% completion), later to Rajpath Infracon.
What was the contract model for this project?	The project was based on a PPP contract with a hybrid annuity model.
Who were the suppliers for this project?	Indian Oil, HP, BP, Ashok Leyland, Tata Motors, Wirtgen Group, SBI, Union Bank of India
What was the approximate cost estimate of the project?	The approximate cost of the project was ₹22.69 crores.
How was the project's progress tracked?	The progress was monitored by "JAWLI-SUTRA" ERP, four cameras for shooting, and MSP for planning.
What was the full project scope as per the contract?	Finishing of the four-lane Amravati–Chikhli section of NH-6, in Maharashtra, in hybrid mode with annuity, under the "Bharat Mala Pariyojna" scheme.
How was traffic managed during construction?	Traffic was controlled by paving one side alternately, maintaining emergency access, coordinating with the police and inhabitants, and providing assistance to travellers.
How was the quality of work ensured?	Quality was guaranteed by having a well-furnished laboratory, testing of materials, controlled mixing, random checking of batches, and written reports.
What equipment was used, and did it run continuously during construction?	80 dump trucks, 5 batching plants, 6 Tandem rollers, 2 pneumatic rollers, and 1 sensor paver with hopper.
How many labour shifts were there during construction?	The labours were working in three shifts with each shift of eight hours each.
How many labours were involved in this project?	The project employed 728 labours.
How was site safety managed?	Safety ensured through PPEs, barricading, signages, traffic management, safety nets, a 24/7 ambulance, and a fire brigade.
Any training sessions conducted before the project? If yes, what were they?	Training covered GWR compliance, safety, operational discipline, work schedules, QC documentation, and digital monitoring.
Was automation used for site surveying before construction?	Drone survey was done every month of the site before construction starts starting from its planning phase
What challenges were faced during construction?	Challenges included NHAI approvals, batch plant breakdowns, paver auger cracks, and exhausting non-stop work.
What awards or recognitions were received after achieving this feat?	Received appreciation from PM Narendra Modi, CM Eknath Shinde, Minister Nitin Gadkari, and Deputy CM Devendra Fadnavis.
How many plants were used for the project?	Total Five plants used one of Marini with capacity 150TPH and Four of Amaan of 200&100TPH.

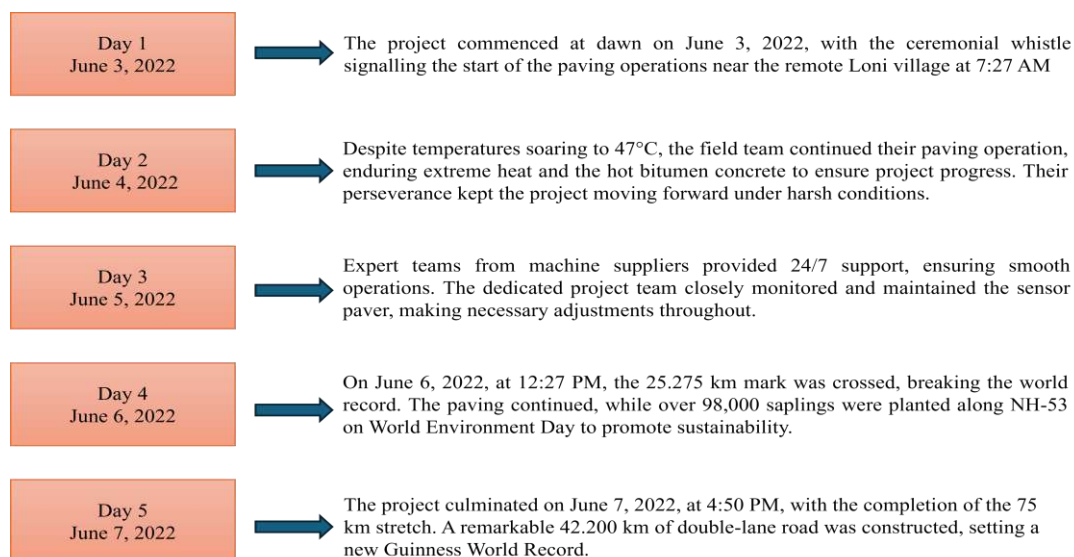
4.0 Project Overview

The Loni village, Amravati district, NH-53 road project included the development of 75-km single-lane bituminous road equivalent to 37.5 km of two-lane shoulders. Sophisticated pavement design, stringent quality control, and Jawli Sutra software facilitated accurate planning and implementation. A quality control laboratory based at Mana Camp tested materials based on NHAH requirements. To limit disruption, traffic management measures involved cooperation with police and residents, short-term lane closures, and providing vital services to drivers. The Guinness World Record attempt enhanced regional connectivity, increased passenger safety, and spurred economic growth, all while meeting strict construction and environmental standards. The facts and numbers that have shaped the history of India's road construction industry will be hard to repeat.

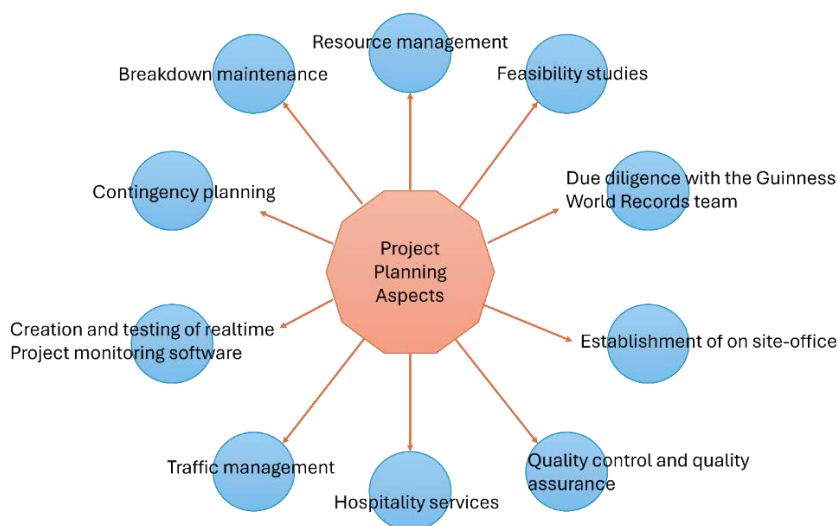
Table 2: Project Statistics

Total Length	75+ kilometres (an actual distance of 84.400 km), Single Lane Bituminous concrete was paved.
Equivalent length	42.200 kilometres Double Lane with Paved Shoulder of Bituminous Concrete.
Start Time & Date	3rd June 2022, 7:27 AM
End Time & Date	7th June 2022, 5:00 PM
Total Time	105hrs 33 minutes
Quantity of Bituminous Concrete Used	36,634 Metric Tonne
Bitumen Quantity used	2,070 Metric Tonne
Tippers Employed	80
Batch mix plant engaged	5
Sensor Paver with Hopper	1
Paver Feeder used	1
Tandem Rollers employed	6
Pneumatic Tyre Roller	2
Total Workers	728

4.1 Milestones of the projects



4.2 Project planning and monitoring



The planning stage involved the establishment of a core team made up of seasoned professionals from every department. The team had intensive meetings for five months and created strategies to make sure that all details were considered. Micromanagement and contingency planning were emphasized, and a thorough on-site reiki was performed prior to it.

A complete simulation exercise was held a week prior to the start of the project to confirm that all systems, processes, equipment, and manpower were in place. The perfectionist attitude of the team did not leave any scope for failure. While monitoring and reporting the project, proper documentation and real-time monitoring were critical. Guinness World Records (GWR) sanctioned a panel of independent experts, six highway experts, six quality experts, six timekeepers, six surveyors, and six lawyers working on a rotational basis. A two-active-camera continuous videography system, a backup camera, photographers, and a drone taking aerial photographs every hour provided round-the-clock operation. All information was sent to the London head office of the GWR for checking, in accordance with world record standards.

5.0 Jawali Sutra

For delimiting the scope of work, allocation of resources and specific scheduling were dominant factors in our critical path study. The tasks were thoroughly searched for by the team, identifying those whose holdup could cause the entire project to fail. One solution offering real-time data was devised in order to provide the different departments with rapid, accurate decisions.

6.0 The Juggernaut

Juggernaut was a culmination of three units of equipment: a feeder, a paver, and a weighbridge. The paving machine consisted of a weighbridge, which supplied the asphalt concrete to the feeder, which maintained the material at the desired temperature and fed the paver in the best possible manner. This provided a very accurate paving process and quality road as per NHAI standards.

7.0 Quality Control and Quality Assurance

Quality control and assurance (QC/QA) in road construction using asphalt guarantees compliance with standards to avoid early failure and ensure national assets' sustainability. The required tests are carried out to determine quality, guarantee consistency, and verify contractual specification compliance, and all results are kept for future use.

8.0 Safety audit report (November 5 – November 8, 2024)

8.1 Authority and stakeholders

- Authority: National Highways Authority of India (NHAI), PIU-Amravati
- Independent Engineer: MSV International Inc. & Sterling Indo Consultants Pvt. Ltd.
- Safety Auditor: Civil Baba Infraconsultant Pvt. Ltd.
- Concessionaire: Rajpath Infracon NH-6 Pkg-1 Pvt. Ltd.

Figure 1: Distance in Kilo Meters Covered by the Paver per Hour

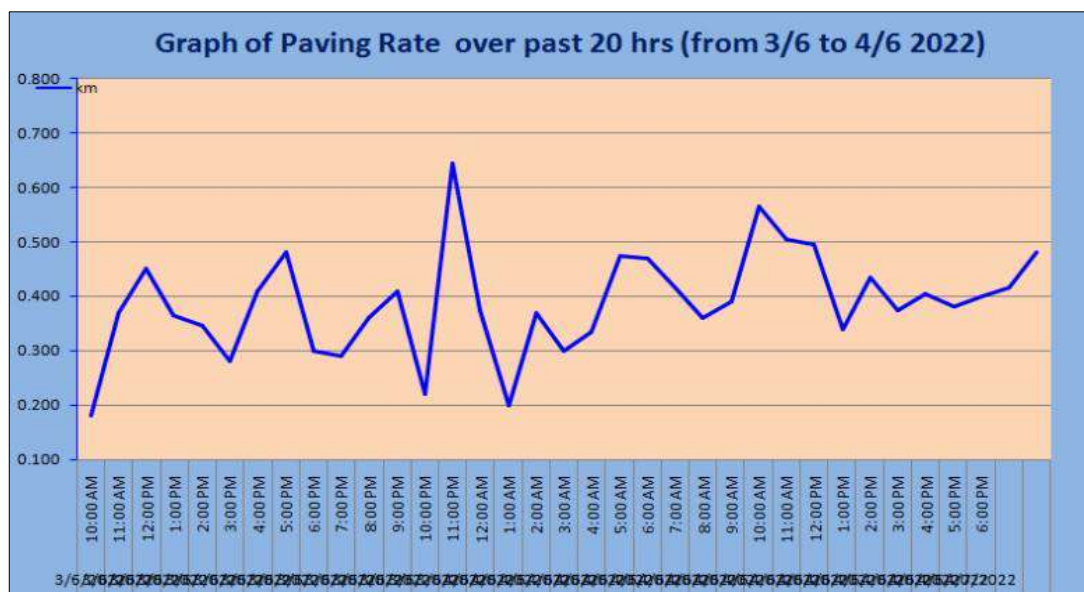


Figure 2: Temperature of the Laid Bituminous Concrete

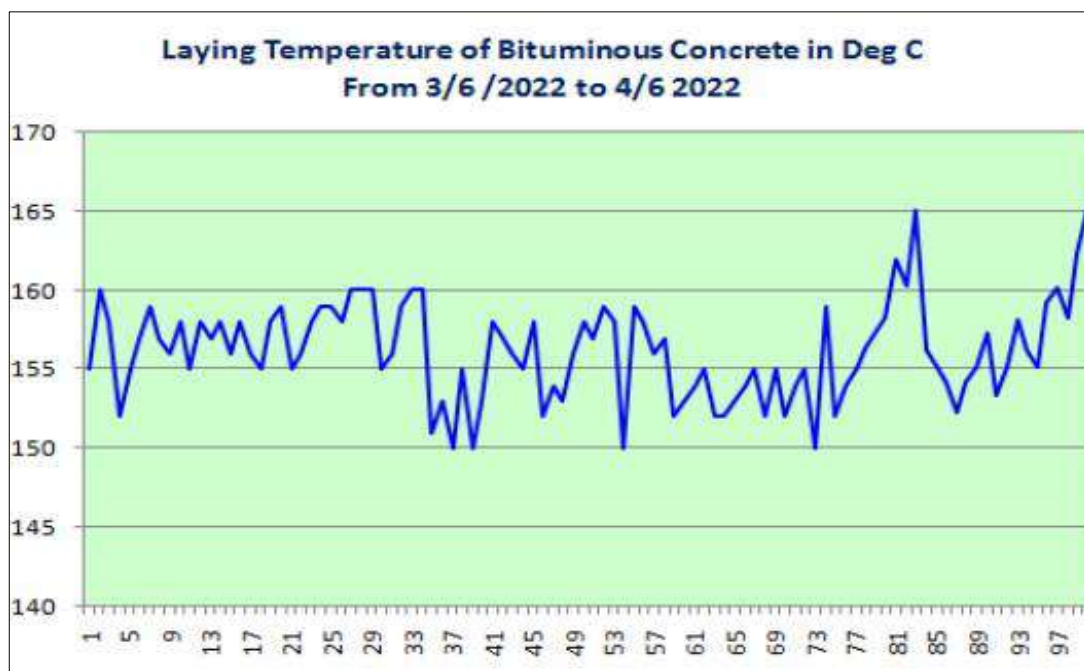
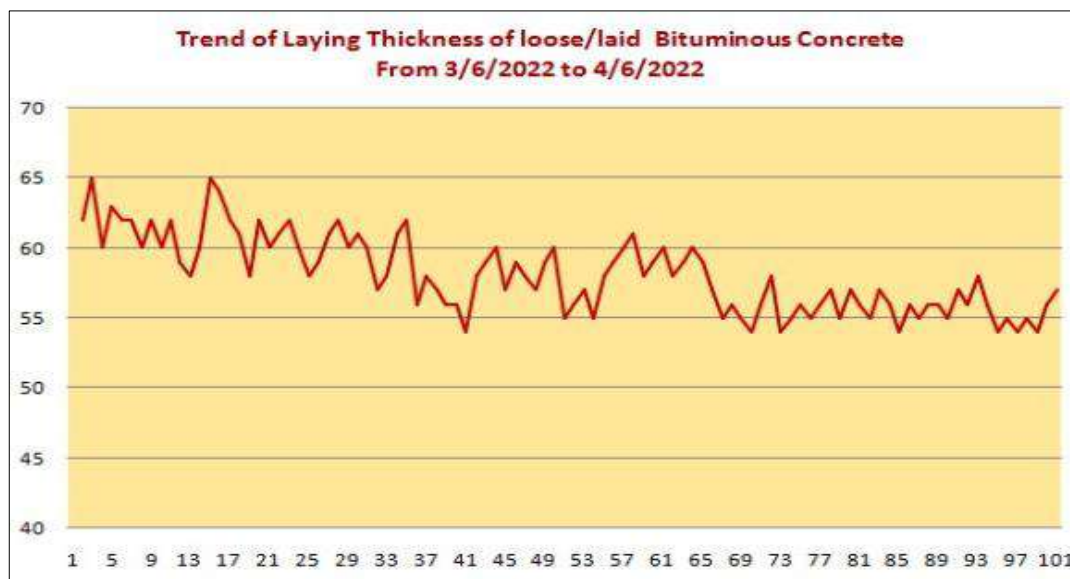


Figure 3: Thickness of the Laid /Loose Bituminous Concrete (before Rolling)



8.2 Safety measures implemented

- Personal Protective Equipment (PPEs): Mandatory for all workers.
- Barricading & Signages: Installed to manage traffic flow safely.
- Traffic Management Personnel: Deployed round the clock.
- Emergency Services: 24/7 availability of ambulances with medical staff.
- Fire Safety: On-site fire brigade stationed throughout the project duration.
- Mobile Office & Monitoring: Safety team actively monitored compliance with safety norms.

9.0 Sustainability

9.1 Reducing carbon footprint

In the National Road No. 53 project, 98,000 saplings were also planted to enhance vegetation cover. The plants are well cared for to help them grow and serve as habitats for different species of birds in the previously barren Mana Camp region. The effort helps in conserving energy, reducing climate change, conserving biodiversity, enhancing public health, and stimulating economic growth.

9.2 Water conservation

Farm ponds have been created in a number of sites, such as Anbhora, Sanjapur, Dalimbi, Dudhaham Chandak, Jamthi, Kurum Vadgaon, and Mana, to remedy water shortages. The ponds

have substantially enhanced groundwater levels, restored dry wells, and improved irrigation capacity within villages that experience water shortages. This sustained effort toward water conservation continues to yield enduring benefits to the area.

Table 3: Safety Audit Matrix

Issue Location	Concern Identified	Risk Level	Recommendation	Compliance
Km 175+350	Vegetation blocking visibility at minor road intersection	Very High	Trim/remove vegetation	Completed
Km 193+600 & 218+100	Missing/partially placed signboards at minor junctions	High	Install speed breakers and proper signage (as per IRC 67-2022)	Completed
Km 186+400	Missing New Jersey Crash Barrier (NJCB) and anti-glare screen	High	Install NJCB with anti-glare screens	Not in Concessionaire's scope
Km 182+500 & 183+500	Missing Object Hazard Markers (OHM)	High	Install OHM before MBCB/crash barriers (as per IRC 79-2019)	Completed
Km 192+350 & 175+350	Missing acceleration/deceleration lanes for fuel pumps	High	Provide 100m acceleration & 70m deceleration lanes (as per NH Circular)	Not in Concessionaire's scope
Km 195+000	Missing MBCB at high embankment curve	High	Install MBCB as per IRC guidelines	Completed
Km 200+500	Faded road markings and missing road studs at narrow bridge	High	Repaint markings and install road studs (as per IRC 3.1 & 9.5)	Completed
Km 216+800 & 220+000	Unprotected gantry signboards (risk of collision)	High	Install MBCB or guard rails	Partially completed

10.0 Research Challenges

The case study faced some research challenges, such as limited access to financial, technical, and proprietary project information due to confidentiality issues. Real-time construction methods and performance information were limited. Guinness World Records (GWR) document approvals caused delays. The size and complexity of the record-breaking project made detailed analysis challenging. Moreover, time and budget limitations within the academic calendar hindered the establishment of on-the-ground relationships, restricting access to important project information. In spite of this, the study was able to record important details of planning, implementation, and innovation, yielding important lessons for the conduct of future large-scale infrastructure projects.

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CHAPTER 31

Cash Flow Analysis for Hybrid Annuity Model of Road Project

Shreeraj Anand Narsale¹ and Ketaki Kulkarni²

ABSTRACT

It is a financial study on the four-laning of Ujjain-Garoth Package 1, from Chandesari to Khedakhajuriya, as a project of road construction in India, emphasizing how important road transportation is for economic expansion and the government's efforts in upgrading infrastructure through a number of programs. The project belongs to a general national strategy toward highway improvement, which provides a means of facilitating trade and communicating different areas. Background The bidding process of the project involves information gathering from case studies to estimate the anticipated markup percent for bids. Several construction tasks' prices include site clearing, digging, building bridges and underpasses, and many more. In addition, the document analyzes various bidding models to determine the final bid price that incorporates both direct and indirect costs. The outcome is expected to enlighten readers on successful tactics in bidding and budgeting for future infrastructure projects of this nature. Considering all factors, the document provides a comprehensive understanding of the financial aspects of road building using the Hybrid Annuity Model. It also helps in decision making regarding the expected mark-up amount of bid using different bidding models.

Keywords: Cash flow analysis; Hybrid annuity model.

1.0 Introduction

Road Transport is a critical infrastructure for the economic development of a country. It impacts the pace, structure, and pattern of development. The capacity of National Highways in terms of handling traffic (passenger and goods) needs to keep pace with economic growth. India has the second largest road network in the world of about 63.72 lakh km. This comprises National Highways, Expressways, State Highways, Major District Roads, Other District Roads, and Village Roads. The National Highways have a total length of 1,40,995 km, which in total serves as the arterial network of the country. The Government of India had launched major initiatives to upgrade and strengthen National Highways through various phases of the National Highways Development Project (NHDP) and is taking the initiative forward through the umbrella program of Bharatmala Pariyojna, Phase-I and other schemes and projects.

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2.0 Literature Review

Infrastructure is considered as one of the key factors by the government of India which is directly related to growth of economy. The world economic forums global competitiveness report 2019-18 shows that India's global competitiveness ranking has fallen significantly in 2019-18. India's rank jumped 10 places lower vis-à-vis 2017- 18, from 58th place to 68th place in 2019-18 which affects the economic growth of country) now in 2022-23 rank is 37th. The National Highways Development Project (NHDP) is a project to rehabilitate, widen and upgrade major highways in India to superiority. National Highways carry about 40% of the total traffic across the country whereas account for only about 2% of the total length of roads (MoRTH 2020). The PPP approach increases the economic value of infrastructure outputs (Zhang *et al.*, 2005) and facilitates the overall development of infrastructure (Li *et al.*, 2016).

The financial success of PPP Project depends on its ability to service the debt and generate the expected rate of return from the Government as well as Private Entrepreneur Point of view. PPP Projects in India involve many risks and problems. It's crucial for private entrepreneurs and the Government to identify and manage the risk associated with investment in PPP Projects (Singh, 2019). The study showed that the three traditional topics risk, procurement, and financing have been expanded over the years to include the following seven research topic categories: investment environment, procurement, economic viability, financial package, risk management, governance issues, and integration research (Cui, 2018).

3.0 Public Private Partnership

Physical infrastructure includes substantial investments that may impose burden on the public treasury, such as roads, water and sanitation networks, and transit systems. This strain is especially beneficial for nations with economies that are rapidly urbanising and developing, like India, where there is a tremendous demand for expanding infrastructure. Governments and public sector authorities throughout the world are increasingly turning to public-private partnerships (PPPs) as a way to offer their citizens and economies more affordable access to infrastructure services.

3.1 Different Public Private Partnership (PPP) models

- Engineering, Procurement and Construction (EPC) Model-Cost is completely borne by the government. Government invites bids for engineering knowledge from the private players. Procurement of raw material and construction costs are met by the government. of engineering expertise. The difficulty of the model is the high financial burden for the government.
- Build Operate Transfer (BOT)-A BOT model is generally used to develop a discrete asset rather than a whole network, for example a toll road. This simple structure provides the most freedom for the private sector partner during construction and the public sector bears the equity risk.

- Build Own Operate (BOO)-This is a similar structure to BOOT (below), but the facility is not transferred to the public sector partner. A BOO transaction may qualify for tax exempt status and is often used for water treatment or power plants.

4.0 Bidding Model

The bidding process represents a game where contractor would like to “win” a bid at a price that gives him the maximum profit. The probability of winning a bid decrease as a contractor tries to increase his profit margin. The probability for a contractor to win a bid depends not only on his mark-up, etc., but also on the approach adopted by the competitors. It is also observed that in present-day construction, the criteria laid down by the client for evaluation of bids become relevant to the bidding process. At times, a client may choose to evaluate a bid on criteria such as the contractor record on quality in executing the job and schedule compliance, apart from consideration of the price quoted. A suitable model based on probability to explain the bidding phenomenon in a construction project has yet eluded researchers, though initial efforts in the direction were made as early as 1956 by Friedman.

5.0 Determining Bid Price

In this research work, we take one case study project which was floated by National Highway Authority of India (NHAI) on e-tenders website. Name of the project is 4- laning of Ujjain- Garoth (Package-I) Chandesari to Khedakhajuriya from Km. 0.00 to (-) 750 & Km 0+000 to km 41.400 section of NH-148NG in state of Madhya Pradesh on Hybrid Annuity Mode. After going through all the schedules, we did the rate analysis.

The tender price or the bid price can be mathematically represented as the sum of total cost and mark-up. The total cost consists of direct costs and indirect costs-the cost of material, labour and plant and equipment could be taken under the former head, while expenses on items such as personnel recruitment, training, and research and development are essentially indirect costs. Generally, a direct cost of an activity is physically traceable to the activity in an economic manner, and thus, is a cost not incurred if the activity is not performed. Indirect costs, on the other hand, are business costs other than direct costs and are not physically traceable to the activity and may be incurred even if the activity is not performed. Cost of project is 678.22 Cr.

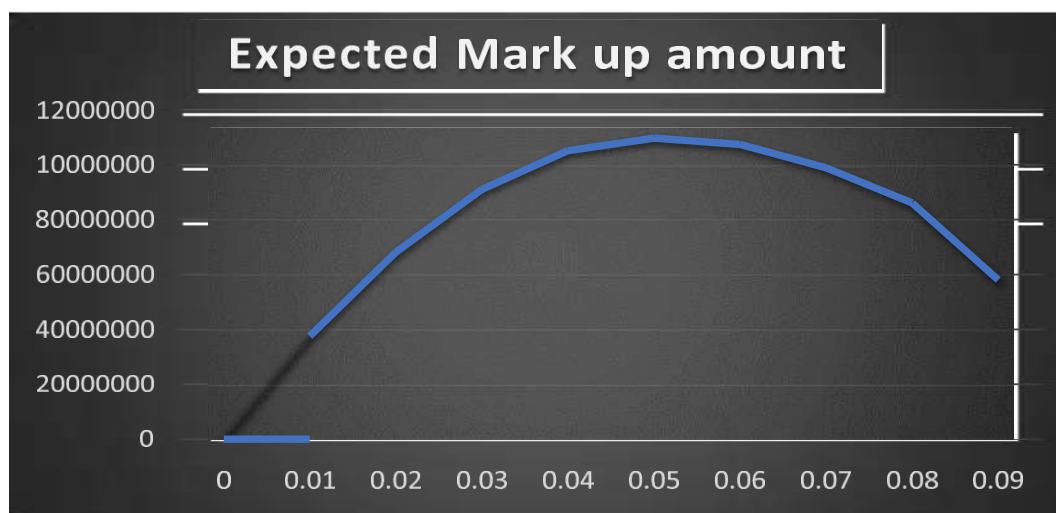
5.1 Friedman’s model analysis

Calculation of Expected Mark-up amount of contractor under study for new project with estimated cost 500,000,000 Rs using Friedman’s Model. For mark-up percentage of 1%, x would be 1.01 and Z approximately -1.27. Similarly, other values of Z can be calculated for different values of x . The probability value corresponding to $Z = -1.27$ can be read out from standard normal distribution table, which is 0.0985. Thus, probability of winning the bid when only single competitor is there = $1 - 0.0985 = 0.9015$

Table 1: Friedman’s Model Analysis

Mark up%	$XX = \frac{1}{1 + (\text{Markup}\% / 100)}$	$Z = \frac{(X - \mu)}{\sigma}$	Probability from standard normal distribution table	Probability of winning the bid with only one typical competitor	Final Probability of winning the bid with 2 typical competitors	Expected Mark up amount = $5000000000 \times (x-1) \times \text{Final Probability of winning the bid}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0%	1.00	-0.92	0.0985	0.9015	0.8127	0.00
1.00%	1.01	-0.77	0.1335	0.8665	0.7508	37541112.50
2.00%	1.02	-0.62	0.1736	0.8264	0.6829	68293696.00
3.00%	1.03	-0.46	0.2206	0.7794	0.6075	91119654.00
4.00%	1.04	-0.31	0.2743	0.7257	0.5266	105328098.00
5.00%	1.05	-0.15	0.3372	0.6628	0.4393	109825960.00
5.20%	1.052	-0.12	0.3483	0.6517	0.4247	110425351.40
5.50%	1.055	-0.08	0.3707	0.6293	0.3960	108905084.75
6.00%	1.06	0.00	0.4013	0.5987	0.3584	107532507.00
7.00%	1.07	0.15	0.4681	0.5319	0.2829	99021163.50
8.00%	1.08	0.31	0.5359	0.4641	0.2154	86155524.00
9.00%	1.09	0.46	0.6406	0.3594	0.1292	58125762.00

Figure 1: Expected Markup Cost using Friedman’s Model



Expected mark-up cost = 11,04,25,351.40 Optimum Mark up % = 5.20%

5.2 Gate’s model analysis

Calculation of Expected Markup amount of contract or understudy for new project with estimated cost 500,000,000 Rs using Gate’s bidding model.

Table 2: Gate's Model Analysis

Mark up%	$X = 1 + (\text{Markup}\% / 100)$	$Z = (X - \mu) / \sigma$	Probability from standard normal distribution table	Probability of winning the bid with only one typical competitor	Final Probability of winning the bid with 2 typical competitors	Expected Markup amount
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0%	1.00	-0.92	0.0985	0.9015	0.8207	0
1.00%	1.01	-0.77	0.1335	0.8665	0.7644	38222320.25
2.00%	1.02	-0.62	0.1736	0.8264	0.7042	70415814.59
3.00%	1.03	-0.46	0.2206	0.7794	0.6385	95780763.56
4.00%	1.04	-0.31	0.2743	0.7257	0.5695	113897826.26
5.00%	1.05	-0.15	0.3372	0.6628	0.4957	123915644.63
6.00%	1.06	0.00	0.4013	0.5987	0.4272	128173838.58
6.20%	1.062	0.03	0.4129	0.5871	0.4155	128813787.25
6.30%	1.063	0.05	0.4207	0.5793	0.4078	128443372.99
7.00%	1.07	0.15	0.4681	0.5319	0.3623	126806757.03
8.00%	1.08	0.31	0.5359	0.4641	0.3022	120867243.96

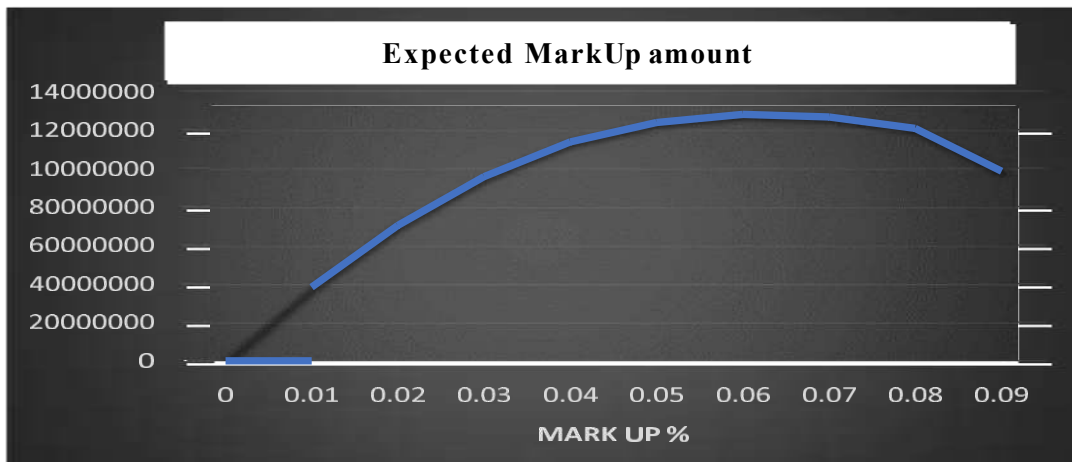
Upto column 5 all the calculations are similar to previously mentioned model. The final probability (column 6) is computed using the expression

$$p = \frac{1}{n \times \left[\frac{(1-p(\text{typ}))}{p(\text{typ})} \right] + 1}$$

Where $n = 2$ is considered

Expected markup cost = 12,88,13,787.25

Optimum Mark up % = 6.20%

Figure 2: Expected Markup Cost using Gate's Model

Now, after analyzing both models we get 5.20% and 6.20% mark up percentage by Friedman's model and Gate's model respectively. Current scenario suggests average of both percentages can be used as final mark-up percentage i.e. 5.75%

6.0 Result

In previous point, after analysing Friedman's and Gate's bidding model we get mark up percentage as 5.20% and 6.20% respectively. As per literature review average of both models result are suggested to be used in practical applications. We are going to apply this mark up percentage on previously mentioned project as case study in abstract of cost in Table 6.1. So, the final bid price is 653.94 Cr.

Table 3: Application of Results from Bidding Model in Abstract of Cost

Four Laning of Ujjain Garoth Package 1 Chandesari to Khedakhajuriya		
Bill No	Description	Tender Amount
1.	Site clearance and dismantling	90,74,695
2.	Earth work	42,93,10,420
3.	Granular sub-bases, bases courses	63,35,11,228
4.	Bituminous courses (flexible pavement)	75,68,27,748
5.	Bill of quantities box culverts	41,90,07,669
6.	Bill of quantities minor bridge box	1,82,61,493
7.	Bill of Quantities of Major & Minor Bridge (Pile Foundation)	84,96,30,799
8.	Bill of Quantities of Minor Bridge (Open Foundation)	13,09,89,642
9.	Bill of Quantities of Underpasses	1,43,13,81,828
10.	Bill of Quantities of Flyover	28,21,05,234
11.	Bill of Quantities of ROB	56,04,61,680
12.	Drainage works	38,88,717
13.	Bill of Quantities of River Training & Slope Protection Work	2,84,00,416
14.	JUNCTION	24,33,695
15.	TRAFFIC SIGNS, MARKINGS & APPURTENANCES	31,90,25,131
16.	Bill of Quantities of Toll Plaza	8,42,31,416
A	TOTAL CONSTRUCTION COST Excluding GST	5,95,85,41,810
B	Supervision Charges @ 3% of Civil Construction Cost (A1)	17,87,56,254
C	Add Labour Cess@ 1%	5,95,85,418
D	Add Mark up cost @5.75%	34,26,16,154.08
	Total Amount(A+B+C+D)	6,53,94,99,637
	RFP Cost	6,78,00,00,000
	% Above/Below	3.55%

7.0 Conclusion

- It ensures a steady cash flow over the project's lifespan.
- More stable cash flows because risk is shared.
- It makes easier to manage finances and plan for future investments.
- There is saving of government money and still high-quality infrastructure outcomes are made.
- Better connectivity helps to reduce travel time & helps to boost economic development.

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CHAPTER 32

Challenges in MEPF Services in Retail Store Setup: A Case Study Approach

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ABSTRACT

Purpose: The study inquiries into the Mechanical, Electrical, Plumbing, and Fire (MEPF) related challenges in mall retail stores during their time of set up and assesses their impact by project life cycle stages. This approach aims to address the multifaceted nature of MEPF challenges, which further contributes to the reduction of project efficiency, safety, and sustainability in the set-up of retail malls. *Methodology:* This study is based on observations and in-depth interviews during site visits to assess existing MEPF set up in malls that were coming up in the cities of Pune, Navi Mumbai and Bengaluru. Observation and analysis during these visits have unveiled a spectrum of challenges. Subsequently, interviews with industry professionals, consultants, facility managers, and retail store managers, have provided insights into the root causes and impacts of these challenges. Identified issues have been categorized and thematically grouped by project life cycle stages, enabling a holistic understanding of their interrelationships, thus aiding the process of addressing them effectively. *Findings:* The findings show that critical challenges in setting up MEPF systems in malls include inadequate ventilation, electrical malfunctions, plumbing leaks, and fire safety concerns which have a substantial influence on cost and time overruns. *Research Limitations:* The case study method enables one to draw a cause-effect relationship within a limited environment. Although the method adopted has enabled the researchers to examine complex issues in MEPF services with a closer lens, further studies may be performed in different contexts and with a wider audience to strengthen the findings hereunder.

Keywords: MEPF services; Retail stores; Sustainability.

1.0 Introduction

In the dynamic landscape of the construction industry, projects are frequently marred by challenges that disrupt timelines and inflate costs. Time and cost overruns are issues that have significant implications for stakeholders, affecting project outcomes. Despite advancements in project management methodologies and technological innovations, these overruns remain a persistent problem, leading to delays, increased financial burdens, and compromised quality.

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In the competitive world of retail, the timely and cost-efficient setup of new stores is critical for business success and market penetration. Inefficiencies in project set up are mainly characterised by time over runs and cost overruns. These overruns can lead to delayed store openings, increased financial burdens, and missed revenue opportunities, ultimately impacting the overall profitability and operational efficiency of the retail business.

This leads us to our research questions as stated below:

RQ1: What are the MEPF related challenges that lead to project inefficiencies in the setup of mall retail stores at various project life cycle stages?

RQ2: What is the effect of MEPF related challenges in setup of mall retail stores?

RQ3: At which stage of project life cycle do most MEPF related challenges occur?

RQ4: What improvements to project framework would address MEPF related challenges in mall retail store set up?

Project management theory outlines a structured approach to managing projects effectively, ensuring that objectives are met within the constraints of time, cost, and quality. The stages of project management are typically divided into five key phases, each with distinct activities and deliverables as below.

Figure 1: 5 Phases of Project Management Process



Source: PMBOK guide

The initiation stage is when the business case is developed and a charter is designed to define the project, identify the site of mall set up and create the project partners. In the planning phase, detailed plans are created to guide the project. This includes defining the project scope, breaking down the project into manageable tasks using a work breakdown structure, and developing a detailed schedule with milestones and deadlines. Resource and budget planning are conducted, potential risks are identified, mitigation strategies are devised, and a communication plan is established to ensure effective information flow.

The execution phase involves implementing the project plans, assigning tasks, and managing the project team to maintain motivation and adherence to the plan. Progress is tracked, quality assurance measures are implemented, and regular communication with stakeholders is maintained. Monitoring and controlling run concurrently with execution, focusing on tracking project performance through key performance indicators and metrics, identifying and analysing variances, managing changes, addressing risks, and ensuring quality standards. Regular status reports are provided to stakeholders. The closing phase finalizes all

project activities, completes and hands over deliverables, gathers feedback, documents lessons learned, closes contracts, releases resources, and celebrates the team's achievements. This structured approach ensures efficient and effective project completion.

2.0 Method

For this study, the Eisenhardt Method of using comparative cases to study the same focal phenomenon was applied (Eisenhardt, 2021). This entails careful selection of cases where a focal phenomenon has occurred. In this case the focal phenomenon is time and cost overruns in retail mall set up due to MEPF related challenges. Further, common case design as suggested by Eisenhardt, 2021 is used across settings to find the answer to our research questions. Through site visits to diverse malls, three cases were identified for study (Annex III for site images). The cities of Pune and Navi Mumbai in the west of India and Bengaluru in the south of India are known as information technology hubs of the country, thus attracting substantial younger population. This in turn has given rise to increased purchase power and emerging mall culture. Hence upcoming malls in the cities of Bengaluru, Navi Mumbai and Pune served as the ideal location for this study. Based on availability of extensive data and access to stakeholders for in depth interviews, three sites were chosen for the study. Care was taken to ensure that all the three sites had similar years of set up and were of small, medium and large sizes, so that cross case comparison was possible.

#	Size (in Sq. feet)	Year of set up	Number of floors	Profiles of persons interviewed
Case 1	3,25,000	Late 2023	3 floors	Facility Managers, Engineers in Charge, Store Managers, design consultants.
Case 2	11,098	2024	1 floor	
Case 3	4,792	2024	2 floors	

3.0 Data Collection

Each of the sites were visited in person by one member from the research team. The fourth member was kept away from the data collection stage as the team needed a non-parsimonious view of the interview outputs and its analysis. This ensured that every piece of information collected during the course of the case was analysed by two independent sets of researchers. The findings on set of challenges were divided by project life cycle phases in order to answer RQ1 and RQ2. In order to keep the identity of the retail malls anonymous, they are named as case 1, case 2 and case 3. Details can however be obtained by contacting the authors. Excerpts from the interviews and analysis are presented hereunder case wise (See Annex 1 for interview questions and Annex II for excerpts from interview responses).

3.1 CASE I

Problem 1: Inadequate Water Drainage System (Planning)

The design specified an open roof, yet lacked a proper water drainage system, leading to flooding in the underground parking area.

Problem 2: Delays in Bill Approval Due to Hierarchical Issues (Monitoring and Controlling)

The bill approval process experienced delays due to hierarchical issues within the organization. The complexities and inefficiencies in the internal approval process significantly delayed the passing of the bill, adversely impacting the overall project timeline.

Problem 3: Structural Compromises Due to Initial Mall Design (Initiation and Planning)

The initial design of the mall segmented the building into three parts, which compromised the quality and overall finish of the structure.

Problem 4: Delays in Delivery of Long Lead Items (Execution)

Long lead items were not delivered before the commencement of on-site work, causing delays in the construction schedule.

3.2 CASE II

Problem 1: Miscalculated Beam Height (Planning)

The absence of a site visit by the Design Team led to an incorrect calculation of the beam's height. Subsequent structural surveys necessitated multiple revisions to the HVAC plan, resulting in five alterations to the design layout. This caused significant time and cost overruns due to the need to reorder fitments and adjust plans, ultimately delaying the store's operation.

Problem 2: Absence of Service Lift/Passage (Initiation and Planning)

The mall authorities did not provide a dedicated service lift or passage. As a result, all loading and unloading of materials had to occur through the main passage, negatively impacting the company's image.

Problem 3: Delay in Drawing Approval (Execution)

The approved drawings were not promptly communicated to the execution team, leading to periods of inactivity and uncertainty regarding their tasks.

Problem 4: Revisions in Firefighting Drawings (Execution)

During the execution phase, the firefighting drawings required revisions due to initial miscalculations in design parameters, further complicating the construction process.

Problem 5: Miscommunication Regarding Material Quality (Monitoring and Controlling)

Significant miscommunication led the execution team to use plywood for cladding according to the drawings. However, the quality team erroneously asserted that the plywood was expired, necessitating its removal and replacement. This caused a 17-day delay, and subsequent investigations revealed that the plywood was not expired.

3.3 CASE III

Problem 1: Drawing Discrepancies Identified by IT/SLP Team (Planning and Execution)

The IT and Security Loss Prevention (SLP) teams observed discrepancies in the drawings, including mismatches between equipment and cable tray locations. These

inconsistencies necessitated last-minute changes to the layout, resulting in repeated work and delays in project completion.

Problem 2: Delay in Pre-Construction Site Visit Drawings (Planning)

There was a significant delay in providing pre-construction site visit drawings to the design team, which in turn delayed the issuance of Good for Construction (GFC) drawings.

Problem 3: Deviation in Design BOQ vs. As-Built Drawings (Execution and Monitoring and Controlling)

Discrepancies between the Bill of Quantities (BOQ) in the design phase and the as-built drawings led to cost overruns.

Problem 4: Incomplete Skirting and Painting Work Post Closure (Closure)

Skirting and painting work remained incomplete after the project closure, impacting the store's final appearance and readiness.

Problem 5: Incomplete Grouting Work Leading to Water Seepage (Closure)

Grouting work for ducts on the outer wall was not completed even after project closure, causing water seepage inside the store and further complicating the post-construction phase.

Problem 6: Delays due to statutory compliances (Planning and Monitoring and Controlling)

The construction process experienced delays due to the need to adhere to various statutory compliances. These regulatory requirements necessitated additional approvals and inspections, which extended the overall timeline of the project.

4.0 Analysis and Findings

In reviewing the challenges from the three case studies, it becomes evident that the planning phase exhibits the highest frequency and impact of issues, fundamentally affecting subsequent project stages. For instance, inadequate water drainage systems and miscalculated beam heights are indicative of insufficient initial site assessments and design validations. Such oversights lead to significant downstream disruptions, requiring multiple revisions and causing delays and cost overruns, irrespective of the mall size.

Additionally, delays in providing pre-construction site visit drawings and discrepancies between the Bill of Quantities (BOQ) and as-built drawings further underscore the planning phase's critical role in project success. These issues highlight lapses in coordination and cost estimation, which are essential components of effective project planning. When initial planning is flawed, the execution phase is often plagued by inefficiencies and corrective actions, as seen in the need for revisions in design layouts and adjustments to project timelines.

5.0 Results and Conclusion

The recurring nature of these planning-related issues underscores a critical need for enhanced planning processes in construction project management. Comprehensive site

assessments, accurate initial measurements, timely coordination, and realistic cost planning are fundamental to mitigating risks and ensuring project success. By addressing these planning deficiencies, projects can achieve smoother execution, better cost control, and timely completion. Ultimately, employment of professional consultants at the planning phase leads to higher quality outcomes and greater stakeholder satisfaction, as projects are delivered within scope, on time, and within budget. Further insights from in-depth interviews into what improvements to the project framework would help address the above identified issues revealed the following:

Timely Physical Inspections: In both Case 2 and Case 3 (mid-sized and small mall), the root cause of errors could be traced back to the absence of a thorough site visit by the design team. A physical inspection of the store space would have provided essential insights into existing conditions, such as ceiling heights, structural constraints, and potential obstacles. This firsthand knowledge would have enabled the design team to make more accurate calculations and adjustments to their plans before construction commenced. Moreover, the lack of a site visit hindered effective communication between the design team, construction crew, and the client. Misinterpretations of architectural drawings and specifications further exacerbated the issues encountered on-site, leading to frustration and additional delays.

Technology Integration: Usage of advanced technologies like Building Information Modeling (BIM) aid in resolution of drawing related conflicts, miscalculations, reorders due to structural changes and timely drawing approvals. In addition, experts also suggested the use of drones to review quality of work done at inaccessible places and address issues such as incomplete grouting, skirting and painting.

Enhanced Stakeholder Engagement: Diverse stakeholder engagement in the planning phase through Design LAB employed server supported by teamwork could allow multiple users to access data. Providing access from the project's initiation phase onwards to all stakeholders could avoid problems such as timely delivery of lead items, faulty initial mall design and delays due to hierarchical issues.

Risk Management Strategies: A risk management framework which combines it with Project life cycle is needed for better implementation of mall retail projects. Since these projects have very short life spans, the industry tends to overlook addressing risks at each life cycle stage. Yet, in spite of shorter life spans, the risks occur stage wise. Hence a framework to look at mitigating cost and time delays due to MEPF challenges by life cycle stages could help address issues such as flooding, irregular site visits and quality checks and uncertainty in tasks.

6.0 Limitations and Future Research Directions

The case studies discussed are limited to specific mall construction projects, which might not represent the full spectrum of challenges encountered in different types of construction projects. Other sectors such as residential, industrial, or infrastructure projects

might face different issues and require distinct approaches. The study also did not consider external factors such as economic fluctuations, regulatory changes, or unexpected events like natural disasters, which can significantly influence the planning and execution of construction projects. The analysis primarily reflects the experiences of planners and project managers. It does not fully explore the perspectives of other stakeholders such as end-users, local communities, or regulatory authorities, who could offer valuable insights into the challenges and successes of the projects. Future research could include comparisons across various types of construction projects, such as residential, commercial, and infrastructure projects. This approach would help identify whether similar planning issues exist across different sectors and how they are managed. Incorporating quantitative data on project performance metrics such as timelines, costs, and resource allocation could provide a more detailed analysis of the impact of planning deficiencies. This data would be useful for developing models to predict and manage potential project issues.

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Annexure I: Interview Questions

1. What are the typical challenges faced in designing and implementing MEPF systems specifically for retail stores?
2. Are there any unique challenges compared to other building types?
3. How were these challenges identified and addressed in that case?
4. Which project management phase has a significant number of problems?
5. Major reason for cost and time overrun? On an average Range of percentage of cost variation.
6. What are the most common challenges you face regarding MEPF services in retail store setups?
7. How do these challenges impact operations and customer experience?
8. Risk which was not initially identified but later surfaced during execution?
9. Difference between retail store setup in a standalone building vs retail store in commercial setup in the project phase?
10. What are the problems faced while handing over the projects?
11. What are the most common challenges you face regarding MEPF services in retail store setups?

12. How do these challenges impact operations and customer experience?
13. How do MEPF considerations integrate with other departments or stakeholders (e.g., design, construction, operations) in your current projects?
14. What strategies are employed to ensure effective collaboration and communication?

Annexure II: Excerpts from Interview responses

Case I:

“One of the primary issues was persistent waterlogging in the basement areas. During the monsoon seasons, the whole place would be flooded. So, tenants had raised concerns”.

“There were wiring errors throughout the mall. So, we had to rewire the whole thing”.

“The STP (Sewage Treatment Plant) had design flaws. We were not in control of it. We ended up being answerable for environmental concerns. Retrofitting needed to be done”.

Case II:

“The scope itself was not defined clearly. The contractor says something, and the supplier contradicts.... finalising layout itself took up so much time”.

“The design kept changing and this changed the budget of course. Unless that is done, how could we get the permits on time?”

Case III:

“Had the design team done an initial site visit, all those delays could have been avoided. They just went by drawings (the site team). Now so many critical issues got overlooked.

“Design team miscalculated beam heights for store layout. These are all structural issues and become worse as construction moves ahead. Cost revisions, timeline revisions. we have seen it all”

Annexure III: Site images

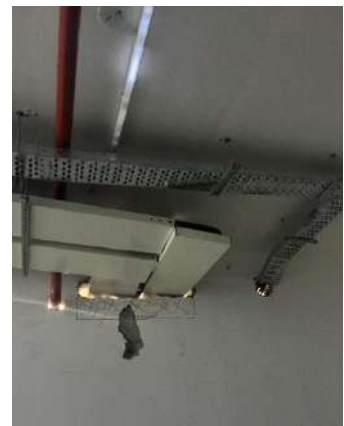
Case I:



Case II:



Case III:



CHAPTER 33

Circular Economy Strategy for Construction Material Reuse through Deconstruction Methods in India

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ABSTRACT

The construction industry in India is experiencing significant growth, yet it is also one of the largest contributors to environmental degradation due to the extensive use of non-renewable resources and the generation of substantial waste. This research explores the adoption of circular economy principles, specifically focusing on construction material reuse through deconstruction methods, to address sustainability challenges in the Indian context. Primary data was collected through surveys and interviews with industry professionals, including construction managers, architects, and waste management experts, across key cities in India. The findings reveal that while there is growing awareness about the benefits of material reuse, there is a lack of infrastructure, policies, and knowledge to support effective deconstruction practices. The study highlights the barriers to implementation, such as high upfront costs, limited availability of skilled labor, and the fragmented nature of the construction industry. Still, it also points out areas for development, especially with regard to the combination of technical advancements, sustainable construction methods, and government incentives. This study offers a road map for legislators and industry players to move toward more sustainable, resource-efficient building techniques in India and offers insightful analysis of the possibility for circular economy initiatives to encourage material reuse in construction.

Keywords: Circular economy; Deconstruction; Design for deconstruction (DfD); Waste management; India.

1.0 Introduction

India's construction industry is being driven by a gigantic boom, led by government spending on infrastructure (US\$ 120.5 billion in Budget 2023) and urbanization. The size of the sector's market is \$778 billion in 2023 and is anticipated to reach \$1.393 trillion by 2033. This boom, however, has an environmental cost. Conventional demolition methods produce humongous amounts of building and demolition waste (C&D waste) – an eye-popping 150

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million tonnes every year, as per the Building Material Promotion Council with projections estimating a concerning increase to 250 million tonnes by 2030. And with an official nominal capacity of recycling a paltry 6,500 tonnes per day (TPD), recycling a mere 1% of the C&D waste, the balance to landfills, contaminating the environment and losing valuable resources. Moreover, the construction sector is a hungry consumer of virgin raw materials globally, with India alone consuming a huge quantity annually Sand: 750 million, Stone (aggregate): 2 billion tonnes, Cement: 297 million tonnes. This widespread application generates environmental pollution via resource extraction and treatment.

1.1 The need for a circular economy approach

The construction industry's present waste route adheres to the "take-make-dispose" linear economy. In growing nations, there is a serious risk from both laxer environmental rules and the generation of CDW throughout the planning, designing, procurement, site management, deconstruction, and disposal phases of the building life cycle. In order to reduce waste and resource consumption, the circular economy (CE) promotes techniques including reuse, recycling, and refurbishing. By ensuring that materials are used for as long as feasible, CE aims to prolong their life cycle. The linear economy, in which resources are harvested, employed, and then discarded, contrasts sharply with this strategy.

The circular economy (CE), which emphasises resource conservation and waste reduction throughout a product's lifecycle, offers a remedy. In order to extend their lifespan and reduce reliance on virgin resources, CE promotes recycling, reuse, and the refurbishment of building materials during construction. By attempting to close the resource loop, this tactic aims to minimise waste production and protect valuable natural resources. As a structure nears the end of its life, there is an opportunity to address waste problems by recycling or reusing construction components. End-of-life salvage must be considered throughout the design phase, which necessitates a shift in the construction industry. When a building reaches the end of its useful life, there are two primary options for disposal: building and destruction.

Through the careful disassembly of structures for material collection and reuse, deconstruction provides a sustainable alternative for demolition. The emphasis on quick removal and disposal in conventional demolition stands in contrast to this. For India's building industry, deconstruction has many benefits, including reduced waste, resource conservation, and alignment with the circular economy.

1.2 Deconstruction as a key circular economy strategy

Deconstruction promotes a circular economy by reducing trash, which saves resources, and creating new business opportunities in the reuse industry. Deconstruction is gaining popularity in countries like the United States and across Europe because to concerns about sustainability and the resource economy. The Dutch government has established a "Green Deal Demolition" program that encourages deconstruction and material reuse, in contrast to Japan's

well-established deconstruction industry with clear regulations and infrastructure. Even while there are still many obstacles to overcome, advancements in technology, sound laws, and more awareness are encouraging wider adoption. Deconstruction methods are still relatively new in India. However, the need for environmentally friendly alternatives to traditional demolition is growing in significance. Deconstruction has great promise for transforming India's construction industry, waste management approach, and circular economy trajectory. It addresses pressing issues such as resource scarcity, waste management, and environmental sustainability. Despite ongoing challenges, a concerted effort by lawmakers, corporations, and the scientific community might create an atmosphere that is conducive to the development of deconstruction methods.

2.0 Literature Review

2.1 Principles of circular economy in construction

Construction circular economy approaches adhere to the concept of closing the material loop through reduction, reuse, and recycling. At the centre of the approaches is the process of deconstruction, which presents an alternative to conventional demolition through dismantling care that facilitates recovery of materials. Research has shown that lean processes integration into deconstruction processes greatly enhances material recovery and reduces wastes (Boukherroub *et al.*, 2024; Benachio *et al.*, 2021). Technologies like Building Information Modeling (BIM) that include material passports offer more convenience through material tracking throughout its life cycle (Neyra & Celoza, 2024; Atta *et al.*, 2021). The systems enable design-for-disassembly (DfD) practices where buildings are prepared upfront for future deconstruction and reuse (Derikvand & Fink, 2023; Olugbenga Akinade & Owolabi *et al.*, 2020). The environmental consequences of this process are overwhelming. Reducing construction waste sent to landfill and lower reliance on virgin materials, deconstruction saves natural resources and lowers greenhouse gases (Bertino *et al.*, 2021; Sehnem *et al.*, 2019). Indications are also shown through evidence of long-term economic gains through the early implementation of deconstruction principles during design (Lima *et al.*, 2023; Ganiyu *et al.*, 2020). In addition, the transition towards circularity is also accompanied by policy interventions and regulations favouring sustainable construction (Ahmed *et al.*, 2024; Arruda *et al.*, 2021).

2.2 Global best practices in construction material reuse

Across the world, a number of case studies demonstrate the effective application of circular economy measures in the construction industry. In Canada, for instance, lean-based deconstruction methods have illustrated how stakeholder engagement at a system level and process optimization can overcome operational challenges to realize higher material recovery rates (Boukherroub *et al.*, 2024; Lynch, 2022). Equally, Han *et al.* (2024) inform that visual demolition waste management systems based on BIM improve decision-making and curtail both

carbon emissions and the cost of waste management considerably. These innovations in digital technologies resonate with European research, where superior practices like 6D BIM have been successfully utilized to improve material traceability and recycling (Mrad & Frölén Ribeiro, 2022; Bertin *et al.*, 2019). Case studies from the United States further underline the potential of deconstruction. Research by Sanchez, Rausch, and Haas (2019) and Cruz-Rios and Grau (2020) studies reveal how disassembly design and adaptive reuse help to generate economic value while minimizing environmental effects. These studies identify that embracing modular design strategies and prefabrication can lead to more effective deconstruction processes and increased circularity (Korde & Jaglan, 2023; Piñones *et al.*, 2023). The use of new procurement methods and digital platforms has also been found to stimulate collaboration between stakeholders and the implementation of circular practices among various projects (Ahmed *et al.*, 2024; Cho, El Asmar, & Aldaaja, 2022). In addition, there is an increased recognition of these strategies by emerging economies. For instance, Bao (2023) records effective circular actions in China, where economic incentives, smart technologies, and government interventions have worked together to advance construction waste recycling and material reuse. Likewise, research in the UAE shows that the adoption of circular practices in Construction and Demolition Waste (CDW) management during the initial stages can drive faster transition towards sustainable construction frameworks (Nie, Dahanayake, & Sumanarathna, 2024).

2.3 Challenges and barriers in India's construction sector

Even with the promise of circular economy practice, India's construction industry has much to learn regarding the adoption of deconstruction practices. The industry is ridden with the dominance of unorganized waste management and a weak market for recycled materials, hence discouraging systemic adoption of deconstruction (Bhavsar *et al.*, 2023; Singhal, Jain, & Jain, 2019). In addition, there is a prevalent broad gap between theoretical benefits of deconstruction and actual application due to inadequate early planning and failure to incorporate advanced technology such as BIM (Swetha *et al.*, 2022; Rahigude *et al.*, 2022). Economic considerations are also a part of the issue. Greater initial cost with deconstruction compared to traditional demolition, along with weak monetary incentives and subsidies, discourage parties to implement such green strategies (Singhal *et al.*, 2019; Tleuken *et al.*, 2022). Furthermore, the absence of inclusive regulatory systems and weak practitioner knowledge discourage widespread application of circular strategies (Johns, Talebi, & Kagioglou, 2022; Eberhardt & Birgisdottir, 2022). For overcoming such challenges, multi-dimensional interventions are required. Policy reforms that include tax incentives, subsidies, and enhanced controls over waste management can prove effective in spurring deconstruction (Rausch *et al.*, 2022; Asante *et al.*, 2022). Training and capacity-building interventions of a specialized type can also create industry capability and competence and thus bridge the theory-practice gap (Smitha & Thomas, 2024; Basta *et al.*, 2020). Government, industry, and academia need to collaborate also in the creation of an enabling environment for circular economy practice (Allam & Nik-Bakht, 2023; Zaman *et al.*, 2018).

3.0 Research Methodology

The research method was formulated to critically analyze the adoption of circular economy methods for material reuse in the construction industry of India through deconstruction techniques. The research aimed to determine the effectiveness, issues, and opportunities associated with material reuse processes in the construction sector. For attaining comprehensive outcomes, a systematic research approach was adopted, encompassing both primary and secondary data.

3.1 Research design

Using a descriptive research approach, this study deepened knowledge of present behaviors, attitudes, and difficulties related with deconstruction techniques in India. This allowed the gathering and examination of quantitative data to identify trends and patterns in the adoption of the circular economy among the building sectors.

- *Primary data:* Structured questionnaires of construction industry players such as architects, engineers, contractors, and legislators helped to gather much of the data. The comments provide a window into the pragmatic constraints, financial viability, and degrees of approval for material reuse depending on deconstruction.
- *Secondary data:* Secondary data came from academic publications, industry reports, government papers, case studies on circular economies and environmentally friendly building techniques. These materials provide a contextual framework and help understand main data.

Table 1: Respondents Profile (Years of Experience)

Years of Experience	Frequency	Percentage (%)
1-5 years	58	38.7
6-10 years	41	27.3
11-20 years	29	19.3
21 years or more	22	14.7
Total	150	100.0

3.2 Sampling method and sample size

To ensure an unbiased selection of respondents from the building industry, a random sampling method was employed. The study targeted experts who were actively engaged in sustainable building, demolition, and material reusing policies. There were discovered to be 150 respondents in the sample, ensuring sufficient representation of stakeholders and maintaining data collecting and analysis feasibility.

3.3 Questionnaire design and respondents' profile

The questionnaire had 27 statements corresponding to various dimensions of deconstruction practice and the perceived impact on economic development and sustainability.

Cronbach's Alpha was used to determine the reliability of the questionnaire, and it scored 0.800, which accounted for superior internal consistency.

4.0 Data Analysis Results and Discussions

The data analysis in this study explores the implementation of circular economy strategies in the Indian construction sector, specifically focusing on material reuse through deconstruction methods. It examines key barriers, including policy, legal frameworks, and cultural attitudes, while highlighting the potential economic and environmental benefits of adopting deconstruction techniques. This analysis provides insights into the feasibility and challenges of integrating sustainable practices in India's rapidly growing construction industry. The data analysis was performed using Descriptive Statistics, Reliability Analysis (Cronbach's Alpha), and One-Sample T-Test Analysis to understand the perceptions, attitudes, and challenges associated with deconstruction methods in India.

Table 2: T-Test

One sample statistic				
	N	MEAN	Std deviation	Std error mean
There is sufficient awareness among construction industry Stakeholders about deconstruction methods.	150	2.10	1.079	.088
Do you believe that government Incentives such as tax rebates or subsidies can help to promote deconstruction techniques	150	3.17	1.368	.112
Cultural attitudes toward waste management and sustainability in India hinder the adoption of deconstruction practices	150	3.45	1.272	.104
Public perception of sustainability affects the demand for deconstructed materials	150	3.23	1.297	.106
Education and public awareness campaigns can contribute to the acceptance of deconstruction practices	150	3.33	1.257	.103
For deconstruction initiatives to be implemented successfully, community involvement is essential.	150	3.39	1.413	.115
Policy inadequacies are a serious hurdle to the implementation of deconstruction in India	150	3.55	1.334	.109

One-sample t-test reveals stakeholders are unaware of deconstruction methods (Mean = 2.10) and also possess different opinions on the effectiveness of incentives provided by the

government (Mean = 3.17). Cultural mindset is revealed to be a barrier to adoption (Mean = 3.45), while public opinion and awareness campaigns have moderate effects on acceptance (Means = 3.23 and 3.33, respectively). Community involvement is considered necessary for successful implementation (Mean = 3.39). Policy loopholes are of utmost concern (Mean = 3.55), and they are also the biggest barrier. The research suggests policy loopholes must be plugged, public awareness must be boosted, and community participation must be increased to make deconstruction methods effective in India.

One-Sample T-Test Analysis: The One-Sample T-Test was conducted to assess whether the mean responses differ significantly from a neutral point (test value = 0).

One-sample t-test results indicate that all statements have statistically significant mean differences with p-values less than 0.05. The results indicate low awareness of deconstruction methods among stakeholders (Mean = 2.10), moderate agreement that government incentives can facilitate deconstruction (Mean = 3.17), and high agreement that cultural attitudes hinder adoption (Mean = 3.45). Public perception of sustainability (Mean = 3.23) and educational campaigns (Mean = 3.33) are observed to enhance acceptance. Community participation (Mean = 3.39) is found to be a prerequisite for effective implementation, while policy gaps (Mean = 3.55) are observed to be the most critical barrier.

Table 3: One-Sample T-test

Statement	Mean	t-value	p-value (Sig.)	Interpretation
There is sufficient awareness among construction industry stakeholders about deconstruction methods.	2.10	23.835	0.000	Low awareness of deconstruction methods.
Government incentives (e.g., tax rebates or subsidies) can help promote deconstruction techniques.	3.17	28.351	0.000	Mixed responses; moderate agreement.
Cultural attitudes toward waste management and sustainability hinder adoption of deconstruction.	3.45	33.187	0.000	Cultural factors are barriers.
Public perception of sustainability affects demand for deconstructed materials.	3.23	30.521	0.000	Positive perception; but needs improvement.
Education and public awareness campaigns contribute to acceptance of deconstruction.	3.33	32.484	0.000	Education plays an important role.
Community involvement is essential for successful implementation of deconstruction.	3.39	29.350	0.000	Strong agreement on community involvement.
Policy inadequacies are a serious hurdle to deconstruction in India.	3.55	32.561	0.000	Policy issues are significant challenges.

The findings reveal a number of challenges and opportunities for promoting deconstruction practice in India. The majority of the respondents are of the view that government incentives,

technological innovation, and policy reforms are essential to drive the adoption of deconstruction. While most of the respondents are aware of the economic and environmental benefits of deconstruction, there are cultural attitude challenges, technological limitations, and policy loopholes. Policy reforms, fiscal incentives, public awareness, and technological innovation would greatly enhance the adoption of deconstruction practices in India.

5.0 Conclusion

This Study “Circular Economy Strategy for Construction Material Reuse through Deconstruction Methods in India” presents the increasing awareness of the utilization of circular economy principles as a primary strategy to enhance India’s sustainability of the construction sector. Research findings state that while a substantial majority of players in the construction sector are aware of the potential economic and environmental gains of the utilization of deconstruction methods, a number of barriers discourage their utilization. These include low awareness, policies, regulatory constraints, a lack of favourable financial support, and weak capacity for technology. Furthermore, most respondents are of the opinion that the intervention of the government by way of incentives and reforms is critical to advocate the use of circular economy principles due to the inefficiency of current waste management structures to enable the large-scale processes of deconstruction. While most respondents acknowledge the potential of deconstruction in minimizing harm to the environment and maximizing economic growth, they still acknowledge the reality that India’s infrastructure, laws, and awareness-raising policies all require major improvement. A further effort is required to address existing barriers and build a framework that favours circular economy strategies in the construction sector based on the excellent match of deconstruction methods and sustainability objectives.

5.1 Limitations

The research is limited by sample prejudice in the sense that it applies to just a single region or type of professional who might not represent all shades of opinion among the construction professional community. Since there is neither primary data and real case study of deconstruction in India, conclusions are also mostly derived in terms of views and impressions and therefore can turn out to be speculative or preconceived ones. Additionally, the study ignores regional differences within India—where local legislation, infrastructure, and industrial practices vary—and does not explore detailed technological solutions or broader political, economic, and educational factors.

5.2 Recommendations

To promote circular economy strategies through deconstruction in India, the study recommends enhancing awareness and education via government-led campaigns and industry workshops aimed at builders, architects, policymakers, and the public. The research is limited by

sample prejudice in the sense that it applies to just a single region or type of professional who might not represent all shades of opinion among the construction professional community. Since there is neither primary data and real case study of deconstruction in India, conclusions are also mostly derived in terms of views and impressions and therefore can turn out to be speculative or preconceived ones

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CHAPTER 34

Clean Energy Transition using Hydrogen in Steel Industry

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ABSTRACT

This paper addresses the innovative potential of the hydrogen technology in driving the decarbonisation of the steel industry, responsible for almost 8% of global CO₂ emissions. It identifies the environmental issue with traditional processes, i.e., the blast furnace basic oxygen furnace (BF-BOF) process that is coke and coal-based. The study compares different hydrogen production routes, including steam methane reforming, partial oxidation, coal gasification, and water electrolysis, subject to their technical viability, economic feasibility, and environmental benefits. The study reveals that green hydrogen through renewable-fuelled electrolysis is the most environmentally friendly solution, and blue hydrogen from carbon capture as a bridging technology. The research addresses challenges to implementation through means of production costs, infrastructural requirements, and technical changes needed in applying hydrogen in steel production. Not despite the prevailing economic difficulties, technological advancements, economies of scale, and friendly policy frameworks would make use of hydrogen in steel-making exist in the future. Lastly, the study concludes that hydrogen is a crucial solution to align steel manufacturing with global climate goals while maintaining access to this significant content for the construction of new infrastructure. The transformation is needed for providing substantial reduction of emissions in one of the world's most carbon-intensive industries.

Keywords: Hydrogen steelmaking; Green hydrogen; Decarbonization; Clean energy transition; Direct reduced iron; Carbon emissions reduction; Blast furnace alternatives; Renewable energy integration; Climate change mitigation; Industrial sustainability.

1.0 Introduction

The transition to renewable energy has become a necessity in the context of climate change and the need to cut greenhouse gas emissions. While the world's industrial economies scramble in order to achieve global climate objectives, the steel sector is particularly hard-pressed because of its environmental load. Steel manufacturing takes up about 8% of total global carbon dioxide emissions, one of the single biggest sources of industrial greenhouse gases in the international context.

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Conventional ironmaking where coal is both when reduced agent and source of energy combine, they end up producing about 2.2 kg of CO₂ for every kilogram of produced liquid steel—an unreliable ratio under carbon-restricted forthcoming years. Steel manufacturing is also one of the most carbon-emitting industrial processes and is accountable for approximately 7-9% of all anthropogenic CO₂ emissions. This vast carbon footprint is mainly supplemented by the widespread application of the blast furnace-basic oxygen furnace (BF-BOF) process that involves heavy dependence on coke and coal. Carbon monoxide, which is used to reduce iron ore produces CO₂ as a by-product. Steel production, other than the release of greenhouse gas, also release other pollutants like sulfur dioxide, nitrogen oxides, and particulate matter, which deteriorate air quality and pose health risks to surrounding communities. The extraction and transportation of raw materials also lead to environmental degradation through land disturbance and water management. Satisfying these sophisticated environmental requirements requires a shift to more environmentally friendly steel production processes that reduce emissions and pollution but still meet the growing need for steel worldwide.

1.1 Drivers for change in the steel industry

The steel sector is experiencing unparalleled demands for transformation in response to ambitious climate policies and market demands for low-carbon goods. The Paris Agreement encourages nearly complete industrial process decarbonization by the middle of this century, compelling steel producers to cut reduction of carbon intensity by as much as 90%, from 1.8 tonnes CO₂ to 0.2 tonnes CO₂ per tonne of steel. This cutback is required in view of the increased world demand for steel, which is set to increase from 1.6 billion tonnes in 2025 to 2.5 billion tonnes in 2050. The addition of required cuts the increase in emissions accompanied by the increase in output levels presents a severe technological problem for the industry, which calls for basic changes in production methods, rather than additions to efficiency.

1.2 Hydrogen as a decarbonization solution

Hydrogen is one of the most promising options for transforming the steelmaking sector, while significantly lowering carbon emissions. Hydrogen, as a chemical element, has unique properties as a reducing agent in iron production. Hydrogen, upon reaction with iron oxide, produces metallic iron and water vapor in the reaction: $\text{Fe}_2\text{O}_3 + 3\text{H}_2 \rightarrow 2\text{Fe} + 3\text{H}_2\text{O}$. This underlying chemistry is rather the opposite of carbon-based reduction, which inevitably creates CO₂. By the replacement of hydrogen by carbon as the major reducing agent, steel manufacture There can be a potential for removing the principal source of the direct emissions from the process. The environmental advantages of hydrogen go beyond the mitigation of reduction-related CO₂ emissions. Hydrogen is a non-polluting fuel, not leaving behind impurities like sulphur in the metal product, and the possible advantage of better product quality and reduced environmental pollution. control equipment. Hydrogen, as a reducing agent and as a fuel, can satisfy more by addressing more than one of the problems of the environment at once, with a production path to carbon neutrality if hydrogen is from low-carbon feedstock.

1.3 Types of hydrogen and their use

Hydrogen Type	Production Method	Carbon Intensity	Key Considerations
Green Hydrogen	Electrolysis using renewable electricity (solar, wind, hydro)	Zero emissions	Most sustainable options require large-scale renewable energy infrastructure
Blue Hydrogen	Steam Methane Reforming (SMR) + Carbon Capture and Storage (CCS)	Lower emissions (compared to gray hydrogen)	Intermediate solution: still relies on fossil fuels but mitigates CO ₂ through CCS
Gray Hydrogen	Steam Methane Reforming (SMR) without CCS	High emissions	Most widely used today, offers limited climate benefits
Brown/Black Hydrogen	Gasification of coal	Very high emissions	Least sustainable; produces significant CO ₂ emissions
Pink Hydrogen	Electrolysis using nuclear power	Low emissions	Low carbon but dependent on nuclear energy availability
Turquoise Hydrogen	Methane pyrolysis (produces solid carbon byproduct)	Moderate emissions	Produces solid carbon instead of CO ₂ ; emerging technology

2.0 Literature Review

2.1 Introduction

The literature on the use of hydrogen in steel making has significantly expanded in recent decades, reflecting expanding interest in the decarbonization of heavy industry sectors. This review consolidates key findings in previous research addressing the use of hydrogen in the steelmaking industry, such as technical feasibility, economic cost, environmental impact, and implementation impediments. There is a new generation of technology, legislation, and market regimes in literature that collectively impact the ability of hydrogen to transform steelmaking technology.

2.2 Review of past research done

Hydrogen-based steelmaking research exists back for a number of decades with early publications examining the underlying chemistry for hydrogen reduction of iron oxides. The last decade, however, has witnessed accelerated momentum fueled by climate necessity and developments in hydrogen production and use. Literature can be broadly grouped into a number of major streams of research: Studies on hydrogen-based steelmaking have changed dramatically, spurred by climate needs and innovation in hydrogen technologies. Prominent fronts include hydrogen-based direct reduction (H-DRI), whereby near-total CO₂ emissions abatement is facilitated using hydrogen levels higher than 95% in pilot plants. The process maximizes reduction efficiency and energy performance using cutting-edge modeling of heat

and mass transfer phenomena. Blast furnace hydrogen injection has also been studied, with 20-30% CO₂ reductions at rates of up to 40 kg H₂ per tonne of hot metal, although the stability of the furnace still relies on coke. Advanced routes such as hydrogen plasma smelting, flash ironmaking, and suspension reduction are developed to overcome drawbacks of traditional techniques but suffer scale-up issues. Economical analyses put the price of hydrogen as the deciding factor with cost parity of conventional steel production when green hydrogen drops to less than \$2/kg and the carbon price hits more than \$50-100/tonne CO₂. Life cycle evaluations verify 80-95% greenhouse gas reduction through green hydrogen but alert toward trade-offs in terms of added water usage. Policy structures and integrating the energy system are key to speeding up adoption and making it economically viable.

3.0 Methodology

3.1 Introduction

This study utilized an in-depth methodological framework to assess hydrogen production routes and their use in steelmaking. The method centered on examining different hydrogen production routes, their efficiency, cost, environmental effect, and scalability. This framework offers a basis for the technical viability and economic feasibility of switching to hydrogen steelmaking. The research investigated both fossil fuel and renewable energy-based methods of hydrogen production, acknowledging that alternative routes can be suitable in different situations depending on the availability of resources, prevailing infrastructure, and local policy structures. Every method of production was assessed against its technical nature, process conditions, and product parameters. Hydrogen production routes to determine their potential in a decarbonized energy system.

Hydrogen use in Steelmaking	Efficiency	Cost (\$/kg H ₂)	Advantages	Challenges	Future Prospects
Direct Reduced Iron (DRI) with Hydrogen	~60-70%	4-6	Zero CO ₂ emissions, improves sustainability	High hydrogen demand, infrastructure modifications needed	Scaling up green hydrogen production, policy support for adoption
Blast Furnace Hydrogen Injection	~50-60%	3-5	Reduces coke consumption, lowers CO ₂ emissions	Partial replacement, requires process adaptation	Gradual transition to full hydrogen-based reduction
Hydrogen Plasma Smelting	~70-85%	6-8	High efficiency, potential carbon-free steel production	High energy requirement, still in research phase	Further technological development and pilot-scale implementation

3.2 Hydrogen in the steel industry

The steel industry is one of the largest carbon emitters globally, primarily due to its reliance on coal-blast furnaces to smelt iron ore. Hydrogen provides a hopeful alternative as a green reducing agent, substituting carbonaceous coke in direct reduction processes.

3.3 Hydrogen production methods

Production Method	Efficiency	Cost (\$/kg H ₂)	Challenges	Future Prospects
Steam Methane Reforming (SMR)	~65-75%	1.3-2.3	High CO ₂ emissions (~9-12 kg CO ₂ /kg H ₂), reliance on natural gas, limited suitability for fluctuating energy inputs	Integration of carbon capture and storage (CCS) to produce “blue hydrogen,” development of enhanced catalysts for efficiency improvements
Partial Oxidation of Hydrocarbons	~60-70%	N/A	Requires oxygen separation, generates CO ₂ , complex setup	Improved carbon capture technologies and efficiency optimization
Coal Gasification	~45-55%	2-3	Highest CO ₂ emissions (~19 kg CO ₂ /kg H ₂), high water consumption, high capital costs	Carbon capture integration for “blue hydrogen” production, process optimizations to enhance efficiency
Methane Pyrolysis (“Turquoise Hydrogen”)	~40-50%	N/A	High energy input, limited commercialization	Industrial-scale implementation, integration with renewable energy sources
Alkaline Electrolysis	~60-70%	4-6	High electricity cost, materials durability	Cost reductions through technological advancements and increased renewable energy adoption
PEM Electrolysis	~55-65%	5-7	High material costs, limited scalability	Technological improvements to reduce costs and enhance efficiency
SOEC Electrolysis	~70-85%	N/A	Pilot-phase development, durability concerns	Large-scale deployment with integration of industrial waste heat sources
Thermochemical & Photocatalytic Splitting	<5%	N/A	Low efficiency, scalability issues	Research into advanced catalysts and solar energy utilization

3.4 Comparative analysis

From above discussion, we reached the conclusion that Fossil fuel-based technologies (SMR, coal gasification) are the leaders in terms of cost and scalability but need carbon capture to avoid environmental damage. Electrolysis and methane pyrolysis offer cleaner options but are

limited by cost and infrastructure scalability. New technologies, including thermochemical and photocatalytic hydrogen production, are still in the initial research phase but have long-term sustainability potential. For the steel sector, hydrogen-based options offer a real route to decarbonization but need breakthroughs in hydrogen production and storage at scale.

4.0 Future Scope of Hydrogen in the Steel Industry: Pathways to Decarbonization and Sustainable Growth

4.1 Escalating global demand for green steel

The demand for low-carbon or “green” steel has been spurred by more stringent climate policies and business sustainability objectives. Sectors like automobile, construction, and consumer products are increasingly looking for materials with lower carbon footprints, presenting market opportunities for green steel manufacturers. This demand is anticipated to increase exponentially, with the global market possibly reaching \$300-500 billion by 2050. Early adopters in high-end sectors such as luxury products and premium automotive are prepared to pay a premium, setting the stage for wider market acceptance as production volumes scale and costs reduce. The competitive environment is becoming more severe, with established producers, new players, and cross-industry consortia cutting costs and increasing efficiency through innovation, reflecting patterns in renewable energy technologies.

4.2 Advancements in hydrogen production and storage

Improvements in the technology of hydrogen production and storage are critical to the economic feasibility of hydrogen steelmaking. Electrolysis technology, for instance, developed More efficient and less expensive electrolyzers have the potential to lower capital expenses. by 50-70% over a ten-year timeframe. Technologies such as high-temperature co-electrolysis and water splitting have further efficiency enhancement but entail continuing research spending. Storage materials like metal hydrides and liquid organic Hydrogen carriers solve problems of energy efficiency and operational complexity. These Technological development enables greater use of renewable energy sources combined with secure hydrogen. demand, thus making steel production from hydrogen more economic.

4.3 Storage and transportation breakthroughs

Effective hydrogen storage and transportation are necessary to scale up hydrogen-based steelmaking, particularly for plants distant from renewable sources. Improvements in liquefaction, compression, and carrier molecules such as ammonia or liquid organic hydrogen carriers (LOHCs) may cut transport costs by 30-50%. Materials science breakthroughs that overcome hydrogen embrittlement in pipelines and storage tanks are important for mass application. Demonstration projects are proving these technologies, with commercial operations set to scale up after 2025, making cost-effective long-distance hydrogen transport possible.

4.4 Infrastructure development and investment landscapes

Hydrogen-based steelmaking depends on sturdy infrastructure growth. Over \$500 billion in investments worldwide is being allocated to production, storage, and transport systems. Regional hydrogen hubs are becoming dominant models, aggregating production with industrial uses such as steelmaking to drive economics of scale. Hubs promote synergies among industries like chemicals and transportation and minimize system costs. Such infrastructure initiatives will have a profound impact on the adoption level of hydrogen in steelmaking.

4.5 Public-private funding models

New financing instruments are meeting the capital-hungry nature of hydrogen-based steelmaking. Green bonds, sustainability-linked loans, public-private partnerships, and carbon contracts for differences (CCfD) are becoming increasingly popular. CCfDs reduce the risk of revenues by assuring minimum carbon prices for emissions cuts to help invest in projects that are still in development. International financial institutions are also coming into play by offering funding, risk mitigation instruments, and policy support to promote faster adoption among both developed and emerging economies.

4.6 High production costs

Hydrogen-based steelmaking faces cost premiums of 30-80% compared to conventional methods due to high hydrogen production expenses. Cost reductions depend on technological advancements in electrolysis, transport infrastructure, and equipment optimization. Carbon pricing policies and market differentiation for low-carbon products can further bridge this cost gap by internalizing environmental costs.

4.7 Energy intensity and efficiency concerns

Hydrogen-based processes require significant energy inputs, particularly for electrolysis-driven hydrogen production. Transitioning global steel production entirely to hydrogen would demand 2,500-3,000 TWh annually—10% of current global electricity generation. Research into hybrid processes combining biomass or fossil fuels with carbon capture could mitigate energy intensity while achieving substantial emission reductions.

4.8 Infrastructure and supply chain limitations

Scaling up hydrogen adoption necessitates expanding electrolyzer manufacturing capacity and renewable electricity generation. Current electrolyzer output meets less than 5% of projected 2030 needs. Supply chain bottlenecks for critical minerals such as iridium and platinum must be addressed through alternative material research and cross-sector collaboration among industries like energy, mining, and chemicals.

4.9 Need for policy support and market signals

Policy frameworks play a decisive role in accelerating hydrogen adoption in steelmaking. Carbon pricing mechanisms remain insufficient in many regions to drive rapid

transformation. Stable policies that incentivize low-carbon products through procurement standards and certification systems are essential to create market differentiation for green steel.

4.10 Long-term environmental and economic impacts

Hydrogen-based steelmaking could reduce global greenhouse gas emissions by 5-7%, offering significant climate benefits alongside improved air quality by eliminating pollutants from conventional processes. Economically, the transition could revitalize industrial regions with abundant renewable resources while creating jobs across the value chain—from renewable energy development to steel production—despite challenges faced by coal-dependent regions during this shift.

5.0 Result

Innovative funding models are responding to the capital-hungry nature of hydrogen-based steel production. Carbon contracts for difference (CCfD), green bonds, sustainability-linked loans, and public-private partnerships are becoming more popular. CCfDs mitigate the risk of revenues by assuring minimum carbon prices for carbon reductions, making investments into first-mover projects more attractive. International financial institutions also have a key role to play by offering funding, risk management instruments, and policy assistance to drive adoption in developed and emerging economies.

The steel industry faces an urgent need to reduce its substantial carbon footprint while maintaining production capacity. Traditional steelmaking through blast furnace processes generates approximately 2 kg of CO₂ per kg of liquid steel produced, along with other pollutants affecting air quality. Hydrogen presents a promising pathway for transformation, producing only water vapor as a byproduct when used as a reducing agent. This transition is being accelerated by converging economic forces, stringent climate policies, and growing market pressure from consumers demanding lower-carbon materials.

Regional approaches vary, with the EU implementing mechanisms like the Carbon Border Adjustment Mechanism, while the US provides funding through the Inflation Reduction Act¹. Significant progress is evident in hydrogen adoption for steelmaking globally. India, the world's second-largest steel producer, has launched ambitious initiatives including a National Green Hydrogen Mission with an initial outlay of ₹19,744 crore. Approximately ₹455 crore is dedicated to pilot projects for hydrogen use in iron and steel production. In October 2024, the Ministry of Steel awarded projects to produce Direct Reduced Iron using 100% hydrogen and to inject hydrogen into existing blast furnaces. India is also developing a dedicated 'Green Steel Mission' with an estimated budget of ₹15,000 crore, which includes production-linked incentives, financial support for renewable energy, and preferential purchasing mandates for government agencies. The shift to hydrogen steelmaking is vital for the decarbonization of a carbon-intensive sector while maintaining the production of critical materials. This study

identifies a number of important conclusions. Hydrogen offers a feasible solution for decarbonization, with different implementation routes depending on regional circumstances. Hydrogen direct reduction and electric arc furnace steelmaking can lower emissions by 80-95% when green hydrogen is used. The environmental gains vary by hydrogen production pathway; green hydrogen has the largest climate benefits, with blue hydrogen achieving significant but partial emission cuts. Economies of scale and reductions in the cost of renewable electricity make the economic hurdles large but falling. Hydrogen-based steel can achieve cost parity with traditional approaches in areas with abundant renewable resources by 2030-2035. Strong policy frameworks are needed to facilitate this shift, involving end-to-end packages that cover both supply and demand sides. The shift needs to be considered as part of an overall industrial system change, which calls for intersectoral collaboration to maximize benefits.

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CHAPTER 35

Comparative Analysis of Solid Waste Management Practices in Pune and Visakhapatnam

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Kota Lns Madhuri² and Satya Vardhan Reddy Goluguri¹*

ABSTRACT

In India, solid waste management is a problem because of rapid urbanization, increase in waste generation, and inadequate infrastructure. This analysis aims to compare solid waste management practices in two cities, Pune and Visakhapatnam, focusing on waste generating activities, segregation efficiency, collection systems, and disposal methods. Findings indicate that Pune has an organized SWM system that is complimented with efficient waste collecting practices, community participation, and centralized community processing of waste. Furthermore, although Visakhapatnam is progressive in the landfill site rehabilitation and waste to energy initiatives, challenges remain in terms of primary sorting and sustainability. The research proposes an Integrated Waste Management Framework consisting of policy, technology, finance, community participation, and education for effective sustainable management.

Keywords: Solid waste management; Waste segregation; Waste collection; Waste processing; Sustainable waste management.

1.0 Introduction

Municipal solid waste (MSW) generation has increased dramatically as an outcome of India's cities' rapid urbanization, creating serious infrastructure, health, and environmental problems. According to Central Pollution Control Board (CPCB), India generates approximately 62 million tons of waste annually, with only 43 million tons collected, 12 million tons treated, and the remaining 31 million tons disposed of in landfills (CPCB, 2021). Adopting sustainable, effective, and technologically advanced waste management practices is necessary because inefficient waste management systems contribute to pollution, resource depletion, and climate change (Gupta *et al.*, 2020). Cities must adopt integrated waste management frameworks in light of the growing population and urban density in order to improve resource recovery mechanisms and lessen the negative effects of inappropriate waste disposal (Swachh Bharat Mission, 2023).

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Two significant Indian cities, Pune and Visakhapatnam, have different approaches to solid waste management (SWM). Pune is renowned for its strong community involvement, decentralized waste management model, and incorporation of waste-pickers into organized waste processing systems (SWaCH-Pune, 2022). Conversely, Visakhapatnam has prioritized waste-to-energy technological advancements, centralized waste processing facilities, and landfill rehabilitation (GVMC, 2021). This study intends to highlight best practices, identify obstacles, and suggest an effective framework for enhancing SWM systems in urban India by comparing these two cities. The effectiveness of the current SWM strategies in Pune and Visakhapatnam with regard to waste collection, segregation, disposal, and recycling is examined in this study. This study aims to identify the advantages and disadvantages of each city's waste management system by examining its financial models, technological interventions, and policies. Through a thorough comparison, policymakers, municipal officials, and urban planners will be able to create data driven, workable solutions to address the SWM issues in other Indian cities (World Bank, 2022).

2.0 Literature Review

Solid Waste Management (SWM) is a critical issue in urban areas, with rapid urbanization and changing consumption patterns contributing to increasing waste generation (Bholey & Mihir, 2017). India generates approximately 62 million metric tons of waste annually, ranking fourth globally in per capita waste production (Sruthi & Bhargavi, 2022). Efficient SWM requires proper waste segregation, collection efficiency, and sustainable disposal methods. However, many Indian cities struggle with inadequate infrastructure, financial constraints, and low public participation (Ramirez-Rubio *et al.*, 2019). Government regulations, such as the Solid Waste Management Rules, 2016, mandate waste segregation at source and involvement of waste pickers in formal systems. The Swachh Bharat Mission (SBM) and Service Level Benchmarking (SLB) have also improved waste collection and monitoring, but enforcement challenges exist (Ministry of Urban Development 2012, n.d.). Studies highlight Pune's success in decentralized composting and community-driven initiatives through SWaCH, while Visakhapatnam has focused on waste-to-energy projects and landfill remediation (Ghosh *et al.*, 2025). Past research suggests that public-private partnerships, policy enforcement, and financial models are essential for improving SWM (T, 2009). The integration of AI-driven monitoring, expansion of composting facilities, and strengthening of recycling initiatives can enhance waste management efficiency. (Shrestha, 2024)

3.0 Research Gap and Need of Study

Many studies that are done in the past are mainly focused on the study of Solid Waste Management (SWM) system in a particular city of India or as complete overview of SWM on

country as whole, this studies lack in doing comparative analysis between cities as each study was done at different timeline and made on different parameters. To bridge that gap we would like to study about SWM practices followed by a few cities at a time, so that the information gathered on the common parameters can be compared for the detailed analysis.

4.0 Objectives

- What are the key factors influencing solid waste generation in Pune and Visakhapatnam?
- How does the waste segregation efficiency compare between Pune and Visakhapatnam?
- What policy recommendations can be made to enhance Solid Waste Management?

Scope: This research offers a comprehensive assessment of urban waste management systems, their efficiency, and potential improvements. This study contributes to multiple domains, addressing environmental, policy, technological, and operational aspects of solid waste management (SWM).

5.0 Research Methodology

A mixed-method approach was used, integrating qualitative and quantitative data collection methods. Interviews were conducted with municipal officials and waste management professionals. Secondary data was collected from government reports, previous studies, and municipal records. The Relative Score calculation method was used with weightages.

6.0 Data Analysis and Findings

6.1 Benchmarks comparison of Pune & Vishakhapatnam

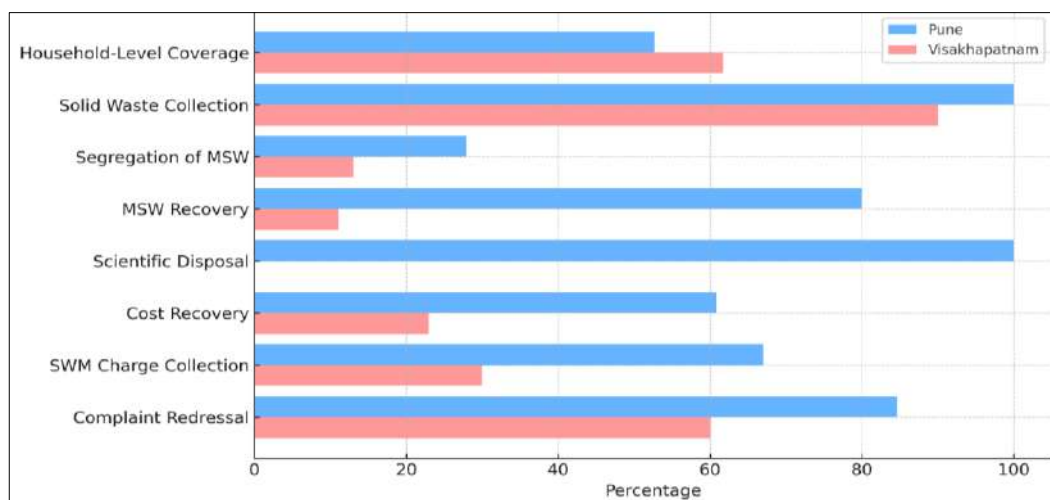
Table 1 and Figure 1 shows Service level Benchmarks Reported by the Sample Cities in 2010-11, which contains 8 benchmark factors for comparison of efficiency between Pune & Vishakhapatnam.

Table 1: Service level Benchmarks Reported by the Sample Cities in 2010-11

Service-level benchmarks	Benchmark	Pune	Visakhapatnam
Household-level coverage	100%	52.7%	61.7%
Efficiency in the collection of solid waste	100%	100%	90%
Extent of segregation of MSW	100%	27.9%	13%
Extent of MSW recovered	80%	80%	11%
Extent of scientific disposal of MSW	100%	100%	0%
Extent of cost recovery	100%	60.9%	23%
Efficiency in collection of SWM charges	90%	67%	30%
Efficiency in redressal of customer complaints	80%	84.7%	60%

Source: Ministry of Urban Development 2012, n.d.

Figure 1: Comparison of Waste Management Factors – Pune vs Vishakhapatnam



Source: Compiled by authors

Additionally, it contains benchmark percentages of 8 factors. In which, Pune beats Vishakhapatnam in 7 factors where as Vishakhapatnam beats only in 1 factor i.e., Household level coverage in 2011.

6.2 Cross comparison between Pune & Vishakhapatnam

Table 2 contains seven parameters which will define efficiency of both cities. Data is collected from PMC and GVMC.

Table 2: 7 Key Factors Considered for Both Cities

Parameter	Pune (%)	Vishakhapatnam (%)	Assigned Weight
Household coverage	90	93	20% (0.2)
Waste Segregation	95	80	20% (0.2)
Collection frequency (everyday)	100	70	15% (0.15)
Door-to-door collection	95	80	15% (0.15)
Use of community bins	5	26	5% (0.05)
Non-payment of service charges (inverse impact)	$(100-20) = 80$	$(100-40) = 60$	10% (0.1)
Willingness to pay	80	50	10% (0.1)

Source: compiled by authors

Table 3 shows justification for 7 parameters considered including weightages.

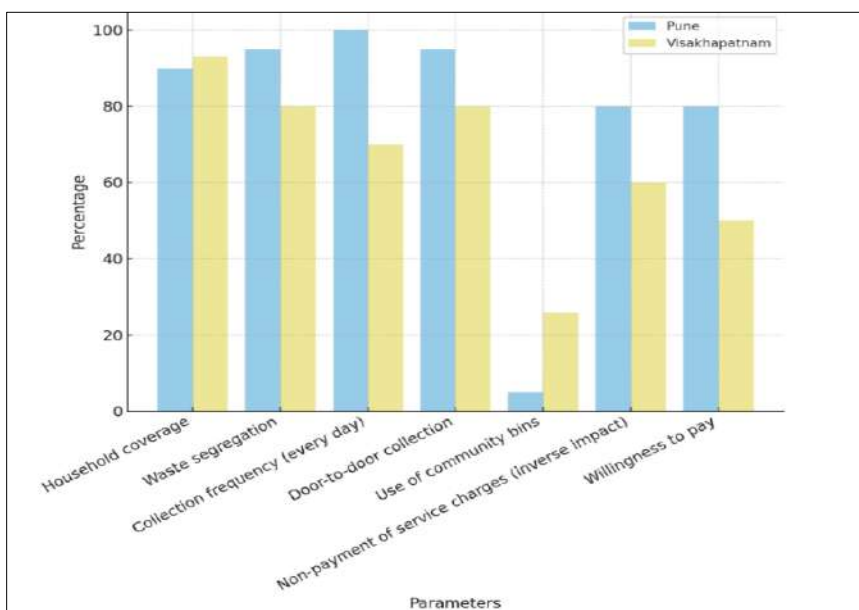
Table 3: Assumption of Weightages

Parameter	Weightage (%)	Justification
Household Coverage	20% (0.2)	Higher coverage ensures effective waste collection and minimal littering.
Waste Segregation	20% (0.2)	Essential for efficient recycling and reducing landfill burden.
Collection Frequency (Every Day)	15% (0.15)	Regular waste collection prevents accumulation and health hazards.
Door-to-Door Collection	15% (0.15)	Increases efficiency and minimizes community bin overflow.
Use of Community-Bins	5% (0.05)	Lower weightage since bins are supplementary to door-to-door collection.
Non-Payment of Service-Charges (Inverse Impact)	10% (0.1)	Financial sustainability is crucial for long-term waste management success.
Willingness to Pay	10% (0.1)	Indicates public participation and the feasibility of waste management funding.

Source: compiled by authors

Figure 3 shows visual aid of Comparison of Waste Management parameters -Pune vs Vishakhapatnam. In which x axis contains Percentages and y axis contains 7 parameters.

Figure 1: Comparison of Waste Management Parameters – Pune vs Vishakhapatnam



Source: compiled by authors

City	Weighted Score	Final Rating (out of 5)
Pune	0.903	4.515
Visakhapatnam	0.7869	3.9345

6.3 Key observations

Waste management performance of Pune and Visakhapatnam stands at 4.515 out of 5 and 3.9345 out of 5 respectively. As compared to Visakhapatnam, Pune has a better score showcasing a more effective and sustainable waste management system.

Key Observations by Parameter:

- *Household Coverage:* With Visakhapatnam (93%) slightly outperforming Pune (90%) it retains a small edge.
- *Waste Segregation:* Aside from segregation, Pune (95%) does much better than Visakhapatnam (80%). Poorer segregation outcomes in Visakhapatnam can translate to more difficulties in managing recycling as well as landfill sites.
- *Collection Frequency:* Pune does daily waste collection for its clients 100% of the time, while Visakhapatnam only manages to do it 70% of the time. This can cause build-up of waste and health concerns for Visakhapatnam.
- *Door-to-Door Collection:* Pune (95%) makes use of a public bin collection system the most, hence needing the least effort to deposit waste in public bins. Visakhapatnam (80%) is more dependent on community bins which lowers efficiency.
- *Use of Community Bins:* Visakhapatnam (26%) has a bigger percentage of people using community bins than Pune (5%), which indicates that there is a problem with direct collection.
- *Non-Payment of Service Charges:* Compliance level for payment in Pune currently stands at 80%, while Visakhapatnam serves at 60%. These figures are bound to affect the financial health of the system, and waste management performance.
- *Willingness to Pay:* In contrast to Visakhapatnam (50%), Pune (80%) shows markedly increased support and payment for waste management services. Public cooperation and financial sustainability look much better in Pune.

6.4 Challenges identified

Despite the improvements in both cities, several challenges persist:

- The high dependence on landfills stems from the low segregation rates observed in Visakhapatnam.
- Problematic financial sustainability, especially in Visakhapatnam, stems from inadequate revenue collection through waste management service fee compliance.
- Inefficient recycling and waste-to-energy processes are a consequence of insufficient technological sophistication in waste processing.
- Insufficient active participation of the public in the segregation and recycling of waste.

7.0 Conclusion

This study illustrates specific challenges and prospects related to Solid Waste Management (SWM) in Indian cities, with particular attention to Pune and Visakhapatnam. Each city has made improvements in their waste management systems; however, notable distinctions still exist. Pune has adopted a community-based model which includes decentralized waste processing, waste-picker cooperatives, and public participation. On the other hand, Visakhapatnam has implemented waste-to-energy methods along with landfill remediation; however, they still have not mastered source segregation and financial self-sufficiency. When comparing the years from 2011 to 2024, these two cities have significantly progressed. A comparative assessment of the two cities suggests that waste segregation, financial hardship, and civic participation are the major issues in both cities. The effectiveness of decentralized strategies in Pune suggests that municipal corporations must focus on source segregation, scientific waste disposal, and community involvement if they want long-term sustainability.

8.0 Recommendations

To address these challenges, an Integrated Waste Management Framework (IWMF) is

- *Policy Changes:* Implement the Extended Producer Responsibility (EPR) policy where industries are answerable for the waste produced and recyclability of their products is promoted. Apply the Polluter Pays Principle where generators of massive waste bear the costs of its disposal. Augment segregation policies through heightened penalties for noncompliance.
- *Improvement in Technology:* Employ AI-powered waste tracking systems to enhance route collection efficiency. Construct mobile applications through which residents can monitor waste collection dates or report if waste has not been collected and provide lower rewards for improper segregation of waste. Improve Material Recovery Facilities (MRFs) by integrating automated sorting of waste for better recycling processes.
- *Financial Plans for Achieving Sustainable Waste Management:* Raise the level of compliance to SWM service charge collection especially in Visakhapatnam through awareness campaigns and rewarding those who pay on time. Grant tax incentives to firms that use a zero-waste approach. Foster Public Private Partnership (PPP) for development aid for investment in waste collection or processing facilities.
- *Public Participation and Civic Education Programs:* Sponsor initiatives dubbed, “Zero Waste Neighbourhood” aimed at mobilizing residents to minimize waste at the community level. Create contests on waste segregation for the citizens in order to enhance participation. Introduce waste-oriented teaching programs to primary schools to promote relevant behavioral change

By adopting these measures, Indian cities can transition towards a more efficient, financially sustainable, and environmentally responsible SWM system, ensuring cleaner urban environments and improved public health.

9.0 Future Scope

- *Lack of Standardized Evaluation Frameworks:* Current research lacks a uniform methodology for assessing operational efficiency, financial sustainability, and technological adoption in SWM.
- *Insufficient Evaluation of Technological Interventions:* It is still unclear how waste-to-energy technologies, automated sorting, the Internet of Things and artificial intelligence (AI) can improve SWM till what extent in percentage.
- *Limited Comparative Studies:* Although Pune and Visakhapatnam use different SWM strategies, there isn't a thorough comparison to assess how effective they are.

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CHAPTER 36

Comparative Study of Conventional and Alu-Form (Mivan) Formwork in High-Rise Buildings

Arya Kiran Sankhe¹ and Snehjit Kumbhar²

ABSTRACT

Time is an essence for any construction project, especially for high-rise building where identical items of work are to be executed in sequence. In the present study it is proposed to compare efficiency, cost-effectiveness, time management, and quality of construction achieved through conventional formwork and Alu-form (Mivan) formwork in high-rise buildings. Data collected for sixty storied building such as construction speed, material wastage, labor requirements, and structural quality were analyzed using quantitative tools. Through on-site observations, interviews with construction professionals, and a detailed cost-time analysis of projects using both conventional and Alu-form formwork is carried out. A mixed-method approach was employed for this study. The results highlight that Alu-form (Mivan) formwork significantly reduces construction time and labor dependency, thereby increasing productivity. Conventional formwork, while cost-effective for small-scale projects, is less efficient in high-rise construction due to higher labor demands and slower cycle times. Although initial investment costs for Aluform are higher than conventional formwork, the long-term benefits in terms of durability and reusability offset these costs.

Keywords: Aluform formwork; Mivan technology; Conventional formwork; High-rise buildings; Construction efficiency.

1.0 Introduction

The increasing demand for high-rise buildings has made advancements in construction technology, particularly in formwork systems, which significantly impact construction speed, cost, and quality. Conventional formwork, made from timber, plywood, and steel, remains widely used due to its adaptability and cost-effectiveness for smaller projects. However, its high labor dependency, slower cycle times, and material wastage raise concerns regarding efficiency in large-scale developments. In contrast, Alu-Form formwork, an aluminum-based modular system, has gained traction for its superior reusability, faster construction cycles, and improved concrete finishes. Despite these advantages, the system's high initial costs and limited design flexibility pose challenges to its widespread adoption.

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Construction methods are commonly classified based on the formwork system used. In high-rise building construction, Conventional Formwork Systems and Aluminium Formwork Systems (Mivan) are the most preferred. In conventional formwork, loads are transferred through beams and columns, with options for post tensioned slabs. The formwork consists of props and spans, providing up to 20 repetitions, while timber alternatives offer only five repetitions, strengthening the RCC structure in approximately 20 days. This method lacks modularity, making it more suitable for basic structural layouts. In contrast, aluminium formwork systems rely on load-bearing concrete walls, allowing for modular construction. This method is particularly advantageous for projects with repetitive slab structures and is economical when around 100 repetitions are achieved, strengthening RCC structures in just 10 days. Though considered a semi-modular system, as it does not offer complete modularity, it enhances construction efficiency and reduces overall project timelines.

1.1 Cost considerations in formwork system

Cost is another critical factor when selecting a formwork system, as it directly influences the overall budget and financial feasibility of a construction project. The cost of formwork includes material procurement, labor wages, installation, maintenance, and reuse potential. Conventional formwork is initially more affordable but has higher long-term costs due to lower reusability and increased labor demand. Mivan formwork, despite its higher initial investment, becomes cost-effective in large-scale repetitive projects due to its ability to be reused up to 250-300 times, compared to 15-25 repetitions for conventional timber formwork.

1.2 Labor productivity in constructions

Labor productivity is a key factor influencing the success of construction projects, particularly in high-rise buildings where efficient workforce management directly impacts project timelines and costs. Productivity in construction is typically measured as the amount of work completed per worker per day, often expressed in square meters of shuttering or concreting per man-day. The efficiency of labor depends on various factors, including the complexity of the formwork system, availability of skilled workers, site conditions, and construction methodology. Conventional formwork, which relies heavily on skilled carpenters and manual adjustments, generally has lower productivity due to frequent reassembly and material wastage. In contrast, Mivan (Alu-Form) formwork, a prefabricated aluminum system, is designed for speed and efficiency, allowing for higher productivity with reduced labor dependency. This study focuses on determining labor productivity for both systems by analyzing the shuttering area covered per worker per day.

2.0 Literature Review

The adoption of aluminum formwork has proven to be a cost-effective and time-saving solution in construction projects. Studies have shown that Mivan technology reduces

construction costs by 18-25% and shortens project duration by 20-30%, despite its 30-40% higher initial investment (Gari & Thomas, 2024). Research on MHADA projects found that Mivan technology lowers labor requirements by 30-35%, reducing costs and minimizing delays (Gopal, 2024). Its implementation in Pradhan Mantri Awas Yojna housing projects in Rudrapur, Uttarakhand, demonstrated improved construction speed and earthquake-resistant housing (Times of India - Realty NXT, 2023). A case study on the Godrej Garden Enclave project revealed that Mivan formwork saved ₹73,27,335 and reduced construction time by six months (Patil *et al.*, 2022). Studies on high-rise projects in Hong Kong indicated that aluminum formwork can reduce construction time by 30% and labor costs by 20-25% (Raymond, 2022). Similarly, research on labor productivity found that aluminum formwork achieved a maximum productivity of 10.36 sqm/man-days, though actual productivity varied depending on project conditions (Singh & Nagarajan, 2022).

However, transitioning from conventional to Mivan technology presents challenges such as higher initial investment and the need for specialized labor training (Karke & Kumathekar, 2021). Comparisons between traditional and modern formwork systems have shown that while aluminum formwork is highly efficient for large-scale projects, conventional timber and steel systems provide greater flexibility for customized designs (Karule & Kumar, 2021). The Industrialized Building System (IBS) approach in Malaysia has also demonstrated economic benefits for repetitive large-scale construction, although material limitations and skill shortages remain key barriers (Baharuddin *et al.*, 2021). Sustainable formwork systems like aluminum significantly reduce material waste and improve cost efficiency, particularly in high-density urban environments (Poon & Robin, 2018). Research on Mivan technology's impact on project timelines showed that it significantly reduces duration in high-rise projects with repetitive layouts, mainly due to reduced labor needs and reusable formwork components (Gulghane *et al.*, 2018). Fast-track construction techniques such as Mivan and Tunnel Form have been identified as essential for urban housing projects, enabling rapid construction while maintaining structural quality (Sorate & Dhiman, 2017).

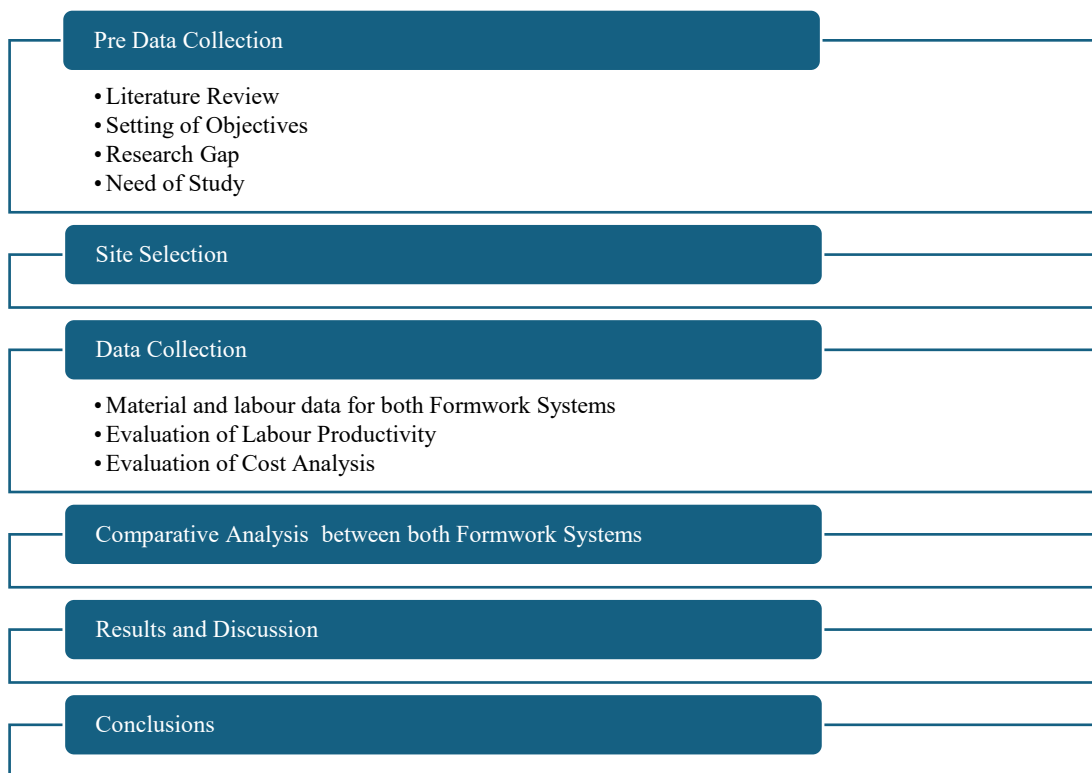
Economic feasibility studies found that aluminum formwork reduces construction costs by minimizing the need for skilled labor and heavy equipment, while also ensuring high-quality finishes that eliminate the need for additional plastering (Selvan, 2016). In terms of efficiency, aluminum formwork reduces the standard floor-to-floor cycle to seven days, compared to 20 days in conventional formwork (Mathane, 2015). Research on formwork reuse highlights that aluminum formwork can be reused 250-300 times, whereas traditional timber and plywood systems degrade after only 15-25 uses, significantly lowering material costs and accelerating project completion (Gambatese & Barbosa, 2014). A study using the Line of Balance technique demonstrated that aluminum formwork effectively reduces both time and cost in multi-story buildings (Vijay *et al.*, 2019). In mass housing projects under Pradhan Mantri Awas Yojna, aluminum formwork reduced construction costs by 18.4% and saved approximately 38 days in project duration (Aditya *et al.*, 2018). Furthermore, comparative evaluations of different

formwork systems concluded that while aluminum formwork is optimal for efficiency, tunnel formwork remains the most cost-effective option, particularly for projects with a high number of repetitions (Renuka *et al.*, 2017).

3.0 Methodology

This research methodology outlines the systematic approach used to analyze and compare labor productivity and cost implications of Mivan and conventional formwork in high-rise construction. This study employs a quantitative research approach, collecting and analyzing real-time construction data from a specific high-rise project. The methodology focuses on site observations, data collection, productivity calculations, and cost analysis to derive meaningful insights (see. Figure 1).

Figure 1 : Methodology Flowchart



4.0 Site Selection

The study is conducted on Oberoi Realty's Sky City project in Borivali East, Mumbai, which consists of two identical G+65 residential towers—one constructed using aluminium

formwork and the other using conventional formwork. Located at 19.228825° N latitude and 72.854118° E longitude, the project spans 25 acres and features six high-rise towers offering premium 3 BHK and 4 BHK residences. The present study focuses on Towers G and H, which share the same design specifications from the 10th to the 23rd floor. Sky City is well-connected to the metro station, enhancing accessibility for residents. The structure is founded on soil with a safe bearing capacity (SBC) of 150 T/Sq.M and incorporates advanced Alu-form technology. Additionally, the project is IGBC Gold certified, ensuring eco-friendly construction, elegant architecture, and sustainable design.

5.0 Data Collection and Analysis

Cost analysis for both Aluminium (Mivan) formwork and Conventional formwork is carried out considering various parameters, including material costs, labor costs, and cycle times. The major cost components include material costs, labor costs, shuttering cycle time, cost per square meter, and shuttering usage ratio. Material costs differ significantly between the two formwork systems. Aluminium formwork requires a high initial investment but offers greater reusability (up to 200 repetitions), reducing long-term costs. It also ensures a better concrete finish, reducing plastering expenses. In contrast, conventional formwork has a lower initial cost but a shorter lifespan (10-20 repetitions), leading to higher cumulative costs over multiple floors. Additionally, it requires more timber or plywood, contributing to material waste.

Labor costs depend on the complexity and time required for assembling and dismantling each formwork system. IS 7272-1:1974 provides labor output recommendations that help estimate workforce requirements for shuttering work. Aluminium formwork enables a 4 to 7-day cycle per floor, significantly improving construction speed, whereas conventional formwork requires 10 to 14 days per floor, resulting in project delays. The cost per square meter of shuttering is derived based on material usage, labor hours, and the reusability factor. Aluminium formwork has higher efficiency, and a lower lifecycle cost compared to conventional formwork. The shuttering usage ratio, which measures the efficiency of formwork material utilization, is calculated as:

$$\text{Shuttering Usage Ratio} = \frac{\text{Quantity of shuttering done in a month}}{\text{Total shuttering available for the month}}$$

Aluminium formwork typically has a lower usage ratio due to higher reusability and faster cycle times, whereas conventional formwork has a higher usage ratio due to frequent replacements and greater material wastage. Labor productivity is assessed based on IS 7272 (Part 1 & 2) standards, which provide guidelines on labor output in building works. It is calculated using the formula:

$$\text{Productivity} = \frac{\text{Quantity of work done}}{\text{Number of Manday/s}}$$

Aluminium formwork achieves higher productivity, requiring 0.2 to 0.25 man-hours per square meter due to its prefabricated modular components. In contrast, conventional formwork

requires 0.35 to 0.5 man-hours per square meter, reflecting a higher labor demand due to manual cutting, fixing, and dismantling processes. The quantity of work completed in a month is determined through quantity estimation. The number of laborers working each month and their average working hours are obtained from labor reports. These reports are updated daily, and a consolidated monthly labor report is prepared. Constraints affecting overall productivity are also documented. Productivity is measured in square meters per man-day. Productivity for Mivan and conventional formwork is calculated separately and tracked against target productivity set by company norms. For the Oberoi Realty project, the target productivity for conventional formwork is 2.5 sqm/man-day, while for Mivan formwork, it is 10 sqm/man-day.

5.1 Evaluation of labour productivity in conventional formwork

For the comparison of conventional formwork and Mivan formwork, we analyzed the construction plan from level 10 to level 23 for both systems. The study considered various parameters, including cost, activity duration, material types, and rates, along with different design aspects from the selected case studies.

Table 1: Productivity Calculation of Conventional Formwork

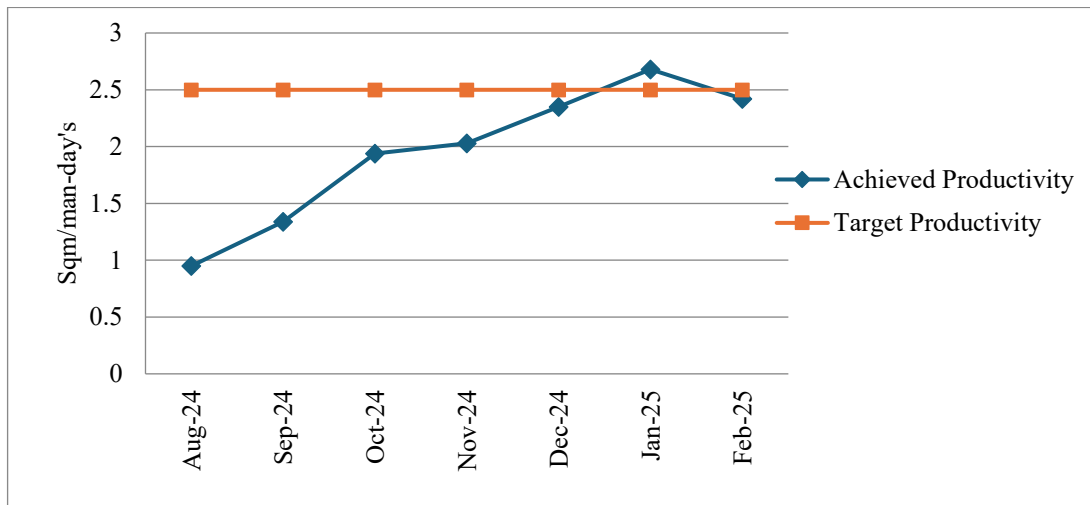
Sr. No.	Months	Qty of work done (sqm) per month A	Working hours per day B	No. of labours per month C	No of man-days per Month (1 manday's = 8hours) D	Productivity (P=A*D)
1	Aug-24	221	10	118	257.25	0.92
2	Sep-24	113	10	542	845.75	1.31
3	Ocr-24	2245	10	856	1185	1.92
4	Nov-24	5654	10	2154	2485	2.02
5	Dec-24	7845	10	2459	3311.5	2.32
6	Jan-25	7326	10	2012	2562.75	2.61
7	Feb-25	6598	10	2210	2458.5	2.41

Productivity for Mivan and conventional formwork was calculated separately and tracked against the target productivity set by company norms. For the Oberoi Realty project, the target productivity for conventional formwork is 2.5 sqm/man-day, while for Mivan formwork, it is 10 sqm/man-day. Labor productivity improves from 0.94 sqm/man-day (Aug 2024) to 2.61 sqm/man-day (Jan 2025), with peak output in December (7845 sqm) (see Table 1). Achieved productivity surpasses the 2.5 sqm/man-day target in January (see Figure 2), indicating efficient labor utilization and optimized construction processes.

Productivity in conventional formwork varies depending on the structural element it is used for. Formwork for columns achieves more repetition than that for beams and slabs. The deshuttering time for columns is 24 hours, whereas for slabs, it extends up to 28 days, despite

covering a larger area. A higher number of repetitions increases the quantity of work completed per month, thereby improving productivity. However, adverse weather conditions, such as rain, can delay construction activities. Equipment failures, including tower crane malfunctions, further contribute to productivity losses. These constraints ultimately reduce construction efficiency and extend project timelines.

Figure 2: Variation of Productivity in Conventional Formwork from Target Productivity (Oberoi Realty – H Tower)



5.2 Shuttering usage Ratio (SUR) in conventional formwork

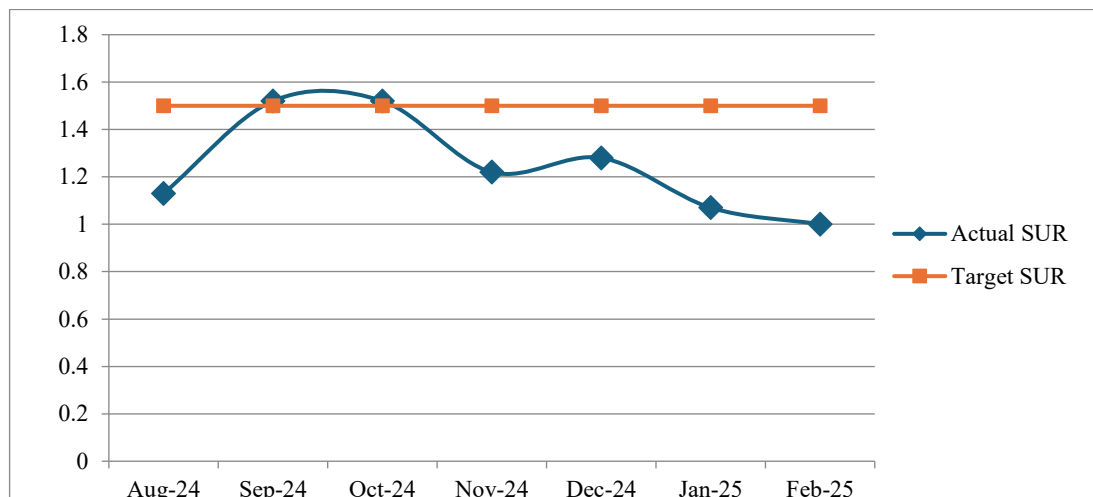
The shuttering usage ratio is defined as the ratio of the quantity of shuttering completed in a month to the total quantity of shuttering available for that month (see Table 2).

Table 2 : Shuttering Usage Ratio Calculation for Different Months in Conventional Formwork

Sr. No.	Month	Shuttering Quantity Available	Shuttering Quantity done	SUR
1	Aug-24	202	221	1.14
2	Sep-24	687	113	1.51
3	Oct-24	1543	2245	1.54
4	Nov-24	4692	5654	1.23
5	Dec-24	6187	7845	1.21
6	Jan-25	6758	7326	1.06
7	Feb-25	6402	6598	1.01

Table shows the variation in the shuttering usage ratio (SUR) for conventional formwork, which depends on the utilization of material per month. Shuttering material used for columns has the highest utilization, whereas slab areas cover a larger surface, leading to variations in SUR. Proper housekeeping, maintenance, and efficient material movement are essential to achieving the target SUR. If shuttering material remains idle for an extended period, the SUR decreases (see Figure 3).

Figure 3: Variation of Shuttering usage Ratio (SUR) from Target Productivity in Conventional Formwork (Oberoi Realty – H Tower)



The graph compares Actual SUR (Shuttering Utilization Ratio) with Target SUR from August 2024 to February 2025. The Target SUR remains nearly constant at around 1.5–1.54, indicating a planned utilization goal. The Actual SUR starts below the target in August 2024 (1.2), peaks around September–October 2024 (1.54), and then gradually declines, falling below 1.2 by February 2025. This suggests that while initial performance met expectations, there was a decreasing trend in utilization efficiency over time, potentially due to project delays, labor inefficiencies, or resource constraints.

5.3 Evaluation of labour productivity in Mivan formwork

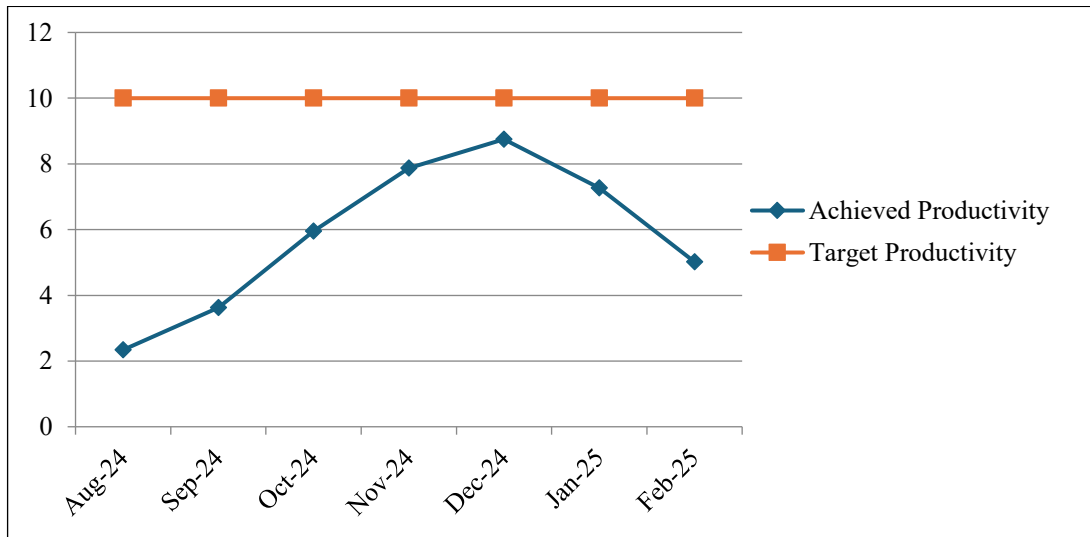
The productivity calculation is done (see Table 3) for Mivan formwork, and variation is determined from target productivity. The data shows a general increasing trend from August 2024 (2.33 sqm/man-day) to December 2024 (8.73 sqm/man-day), indicating improved efficiency. However, productivity declines in January (7.21 sqm/man-day) and February 2025 (5.01 sqm/man-day), possibly due to higher labor involvement without a proportional output increase (see Figure 4). This drop was primarily caused by the Brihanmumbai Municipal

Corporation (BMC) halting construction work in Borivali East and Byculla due to poor air quality, issuing stop-work notices to 78 sites and enforcing GRAP-4 guidelines.

Table 3: Productivity Calculation in Mivan Formwork

Sr. No.	Months	Qty of work done (sqm) per month A	Working hours per day B	No. of labours per month C	No of man-days per Month (1 manday's = 8hours) D	Productivity (P=a*d)
1	Aug-24	3120	10	1215	1247.55	2.33
2	Sep-24	7122	10	1596	1942.55	3.64
3	Ocr-24	19422	10	2452	3242.51	5.91
4	Nov-24	24301	10	2635	3010.05	7.84
5	Dec-24	31225	10	2756	3580.03	8.73
6	Jan-25	29012	10	3159	3946.02	7.21
7	Feb-25	16984	10	2704	3658.21	5.01

Figure 4: Variation of Productivity in Mivan Formwork from Target Productivity (Oberoi Realty – G Tower)



The variation in the productivity of Mivan formwork occurs due to several factors. Initially, productivity is low because time is required for setting out and aligning the formwork. As the number of floors increases, productivity improves due to the repetition of the same tasks. In this project, both towers have different start dates, which affects the overall productivity.

6.0 Method of Cubic Contents – Cost Analysis

The Cubic Contents Method is especially useful for determining the total volume of construction activity. The length, width, and depths of the building components are multiplied to give the total amount of that particular piece in this precise technique. In the case of surface plastering and other surfacing work, the total surface area is computed by multiplying the lengths by the breadth of the area to be worked on. The amount necessary to complete the work is calculated by multiplying the rate in terms of construction work by the entire quantity of work. This technology is more commonly utilized in the construction of multi-story buildings. This technology is more commonly utilized in the construction of multi-story buildings. It is more exact than the other two techniques of computation, the plinth area technique and the unit base approach.

6.1 Comparative cost analysis of mivan and conventional formwork

The comparison between conventional and Mivan (Alu-Form) construction highlights key structural differences while maintaining similar project parameters. Both use M35 grade concrete and identical steel reinforcement sizes (32mm, 25mm, 16mm, 10mm, and 8mm). However, Mivan walls (140mm & 160mm) are thinner than conventional walls (160mm & 230mm), enhancing material efficiency and carpet area. Slab thickness in Mivan varies (125mm, 150mm, 180mm), whereas it remains 150mm in conventional construction. Despite structural differences, both methods support a G+65 structure with 843.88 sq.m floor area, showcasing Mivan's material efficiency (see table 4). The cost comparison shows Mivan is ₹8,458,826 (0.122%) more expensive. While reinforcement and concreting costs are higher by ₹1.18 crore and ₹6.25 crore, it eliminates brickwork and plastering, saving ₹7.26 crore. Additionally, Mivan's formwork cost is lower at ₹41,100 due to 250 repetitions, compared to ₹4.65 lakh in conventional construction with just 10 repetitions (see table 5).

Table 4: Comparison of Items

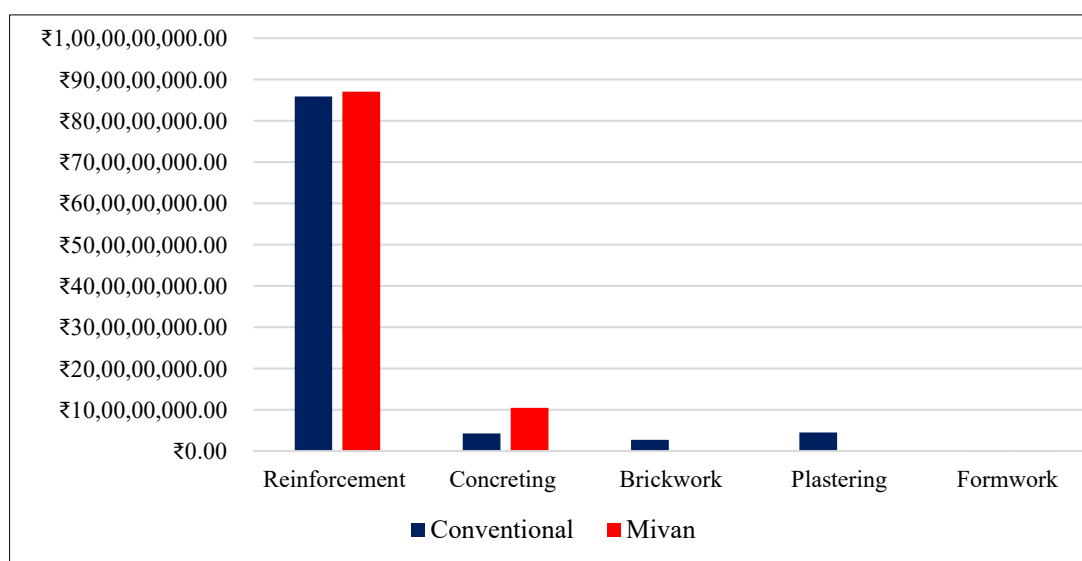
Sr. No	Content	Conventional	Mivan
1	Concrete Grade	M35	M35
2	Thickness of Wall	160mm, 230mm	140mm, 160mm
3	Steel	40mm ,32mm, 25mm, 16mm 10mm, 8mm	40mm ,32mm, 25mm, 16mm 10mm, 8mm
4	Slab	125mm, 150mm	125mm, 150mm,180mm
5	Number of floors	G+65 (L10-23)	G+65 (L10-23)
6	Floor Area	843.88 sq. m	843.88 sq. m

Reinforcement is the highest cost in both methods, with Mivan requiring slightly more due to its monolithic structure. Concreting costs are also higher in Mivan, as it integrates walls and slabs in a single pour.

Table 5: Cost Comparison between Conventional & Mivan Method

Sr. No	Particular	Conventional	Mivan	Cost Difference
1	Reinforcement	₹ 85,44,11,946.00	₹ 87,46,24,146.00	-₹ 20,212,200.00
2	Concreting	₹ 4,14,15,560.00	₹ 10,10,62,642.00	-₹ 59,647,082.00
3	Brickwork	₹ 2,74,73,752.00	₹ 0.00	₹ 2,74,73,752.00
4	Plastering	₹ 4,35,21,822.00	₹ 0.00	₹ 4,35,21,822.00
5	Formwork	₹ 4,45,982.00	₹ 41,100.00	₹ 404,882.00
	Formwork	(10 Repetitions)	(250 Repetitions)	
Total =				= -8,458,826.00
				0.122% Uneconomical by Mivan

Figure 5: Cost Comparison between Conventional and Mivan Formwork



A key difference is in brickwork and plastering, which are absent in Mivan due to its smooth aluminum formwork. Mivan has a high initial cost but is more economical, over 250 repetitions, compared to 10 in conventional formwork. Despite higher reinforcement and concreting costs, Mivan reduces labor-intensive activities, making it ideal for large-scale projects by improving speed and quality (see, Figure 5).

7.0 Result

The comparative analysis of conventional and Alu-Form (Mivan) formwork in high-rise construction provided significant insights into their efficiency, cost-effectiveness, and labor productivity. The study results indicate the following:

Labor Productivity: Mivan formwork demonstrated higher labor productivity, reaching up to 8.75 sqm/man-day compared to 2.68 sqm/man-day for conventional formwork. The increased productivity is attributed to the modular nature of Mivan, requiring fewer adjustments and skilled labor.

Construction Speed: The Mivan system enabled a faster slab cycle (5 to 7 days per floor), whereas conventional formwork required 10 to 14 days per floor. This acceleration in construction timelines leads to faster project completion.

Material Utilization: Mivan formwork showed a lower shuttering usage ratio (SUR) due to higher reusability (250 repetitions) compared to conventional formwork (10–20 repetitions). This reduced material waste and enhanced sustainability.

Cost Analysis: Despite the higher initial cost of Mivan formwork, the long-term benefits justified its application. The total cost difference between the two methods was minimal, with Mivan being only 0.122% more expensive. However, savings were achieved in labor, plastering, and brickwork costs.

Structural Quality: The Mivan system provided superior structural quality with better concrete finishes, eliminating the need for plastering. Conventional formwork required additional surface treatments, increasing labor and material costs.

8.0 Conclusions

The study concludes that while conventional formwork remains a viable option for small-scale and customized structures, Mivan formwork offers significant advantages for high-rise buildings due to its efficiency, labor productivity, and cost-effectiveness. The major conclusions drawn are:

- Mivan formwork reduces construction time and labor dependency, making it ideal for repetitive high-rise projects.
- Conventional formwork, although cheaper initially, results in higher long-term costs due to increased labor requirements and lower reusability.
- The initial investment in Mivan is justified by long-term benefits, including reduced wastage, higher productivity, and minimal surface treatment needs.

9.0 Recommendations

Adoption of Mivan formwork in high-rise projects: Due to its efficiency, developers should prefer Mivan technology for projects with repetitive floor layouts.

Training for skilled workforce: The transition to Mivan requires skilled labor for assembly and maintenance; therefore, workforce training programs should be implemented.

Cost optimization strategies: Contractors should optimize material procurement and reuse strategies to mitigate the high initial cost of Mivan formwork.

Hybrid approach: For projects requiring flexibility, a combination of both formwork systems could be considered, utilizing conventional formwork for complex designs and Mivan for repetitive elements.

Further research: Future studies can explore additional case studies and real-time tracking of labor efficiency across different project phases.

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CHAPTER 37

Comparative Study of Lean Tools to Reduce Wastage and Increase Efficiency in Residential Building

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ABSTRACT

This research assesses the comparative effectiveness of three construction methods—Conventional Method, Just-in-Time (JIT), and the Last Planner System (LPS)—in curbing waste and improving efficiency of manpower in residential construction projects. Based on a 1225 sq ft project site located in Satara district, Maharashtra, the study targets external plaster work in three bungalows, each adopting a different approach. The results indicate that the JIT approach performs far better than the rest, with minimal wastage of materials in cement and sand at 4.92% and 2.35% respectively. Furthermore, JIT showed the greatest labor efficiency, with masons at 85.7% and helpers at 66.67% for plaster work (actual work done as per lean construction method Vs theoretical value) and also proved to be the cheapest method with the total cost of the project at ₹66,300. The research focuses on the capability of lean tools, especially JIT, to maximize resource efficiency, reduce environmental footprint, and increase customer satisfaction through enhanced project performance. The research places a strong focus on the relevance of ongoing process improvement in reaching sustainable construction methods.

Keywords: Lean construction; Just-in-time; Last planner system; Waste reduction; Efficiency improvement.

1.0 Introduction

1.1 General

Lean construction is a strategic approach aimed at enhancing process quality and efficiency while minimizing waste in construction projects. By implementing lean principles, organizations can continuously improve processes throughout a project, applying lessons learned to subsequent endeavors. This approach reduces resource usage and construction time, subsequently lowering costs. Over time, cumulative improvements lead to better project outcomes. Lean construction enables teams to identify process inefficiencies and take proactive measures to enhance productivity and client satisfaction while minimizing environmental impact.

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Waste in construction projects, such as idle time, unnecessary transportation, and excessive material usage, can hinder progress and inflate costs without adding value to the client. Lean construction mitigates these issues by optimizing processes to reduce waiting times and improve personnel productivity, ultimately enhancing profitability. The concept of Kaizen, originating from Japan, emphasizes continuous improvement by systematically identifying and eliminating waste. Lean construction views improvement initiatives as investments that add value to customers. Importantly, employees directly involved in processes play a crucial role in driving continuous improvement, fostering a culture of proactive waste reduction.

Implementing sustainable building practices, such as renewable materials and energy-efficient designs, aligns with lean principles by minimizing environmental impact. Techniques like the 5S (sort, set, shine, standardize, shine) methodology improve workplace organization, enhancing safety and efficiency by reducing material wastage and ensuring quick accessibility to essential tools and resources. Reducing waste correlates with lower project costs, directly benefiting clients. Continuous process improvements enhance communication, minimize misunderstandings, and ensure timely project completion. Lean construction improves overall client satisfaction by delivering high-quality outcomes within set timelines.

1.2 Background

Lean production originated from Henry Ford's early 20th-century assembly line innovation, which streamlined labor processes to boost productivity and minimize errors. The Toyota Production System advanced this concept in the 1970s by focusing on customer value addition alongside waste reduction. Toyota's success, with peak profits exceeding \$15 billion, showcased the impact of lean manufacturing on profitability and global competitiveness. TOYOTA PRODUCTION SYSTEM is a structured approach emphasizing waste reduction and process consistency. Its four guiding principles include continuous improvement, just-in-time production, standardized work, and respect for people. This system has inspired industries globally to enhance quality and productivity while maintaining high employee engagement. In the 1990s, industry leaders such as W. Edwards Deming and Taiichi Ohno popularized lean manufacturing beyond production environments, expanding its application to customer service and product development. This evolution reflects the adaptability of lean principles in achieving strategic goals, such as cost reduction and quality improvement across various industries.

1.3 Need for study

Residential construction in rural and suburban regions faces significant challenges, including time and financial constraints, resource inefficiencies, and quality concerns. This study addresses these issues by implementing lean construction techniques to identify and eliminate waste in processes such as material handling, movement, and inefficient workflows. By fostering a culture of continuous improvement, we aim to optimize resource utilization, reduce costs, and enhance client satisfaction through timely and quality project delivery.

1.4 Research objective

- To identify the most suitable lean construction methods applicable to residential projects in rural and semi-urban areas.
- To evaluate and contrast particular lean construction tools according to how they affect cost savings, efficiency gains, and waste reduction.
- To identify the optimal lean construction tool for residential buildings that maximizes efficiency and cost-effectiveness while reducing waste.

2.0 Literature Review

The incorporation of Lean Construction methods has come to be recognized as an innovative way of optimizing efficiency, waste minimization, and optimal use of resources in the construction sector. Several studies have illustrated how the application of Lean principles enhances project performance through minimizing inefficiencies and continuous improvement. Nowotarski *et al.* (2019) highlighted the application of the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) cycle in wall masonry during the construction of the Pixel office buildings in Poznań. This approach led to a 50% reduction in waste and a significant increase in productivity, showcasing the scalability of Lean methods to other construction processes. Similarly, Jose *et al.* (2018) emphasized the role of the Last Planner System (LPS) in reducing construction waste and improving resource management. By minimizing workflow variability and optimizing process coordination, they demonstrated how Lean design results in better efficiency and balanced trade-offs between time and cost, ultimately streamlining project execution and reducing delays.

Further reinforcing the effectiveness of Lean methodologies, Kulgude *et al.* (2019) examined the impact of various Lean tools, such as the Production Display Method, Relative Importance Index (RII), Visual Management Production, and LPS, on material waste reduction and project duration. Their findings underscored the importance of RII in maximizing time management and material efficiency, reaffirming Lean's role in enhancing construction productivity. Likewise, Awad *et al.* (2021) explored Lean Construction principles in multi-story residential buildings in Pune, identifying key causes of waste through surveys, case studies, and literature reviews. They developed a Lean-based managerial framework to differentiate waste types and demonstrated that Lean methods are more effective than traditional project management approaches in improving efficiency, sustainability, and resource optimization.

The limitations of conventional project management methods have also been scrutinized in the context of dynamic construction environments. More *et al.* (2017) analyzed the shortcomings of the Critical Path Method (CPM) and proposed LPS as a superior alternative due to its advantages in coordination, planning, and stakeholder communication. They emphasized that training, risk assessment, and management support are critical for successful LPS adoption, leading to enhanced collaboration and improved project efficiency. Similarly,

Porwal *et al.* (2012) examined the challenges of implementing LPS for production control in construction projects. Despite its potential to stabilize workflow and improve plan reliability, they identified obstacles such as inadequate training, resistance to change, and leadership gaps. The study highlighted the need for structured training programs and strong leadership to overcome these barriers and enhance project performance.

In addition to improving efficiency, Lean Construction has been linked to sustainability and resource optimization. Waite *et al.* (2020) explored the relationship between Lean principles and sustainable practices, reviewing the current state of Lean adoption in construction alongside the influence of emerging technologies. While Lean's sustainability benefits are well-established in manufacturing, their application in construction is still developing. The findings suggested that Lean methods can enhance both sustainability and productivity, though further research is needed to maximize their effectiveness in the construction industry. Fauzan *et al.* (2019) also examined Lean Construction practices, focusing on methodologies such as Just-in-Time (JIT), LPS, Six Sigma, and 5S (sort, set, shine, standardize, shine) management in the Australian construction industry. Their survey of construction professionals in Sydney revealed a strong correlation between Lean adoption and improved project performance. They emphasized the importance of performance monitoring, management commitment, and standardized housekeeping practices to enhance Lean implementation, reinforcing its impact on waste reduction and overall project success. When taken as a whole, these studies demonstrate how adaptable Lean Construction methods are in tackling the difficulties the construction sector faces. Lean concepts have been successful in increasing productivity and resource use in a variety of contexts, from time management and waste reduction to sustainability and continuous improvement. These results provide a solid basis for more research into Lean techniques and how they could enhance performance in residential building projects

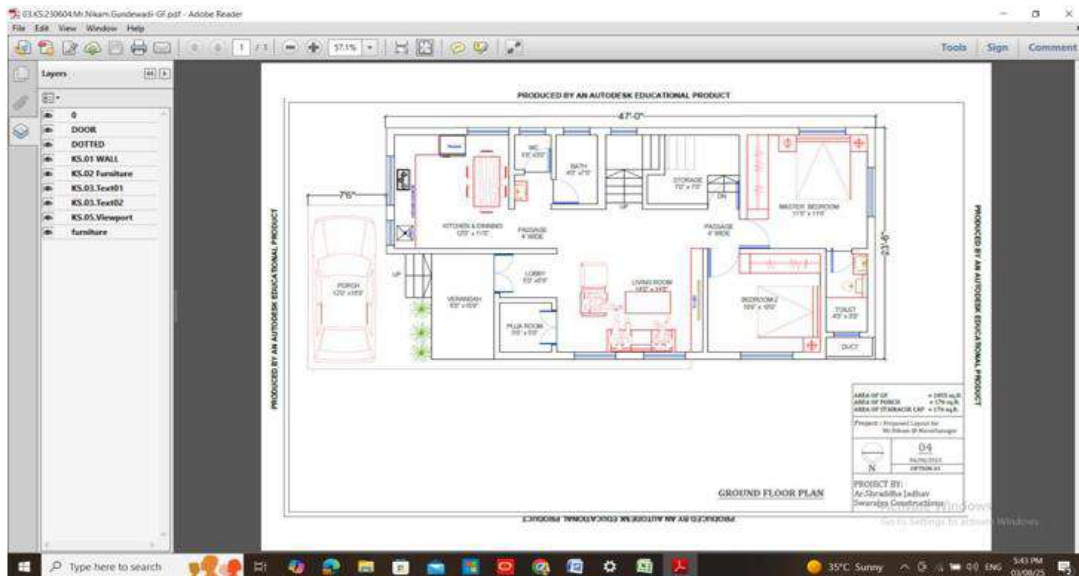
3.0 Research Methodology

This study employed observational methods and systematic data collection to assess waste management in construction activities, specifically plastering and flooring. Direct on-site observation enabled the identification of inefficiencies, material management issues, and best practices. Primary data was gathered through interviews with site supervisors and project managers, along with surveys and documentation of waste generated during activities. Secondary data focused on implementing Just in Time (JIT) and the Last Planner System (LPS) at a 1225 sqft site in Satara district, Maharashtra. Three bungalows were analyzed: conventional methods for Bungalow A, JIT for Bungalow B, and LPS for Bungalow C.

Key data points included theoretical vs. actual material and manpower usage, material wastage, manpower efficiency, and cost savings. A Fishbone diagram analysis identified root causes of inefficiencies. For JIT, issues included poor material quality, over ordering, and delayed deliveries. In LPS, challenges involved poor planning, miscommunication, and resource

misallocation. Addressing these factors highlighted the potential of Lean tools to improve efficiency and reduce waste.

Figure 1: Plan Building



Source: Compiled by author

4.0 Data Analysis

4.1 Site details

At actual site 1225 sqft located at CHITALI, Satara district in Maharashtra 415506. External plastering was executed using three distinct methods: the Conventional Method, JIT, and the LPS. The study focuses on comparing three lean construction methodologies—Conventional Method, JIT, “and the LPS—to identify their effectiveness in reducing waste and increasing efficiency in residential building projects.

Table 1: Material Wastage Analysis

Method	Theoretical Cement (Bags)	Actual Cement (Bags)	Cement Wastage (%)	Theoretical Sand (Bags)	Actual Sand (Bags)	Sand Wastage (%)
Conventional	30.5	35	14.75	170	185	8.82
Just-in-Time (JIT)	30.5	32	4.92	170	174	2.35
Last Planner (LPS)	30.5	34	11.48	170	180	5.88

Source: compiled by author

The research was conducted on a 1225 sq ft construction site located in Satara district, Maharashtra, where external plaster work was carried out using all three methods. The JIT method's minimal wastage underscores its efficiency in managing materials by ensuring delivery aligns with daily requirements, reducing the risk of overstocking and deterioration.

Table 2: Manpower Efficiency

Method	Theoretical Masons	Actual Masons	Mason Efficiency (%)	Theoretical Helpers	Actual Helpers	Helper Efficiency (%)	Scaffolder Efficiency (%)
Conventional	12	16	75	12	19	63.16	100
Just-in-Time (JIT)	12	14	85.7	12	18	66.67	100
Last Planner (LPS)	12	15	80	12	19	63.2	100

Source: compiled by author

JIT's superior manpower efficiency can be attributed to its real-time tracking system and daily task breakdown, which minimized idle time and optimized workforce utilization. The JIT method's cost-effectiveness is evident in its ability to reduce material overuse and optimize labor, despite slightly higher transportation costs due to multiple deliveries. The reduced material wastage in JIT not only cuts costs but also lessens environmental impact by minimizing waste disposal requirements. This aligns with sustainable construction goals. The study conclusively identifies the JIT method as the most efficient and sustainable lean tool for external plastering in residential buildings. Its ability to significantly reduce material wastage, improve labor efficiency, and lower overall project costs makes it the optimal choice over conventional and LPS methods. Implementing JIT in residential construction projects could lead to better resource management, cost savings, and environmental sustainability.

Table 3: Cost Implications

Method	Manpower Cost (₹)	Material Cost (₹)	Transport Cost (₹)	Total Cost (₹)
Conventional	35,400	33,050	2,800	71,250
Just-in-Time (JIT)	32,600	30,800	2,900	66,300
Last Planner (LPS)	34,300	32,140	2,800	69,240

Source: compiled by author

5.0 Conclusion

The study unequivocally proves that lean building equipment, namely the Just-in-Time (JIT) system, offers higher efficiency and sustainability in house building projects. JIT, through synchronization of material supply with work needs on a daily basis, reduces wastage to the

barest minimum, keeping cement wastage to 4.92% and sand wastage at 2.35%. Its hourly tracking facility and work division into daily tasks increase manpower effectiveness, with masons attaining 85.7% efficacy and helpers 66.67%, bettering the Conventional and LPS methods. Additionally, the cost analysis in total reinforces JIT as the most cost-effective method with a project cost of ₹66,300, illustrating its equilibrium between cost reduction and productivity. Apart from cost effectiveness, JIT's low environmental footprint via waste minimization is consistent with sustainable construction practices, making it the most appropriate for residential building projects. The research emphasizes continuous improvement, proper resource utilization, and active reduction of waste as key drivers towards high-quality construction results. The research promotes further application of lean principles, specifically JIT, across residential and other construction industries in order to optimize project efficiency, minimize environmental footprints, and maximize overall client satisfaction.

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CHAPTER 38

Comprehensive Review of BIM Integration for Advancing Circular Economy Practices in Construction

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ABSTRACT

The construction sector is a major contributor to the world's waste production and resource consumption, which emphasizes how urgently the linear economy (CE) model needs to give way. By enabling sustainable design, construction, and demolition practices, Building Information Modeling (BIM) has become a transformative tool that has the potential to ease this transition. This thorough analysis summarizes findings from 30 studies investigating how BIM can be integrated to support CE principles in the construction industry. Key BIM applications that support resource recovery, lifecycle assessment, waste reduction, and material efficiency are identified by the analysis. New developments emphasize the application of BIM for predictive waste analytics, deconstruction planning, and end-of-life material tracking. However, obstacles like a lack of standardized frameworks, a lack of stakeholder collaboration, and technological barriers prevent widespread adoption. In order to achieve sustainable construction practices, this study highlights the necessity of integrated strategies that combine BIM with circular design approaches, stakeholder engagement, and policy support. The results offer a road map for academic institutions and industry participants to fully utilize BIM's potential in promoting environmental sustainability, circular economy goals, and resource efficiency across the building lifecycle.

Keywords: Building Information Modeling (BIM); Circular Economy (CE); Sustainable construction; Waste minimization; Lifecycle assessment.

1.0 Introduction

These problems have been transformed by the concept of the Circular Economy (CE), which encourages recycling, reuse, and sustainable design of products as ways of reducing resource depletion. The construction sector is a global leader in waste generation and resource usage as it is founded mainly on a linear economic pattern based on the “take, make, dispose” approach. The model ends up in large quantities of waste materials, harm to nature, and poor management of resources.

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The key purposes of CE principles are reducing impacts on the environment, increasing the productivity of resources, and maintaining the longevity of materials. Applying the principles of the circular economy using BIM has fascinated the construction industry. It is made possible across the duration of a project through data-driven decision-making using BIM's digital representation of building elements and processes. The application of BIM together with CE principles improves procedures of deconstruction and reuse, traces material flows, and optimizes design. Nonetheless, BIM-CE integration research is in its early stages and is confronted with several challenges, including data interoperability, regulatory systems, and stakeholder engagement. The aim of this review is to provide a critical overview of the literature on utilizing BIM to enable circular economy practices in the construction sector. This paper summarizes the primary methods, challenges, and research areas for further investigation in this area based on a critical examination of thirty well-selected research articles. This study contributes to the ongoing discussion on sustainable building and the shift towards a circular economy by consolidating the body of existing literature and proposing potential directions for future innovation.

2.0 Research Objectives

- To assess the existing use of BIM in construction against the principles of the circular economy.
- To establish the principal benefits and challenges of implementing BIM to advance the principles of the circular economy.
- To examine the roles of BIM throughout the course of a life, such as design, construction, use, and end-of-life.
- To give a guideline for expanding BIM application in order to serve circular construction targets.

3.0 Literature Review

As the construction industry is among the largest generators of waste and carbon emissions globally, it is crucial that it be complemented by technologies addressing waste minimization, resource efficiency, and material recovery. In its implementation of CE practices, BIM—a computerized representation of an asset life cycle—is central to enabling decision-making, information sharing, and predictive modeling. Studies prove how BIM can maximize resources, handle end-of-life (EOL) processes, and reduce construction waste. Predictive material recovery and reuse are enabled by stakeholders' capacity to anticipate waste generation in the early design stage due to predictive modeling integrated into BIM platforms such as Adaptive Neuro-Fuzzy Inference Systems (ANFIS). BIM also facilitates ease of collaboration between contractors, architects, engineers, and material suppliers, coordinating decision-making

for optimization of resources and minimization of waste. Despite these benefits, several barriers to extensive use of CE principles in BIM exist, including a lack of adequate waste management databases and standards. Existing solutions are often incomplete frameworks with limited interoperability, thus restricting their potential to leverage the full capabilities of BIM in circularity. BIM is an essential tool for enhancing CE practices due to its ability to document, visualize, and assess materials. In summary, BIM holds much potential for embedding CE principles within the construction processes, but more research needs to be undertaken in order to overcome organizational and technological challenges. Attaining a circular construction model is going to involve enhancing the ability of BIM and promoting stakeholder collaboration.

4.0 Research Methodology

This review paper utilizes a systematic method to bring together and critically analyze the means through which circular economy (CE) and building information modeling (BIM) converge in the construction industry. The aim of the methodology is to critically look into, group, and analyze the findings of 30 precisely selected research papers. The approach is explained in steps below:

- *Selection of Literature:* 30 peer-reviewed journal articles and conference proceedings make up the review, which is centered on studies for BIM application and CE practice in construction. The articles were selected according to their quality, relevance, and suitability to the objectives of the study. Keywords such as “building information modeling,” “circular economy,” “construction waste management,” and “material reuse” were employed to search the literature.
- *Thematic Categorization:* The selected studies were categorized using key themes like lifecycle analytics, material recovery, waste prediction and reduction, BIM for end-of-life (EOL) management, and collaborative methods. This thematic categorization enabled a focused analysis of how BIM supports various aspects of CE implementation.
- *Critical Analysis and Integration:* Important observations about the technologies, tools, and methods applied to integrate BIM with CE principles were drawn from every study through analysis. Comparison analysis was conducted to find out the gaps, challenges, and progress in the sector. Special focus was laid on how BIM assists with stakeholder coordination, predictive modeling, and waste minimization.
- *Framework Development:* Grounded in the integration of literature, a conceptual model is presented to guide the incorporation of BIM into CE practice in the construction sector, and the optimal BIM uses and their conformance to CE purposes and call for additional research and development.
- *Validation through Expert Feedback:* Experts in BIM and sustainable construction examined the results and suggested a framework to confirm the conclusions’ precision, applicability, and relevance.

- *Reporting and Interpretation:* The results were collated into a coherent narrative to provide readers with a comprehensive understanding of how BIM promotes circular economy principles. The research captures significant concerns, fresh advances, and practical recommendations for future study and practice.

The essay makes a contribution to the knowledge base regarding the integration of CE practices and BIM in the building sector through a systematic methodology that ensures extensive and credible analysis.

5.0 Data Analysis

A survey on BIM integration with the circular economy and qualitative values will be employed to gather vital information regarding the industry's knowledge, adoption, and challenges in encouraging BIM in circular economy practice.

Familiarity with BIM and the Circular Economy

- 44.4% of those interviewed are relatively well-informed about BIM, while 16.7% have no idea about it
- 30.6% of the participants knew enough about the circular economy to manage, and 22.2% knew much about it.
- Though BIM's well-proven benefits, not a lot is known about how effective it can be when incorporated with circular economy principles.

Construction Sustainability

- 27.8% of the respondents consider sustainability to be very important, and 30.6% consider it highly important.
- While a large part of the industry accepts sustainability as an important aspect of problem-solving, it sometimes suffers from having problems applying such practices.
- 47.2% of the respondents agree that construction works are enhanced by the combination of BIM with circular economy principles.

Barriers to the effective application of BIM in the circular economy

- The largest obstacle, as seen by 44.4% of participants, is lack of time.
- Twenty-two percent of the participants mentioned limited knowledge and cost limitations as problems.
- Beyond doubt, the effective use of BIM for sustainability purposes is still hindered by the absence of expertise.

Cutting down on material waste techniques

- Amongst those polled, 52.8% recommended material recycling and reuse as a common facility waste reduction method.

- In spite of the fact that site waste management regulations are adopted in 50% of all cases, it has been established that only 38.9% of the respondents complied with them after becoming aware of them.
- BIM proves useful in material management, 36.1% of respondents said, and extremely useful, 38.9% said.
- 33.3% of the respondents acknowledged knowing Life Cycle Assessment (LCA), showing a moderate level of familiarity with it.

Blending aesthetics with structural integrity

- 66.7% prioritize durability and structural strength before visual appeal.
- Despite the adoption of green accredited construction practices, one of the biggest IGBC Platinum rated projects in Mumbai has experienced its initial level of sustainability going down in a matter of months, requiring improved material choices.
- Interviews and case studies have revealed that a sole focus on aesthetics can jeopardize durability over time and project cost.

Other industry opportunities for BIM implementation

- Out of the people polled, 41.7% believe that the construction sector will likely adopt BIM with circular economy principles within the next five to ten years, and 30.6% are neutral.
- Other reasons given to support the use of BIM by the respondents are enhanced awareness about benefits related to sustainability, reported by 66.7% of respondents.
- 52.8% of the respondents mentioned skill improvement and training.
- 47.2% of respondents proposed government regulations and incentives.

5.1 Key observations

- *Structural durability problems:* Even though they are certified sustainable, the lifespan of the structures has allegedly been reduced by approximately 35%, and wear has started to show on these built structures.
- *Cost-quality:* Excessive elevation overrun (20% of project cost) led to loss of quality in one research setting. Lowering elevation costs to 5–7% and enhancing material quality would be an improved trade-off.
- *Project waste reduction methods:* In the aspect of material waste management, Mivan shuttering and ready-mix plastering operations have proven effective.
- *Focus shift on project planning:* Project Managers interviewed indicated that the emphasis of project planning has shifted from aesthetics to structural integrity due to complaints of poor quality from clients.
- *Decisions with BIM:* The process of utilizing BIM itself would improve lifecycle analysis, enabling separation of various building elements on the basis of importance to make greener decisions.

5.2 Key learnings

- *BIM training and awareness are important:* The ability of BIM to solve problems related to the circular economy can be undermined by training and awareness among BIM practitioners and scholars because of a lack of technical skills and awareness.
- *Selection of early design sets will change lifecycle performance:* Product durability must be the priority for projects in terms of design set selection to enhance service life and reduce repair costs.
- *Perhaps it will perform more effectively if done more frequently:* Techniques such as ready-mix plaster, prefabricated assemblies, and computerized design systems will promote such increased utilization efficiency.
- *Lifecycle assessment must be integrated into BIM workflows:* More frequent use of LCA in BIM would enhance material selection and design sustainability.
- *Regulatory and incentives support would drive adoption:* Government incentives have to consist of a common code for sustainability as well as a rational material taxonomy to allow extensive application by practitioners for most uses of BIM within circular economy methods.

This study demonstrates how BIM can be an integral part of sustainable construction with greater awareness, industry-wide training, and improved regulatory support.

6.0 Conclusion

How Building Information Modeling (BIM) can enhance circular economy (CE) practices and transform the construction industry is emphasized in this study. As per the principles of CE, BIM presents a robust digital platform that makes material optimization, waste minimization, and life cycle analysis easier. Through collaborative platforms, end-of-life (EOL) management features, and predictive modeling software, BIM allows stakeholders to make informed decisions that ensure resource efficiency and sustainability. Despite its promise, barriers such as a shortage of standardization, poor databases, and poor stakeholder awareness have hindered the complete implementation of CE principles in BIM workflows. Practical implementation in real projects is lacking, even though many studies provide theoretical frameworks and pilot tests. More robust legislative frameworks and regulatory incentives are also required to support the widespread use of BIM for circularity.

The findings emphasize the importance of advanced BIM-compatible tools that utilize CE principles such as lifecycle analytics, material recovery analysis, and computational waste prediction. It will take stakeholder coordination, supported by BIM's centralized abilities, to overcome construction industry fragmentation and achieve shared sustainability objectives. In conclusion, BIM is essential in enabling CE practices within the building sector. As technology advancements, governmental support, and stakeholder participation increase, BIM can help transform the building sector into a circular and sustainable one. Future studies should focus on

overcoming existing barriers and developing scalable, feasible solutions to implement CE principles effectively into BIM processes.

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CHAPTER 39

Comprehensive Review on Infrastructure Project Delays

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ABSTRACT

Infrastructure projects are vital for fostering economic growth and societal progress. However, delays in these projects are a recurring challenge, often leading to substantial cost overruns, compromised quality, and missed deadlines. This paper highlights the key factors contributing to project delays and explores effective mitigation strategies to enhance construction project delivery. The study involves a comprehensive review of research papers analyzing delay causes, with the literature systematically categorized for comparative analysis. Tackling these challenges requires a deep understanding of their root causes, consequences, and viable solutions to improve project efficiency. The research focuses on identifying the primary delay factors, their effects on cost, quality, and timelines, and proposing practical measures to address them. Data was gathered through a review of project reports, research papers, and relevant literature. Findings indicate that the leading causes of delays include inadequate project planning, financial constraints, inefficiencies among contractors, and regulatory challenges. These delays result in higher costs, reduced quality, and public dissatisfaction. Additionally, the paper highlights gaps in previous studies and outlines future research directions to address the fundamental causes of construction project delays.

Keywords: Construction delay; Delay causes; Infrastructure projects; Mitigation strategies; Project planning.

1.0 Introduction

Infrastructure projects are vital for economic development, urban expansion, and societal advancement (Baporikar & Neeta, 2016). However, project delays remain a persistent challenge, leading to cost overruns, legal disputes, and negative socio-economic impacts (Sunjka *et al.*, 2015). Various factors contribute to these delays, including poor project planning, financial constraints, inefficient risk management, regulatory hurdles, and unforeseen site conditions (Agyekum-Mensah *et al.*, 2017). Delays in infrastructure projects not only affect contractors and stakeholders but also hinder national economic growth by delaying essential public utilities like transportation networks, energy supply, and water distribution systems (Ameyaw *et al.*, 2013).

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Understanding the causes and mitigation strategies for infrastructure project delays is crucial for enhancing efficiency in project execution (Adebanjo & Michael, 2024). The construction industry has adopted several project management methodologies, including Critical Path Method (CPM), Building Information Modeling (BIM), Lean Construction, and Integrated Project Delivery (IPD), to minimize delays (Sepasgozar *et al.*, 2019). However, issues such as inadequate stakeholder communication, bureaucratic approvals, labor shortages, and technological adaptation challenges persist. Additionally, recent advancements like Artificial Intelligence (AI) for predictive analytics, blockchain for contract management, and digital twins for real-time monitoring offer promising solutions, but their implementation is still evolving. Despite these technological advancements, many projects continue to suffer delays due to systemic inefficiencies and resistance to change (Waddell & Steve, 2017).

Several studies over the last five years have analyzed infrastructure project delays and their impact on the construction industry (Wang *et al.*, 2017). Delays in transportation projects (Alkharashi & Bassam, 2020) highlight financial mismanagement as a critical factor (Ssimbwa & Edward, 2023). Public infrastructure project delays (Singh *et al.*, 2021) emphasize bureaucratic inefficiencies and corruption (Ssimbwa & Edward, 2023). Risk assessment models for construction delays (Zafar *et al.*, 2022) propose AI-driven frameworks for delay prediction (Bodrunnessa *et al.*, 2025). The impact of digital project management tools (Rahman *et al.*, 2023) finds that BIM integration reduces project delays by 18%. Labor shortages and their effect on the post-pandemic workforce crisis (Kassem *et al.*, 2023).

Effectiveness of alternative dispute resolution (ADR) methods (Kumar & Patel, 2023) in mitigating contract-related delays. Role of government policies (Fernando *et al.*, 2021) in shaping infrastructure project timelines (Kalogeraki *et al.*, 2024). These studies highlight the need for better project planning, risk management, and the integration of digital solutions to mitigate delays (Egwim & Nnaemeka, 2024). Despite numerous studies on infrastructure project delays, significant gaps remain in understanding the effectiveness of modern technological interventions, data-driven decision-making, and real-time monitoring in delay mitigation (Psarommatis *et al.*, 2024). Most studies have either focused on conventional delay factors or industry-specific causes but lack comprehensive frameworks integrating new advancements (Ekhlasi & Tahmineh, 2024).

Additionally, existing literature provides limited empirical evidence on the long-term impact of digital project management tools on minimizing delays. This study aims to highlight this gap by exploring a holistic approach combining traditional delay mitigation strategies with emerging technologies (Gbahabo *et al.*, 2017). The primary objectives of this study include Identifying key factors contributing to infrastructure project delays and the effectiveness of emerging technologies in delay prevention (Nikolov & Aleksandar, 2022). The research adopted data collection through use of research papers/reports & documented cases with increasing investment in infrastructure globally, minimizing project delays is critical for economic stability and investor confidence (Queirós *et al.*, 2017). While this study provides a comprehensive

analysis, it has certain limitations, including reliance on secondary data (Gbahabo *et al.*, 2017). Nonetheless, the research will offer valuable recommendations for reducing infrastructure project delays and improving overall project delivery efficiency (Attah *et al.*, 2024).

In conclusion, infrastructure project delays are a significant global issue requiring systematic solutions (Larsen *et al.*, 2016). This study aims to fill critical knowledge gaps and offer strategic recommendations for minimizing delays through innovative project management approaches and technology-driven solutions (Gbahabo *et al.*, 2017).

2.0 Literature Review

Delays in infrastructure projects have long been a critical issue in the construction industry, impacting cost, schedule, and quality (Doloi *et al.*, 2012). Several studies have examined the causes, consequences, and mitigation measures associated with project delays. This chapter provides a comprehensive literature review, structured into key sections: the current scenario of delays, major causes, and possible remedies. The review highlights the growing concern over project overruns and concludes with the necessity of this research.

2.1 Current scenario of project delays

Infrastructure project delays are a global challenge. Several studies have documented the persistent issue of project time overruns in different countries, emphasizing their adverse economic and social impacts (Flyvbjerg & Bent, 2008). Doloi *et al.* (2001) analyzed delays in Indian construction projects and identified poor commitment and financial constraints as major factors, with inefficient site management further exacerbating the issue. Flyvbjerg *et al.* (2003) examined cost overruns in megaprojects and found that inaccurate initial forecasts often lead to severe schedule deviations, affecting overall project feasibility. Alaghbari *et al.* (2007) conducted research in Malaysia and found that improper planning and weak contractor performance were key contributors to project delays. Sambasivan & Soon (2007) highlighted that contractor-related problems, material shortages, and labor inefficiencies significantly affect project timelines, making them a major challenge in infrastructure development. Williams (2003) studied the impact of project delays on feasibility and cost in large-scale projects, showing that overruns often lead to financial strain and contractual disputes. The increasing frequency of project delays underscores the need for deeper analysis into their root causes, which is discussed in the next section.

2.2 Causes of project delays

Several factors contribute to construction project delays, categorized into contractor-related, consultant-related, and external factors. Koushki *et al.* (2005) found that financial issues and cash flow constraints among contractors lead to significant delays in project execution. Iyer & Jha (2006) emphasized that poor project management, lack of coordination, and ineffective

decision-making often result in inefficiencies in execution. Frimpong *et al.* (2003) identified contractor incompetence and improper scheduling as critical delay-inducing factors in infrastructure projects. Chan & Kumaraswamy (1997) revealed that frequent design changes and slow decision-making by consultants significantly delay construction progress. Love *et al.* (2000) found that poor communication between consultants and contractors further worsens time overruns, creating inefficiencies in project execution. Arditi *et al.* (1985) noted that inadequate contract administration is another major bottleneck, leading to prolonged disputes and increased costs. Al-Momani (2000) examined delays in public projects and found that unpredictable weather conditions significantly affect construction schedules, leading to time overruns. Ogunlana *et al.* (1996) studied the impact of regulatory delays and bureaucratic inefficiencies, showing that government policies can be a major hindrance to project completion. Kaming *et al.* (1997) concluded that inflation and material price fluctuations lead to severe cost and time overruns, increasing project risk.

2.3 Possible remedies to mitigate delays

Numerous studies suggest different strategies to reduce delays and improve efficiency in infrastructure projects.

2.3.1 Improved project planning and management

Ogunlana *et al.* (2003) recommended implementing efficient project planning techniques, such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), to ensure better time management. Rahman *et al.* (2017) emphasized the importance of proactive risk management in project planning to mitigate unforeseen disruptions. Smith and Wilkins (2020) suggested adopting Building Information Modeling (BIM) to enhance coordination and reduce miscommunication among project stakeholders.

2.3.2 Enhancing financial management and cash flow control

Koushki & Kartam (2004) proposed financial risk management frameworks to help contractors maintain better cash flow and avoid financial constraints that cause delays. Mahamid *et al.* (2012) emphasized proper cost estimation and budgeting techniques to prevent cost overruns that lead to project stagnation. Cheng *et al.* (2019) examined the role of financial incentives and early payment systems in improving contractor performance.

2.3.3 Efficient communication and stakeholder collaboration

Love *et al.* (2004) recommended improving communication channels between contractors, consultants, and clients to reduce conflicts and delays caused by misunderstandings. Nguyen *et al.* (2018) highlighted the significance of real-time data sharing and collaborative platforms to ensure all stakeholders are well-informed throughout the project lifecycle. Azhar *et al.* (2012) suggested integrating digital communication tools, such as cloud-based document

management, to improve project documentation and tracking. Zhao *et al.* (2016) explored the use of Artificial Intelligence (AI) and machine learning to optimize project scheduling and identify potential risks early. Patel (2021) examined how automation in material tracking and workforce management helps in reducing inefficiencies and improving overall productivity. Alaloul *et al.* (2020) advocated for the adoption of drones and IoT-based monitoring systems to track project progress in real-time and prevent potential delays.

2.3.4 Regulatory and policy interventions

Tanaka (2014) emphasized the need for streamlined approval processes and reduced bureaucratic hurdles to minimize delays in government infrastructure projects. Kumar and Maheshwari (2015) proposed regulatory reforms that encourage transparency in contract allocation and dispute resolution mechanisms. Olatunji *et al.* (2016) examined the role of stable government policies and financial backing in ensuring the timely completion of infrastructure projects. The literature review highlights that infrastructure project delays result from multiple interrelated factors, including financial constraints, project mismanagement, and external influences. While various strategies have been suggested to mitigate delays, the persistence of this issue indicates the need for further research. This study aims to bridge the gaps in existing literature by providing a detailed analysis of delay factors in infrastructure projects and proposing effective solutions based on real-world case studies. The findings of this research will help improve project management practices and minimize the risks of project delays.

Table 1: Key Findings from Literature Review

Key Factors for Project Delays	References					
	[16]	[25]	[43]	[28]	[3]	[10]
Lack of communication	✓	✓	✓		✓	
Resource shortages	✓		✓	✓		✓
Poor project planning	✓	✓	✓	✓	✓	✓
Weather conditions	✓			✓		✓
Financial constraints	✓	✓		✓	✓	
Regulatory approvals	✓	✓	✓	✓	✓	✓

3.0 Results and Discussion

The findings of this study align with previous research, highlighting the persistent challenges faced in construction projects due to delays. One of the most significant factors identified is poor project planning and scheduling, which has been extensively discussed in the literature, including the study by Karunakaran (2019). In the analysis, it was observed that inadequate scheduling and lack of coordination among stakeholders contributed to significant project overruns. Additionally, inefficient site management and lack of commitment emerged as critical issues, supporting the findings of Doloi *et al.* (2001), who emphasized that ineffective

supervision and weak managerial oversight result in project disruptions and missed deadlines. Another major cause of delay identified in both the literature and our study is financial constraints, particularly delays in contractor payments. According to the research conducted by Bagrecha (2017), financial mismanagement and cash flow problems are among the top reasons for construction delays. Our study corroborates this by revealing that late payments to contractors not only slow down work but also create a cascading effect that impacts material procurement, labor wages, and overall project progress. Similarly, labor shortages and subcontractor inefficiencies were found to be crucial delay factors, supporting the study by Mbuyamba Mbala Jean Paul, which emphasized that insufficient skilled labor and unreliable subcontractors significantly affect construction timelines.

By linking the findings to previous research, it is evident that these delay factors are not isolated incidents but recurring challenges in the construction sector. The consistency between the study and existing literature highlights the urgent need for systematic project management practices, improved financial planning, and better regulatory oversight to mitigate delays. Addressing these issues through strategic interventions, such as stricter compliance with project schedules, financial discipline, and workforce planning, can significantly improve project delivery timelines (Ahuja *et al.*, 1994). The findings of this study reinforce the objectives set at the beginning of the research, establishing a strong connection between the identified causes and the necessity for more structured project execution methodologies.

4.0 Conclusion

Delays in construction projects remain a significant challenge, leading to cost overruns, legal disputes, and inefficiencies in project execution (Samarghandi *et al.*, 2016). This study aimed to identify the key factors responsible for delays and assess their impact using insights from both literature and empirical findings. Through a thorough review of past research and our own analysis, we have found that poor project planning, inefficient site management, financial constraints, and labor shortages are among the most critical contributors to delays. Studies by Hemanta Doloi *et al.* (2001) and Karunakaran (2019) emphasized that inadequate scheduling and lack of commitment are major factors affecting project timelines, a trend that was evident in our findings as well. Furthermore, financial issues, particularly contractor payment delays, were consistently highlighted in previous studies such as those by Bagrecha (2017), which aligns with our observation that cash flow problems significantly hinder project progress (61). Review findings reinforce the objectives set at the beginning of the research, as authors aimed to identify the root causes of construction delays and their impact on project completion. The study successfully establishes that these delays stem from systemic inefficiencies, which can be mitigated through improved project planning, financial management, and better coordination among stakeholders. The alignment of review results with existing literature further strengthens the validity of our study, demonstrating that these issues are not isolated but rather industry-

wide challenges that require urgent attention. Looking ahead, future research should focus on developing predictive models for delay mitigation, incorporating advanced project management technologies such as Building Information Modeling (BIM) and artificial intelligence-driven scheduling tools. Additionally, policy interventions should be considered to enforce stricter compliance with project deadlines, ensure timely payments to contractors, and promote skill development programs to address labor shortages. The adoption of these strategies can significantly reduce delays and enhance the efficiency of construction projects, ultimately leading to a more sustainable and well-managed industry.

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CHAPTER 40

Construction and Demolition Waste Management

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ABSTRACT

Urbanization has resulted in accelerated construction activities, which stimulate economic growth while also increasing environmental stress, especially by creating Construction and Demolition (C&D) waste. The sources, amount, and management processes of C&D waste are analyzed in this study with a focus on the hindrances in effective recycling and the influence of policy, technology, and budget allocation on increasing sustainability. Using a mixed- method research strategy, the study gathered primary data using a questionnaire survey of 100 stakeholders, namely municipal officials, construction professionals, and environmental experts, and secondary data from literature reviews, case studies, and policy reports. A visit to the PCMC C&D Waste Management Plant in Moshi offered first-hand insights into waste recycling and processing operations. The surveys point out that plastic waste forms 33 percent and concrete debris 27 percent of C&D waste and shows wide variations in recycling figures of different projects. The major and most frequently cited and severe hindrances were scarcity of recycling facilities (36 percent), regulation barriers (23 percent), and high recycling costs (16 percent). The study gives evidence toward better and efficient waste management and strategies such as enhanced stakeholders' awareness, technology adaptation, and policy and regulatory interventions. By filling the gap between conceptual frameworks and reality on the ground, this study provides practical advice to foster sustainable urban development, minimize environmental footprint, and enhance regulatory compliance for C&D waste management.

Keywords: Construction and demolition waste; Recycling; Sustainability; Urbanization; Waste management.

1.0 Introduction

Urbanization drives rapid construction activity, leading to significant economic growth but also posing environmental and infrastructural challenges. Construction and Demolition (C&D) waste, a major component of urban solid waste, exacerbates issues like resource depletion, pollution, and landfill overflow.

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Despite existing regulations, inefficient waste management practices persist due to poor recycling rates, outdated infrastructure, and limited adoption of advanced technologies like AI and IoT. This study aims to identify key factors influencing C&D waste generation, evaluate current waste management strategies, and explore how policy, cost control, and technology can enhance sustainability in urban construction projects. The research addresses critical questions regarding the sources and volume of C&D waste, challenges in recycling, and the impact of budgets, regulations, and technology on waste management. By bridging the gap between theoretical models and practical implementation, this study provides data-driven insights and recommendations to improve waste management practices. Ultimately, the findings aim to reduce environmental impact, enhance regulatory compliance, and promote sustainable urban development.

1.1 Objectives

The research objectives of this study are to analyze the volume and sources of Construction and Demolition (C&D) waste generation across various project types, evaluate current recycling and waste management practices while identifying barriers and cost-effective strategies, and assess the impact of regulatory compliance, budget allocation, and technological adoption on sustainable C&D waste management. By addressing these objectives, the study aims to provide actionable insights and recommendations to enhance waste management practices, promote sustainability, and support the development of environmentally responsible urban construction projects.

2.0 Literature Reviews

The literature review highlights the growing focus on Construction and Demolition (C&D) waste management, driven by urbanization and sustainability concerns. Elshaboury *et al.* (2022) conducted a bibliometric analysis of C&D waste management research, identifying key trends and gaps, such as estimation techniques, environmental impacts, and emerging technologies. Similarly, Islam *et al.* (2024) reviewed sustainable C&D waste management challenges, emphasizing the need for integrated frameworks, stakeholder engagement, and technology adoption.

Srećković *et al.* (2024) explored circular economy (CE) applications in the building life cycle, revealing gaps between theory and practice in the Architecture, Engineering, and Construction (AEC) industry. Hasibuan *et al.* (2025) investigated CE integration in C&D waste management, highlighting the potential of digital tools like Building Information Modeling (BIM) and Life Cycle Assessment (LCA) while noting challenges such as high costs and policy inconsistencies. Gherman *et al.* (2023) provided a comprehensive review of C&D waste management within the CE framework, identifying research gaps in economic and social evaluations.

Swarnakar & Khalfan (2024) analyzed CE adoption in C&D waste management, emphasizing the lack of structured frameworks and the need for advanced technologies and decision-support systems. Purchase *et al.* (2021) identified legal, technical, and economic barriers to CE adoption, advocating for global frameworks to support sustainable practices. Zhao *et al.* (2022) examined C&D waste management in Australia, highlighting the role of design-phase interventions and cross-jurisdictional challenges. Colorado *et al.* (2022) focused on Colombia, revealing knowledge gaps and inefficiencies in C&D waste management common across developing nations.

Gayakwad *et al.* (2015) addressed India's C&D waste challenges, stressing the lack of regulatory enforcement and the need for sustainable waste hierarchies. Ray *et al.* (2024) quantified C&D waste disposal during COVID-19 using satellite imagery, offering a framework for indirect waste estimation. Abulebdah *et al.* (2024) proposed an integrative approach for optimizing C&D waste management in developing countries, demonstrating significant cost savings through GIS and optimization models. Mukherjee *et al.* (2023) reviewed C&D waste management in India, emphasizing the need for uniform regulations and sustainable practices. Alhawamdeh *et al.* (2024) used the PESTLE framework to analyze drivers for improved C&D waste management, highlighting the role of policy, technology, and stakeholder engagement.

Wei (2024) explored advanced management techniques to improve recycling efficiency and reduce carbon emissions, emphasizing government incentives and BIM. Huanyu Wu *et al.* (2019) reviewed performance assessment methods for C&D waste management, noting the underrepresentation of social factors in evaluations. Menegaki (2018) examined global C&D waste challenges, proposing a conceptual map to address systemic issues. José-Luis Gálvez-Martos *et al.* (2018) highlighted best practices in Europe, advocating for waste reduction, improved recycling, and enhanced secondary material quality. Ma *et al.* (2020) identified challenges in China's C&D waste recycling, including unstable waste sources, high costs, and poor coordination, offering policy recommendations for improvement.

3.0 Research Methodology

The research methodology combined qualitative and quantitative approaches to study Construction and Demolition (C&D) waste management. Primary data was collected through a questionnaire survey of 100 stakeholders, including municipal authorities, waste professionals, and construction experts. Secondary data was gathered from literature reviews, case studies, and policy documents. An on-site visit to the PCMC C&D Waste Management Plant in Moshi provided practical insights into waste processing and recycling. The systematic process included problem identification, literature review, survey design, data collection, analysis, and recommendations, offering a comprehensive understanding of C&D waste management challenges and solutions.

4.0 Data Analysis

The data analysis section examines the responses collected from 100 stakeholders involved in Construction and Demolition (C&D) waste management. It highlights key trends, challenges, and opportunities in waste generation, recycling practices, and barriers to effective waste management.

Table 1: How Many Years of Experience Do You Have in the Construction Industry?

		Frequency	Percent
Valid	Less than 2 years	17	17.0
	2–5 years	32	32.0
	6–10 years	34	34.0
	More than 10 years	17	17.0
	Total	100	100.0

Source: Compiled by authors

Table 2: What Type of Construction Projects do You Primarily Work on?

		Frequency	Percent
Valid	Residential	19	19.0
	Commercial	20	20.0
	Industrial	41	41.0
	Infrastructure (roads, bridges, etc.)	20	20.0
	Total	100	100.0

Source: Compiled by authors

The data shows construction professionals' experience levels. Many mid-career professionals work in the area, as 34% have 6–10 years of experience. This is followed by individuals with 2–5 years of experience (32%), indicating a continual migration of fresher professionals. Early-career professionals with less than 2 years of experience and highly experienced professionals with more than 10 years each make up 17% of the sample. This fair distribution shows that a combination of new and experienced personnel helps the sector thrive and survive. Industrial construction projects dominate the industry, with 41% of respondents being involved. Commercial and infrastructural projects employ 20% of the workforce, demonstrating a balanced approach to large-scale undertakings. Residential development accounts for 19% of replies, indicating a reduced housing project priority. The industry's focus on industrial development while being active in commercial, infrastructural, and residential sectors boosts economic growth and urban expansion.

Table 3: What are the Primary Sources of waste in Your Projects?

		Frequency	Percent
Valid	Concrete and cement debris	27	27.0
	Wood and timber waste	11	11.0
	Metal scraps	9	9.0
	Plastic waste	33	33.0
	Hazardous materials (e.g., asbestos)	20	20.0
	Total	100	100.0

Source: Compiled by authors

Plastic trash accounts for 33% of construction and demolition (C&D) waste, raising concerns regarding non-biodegradable waste management. Concrete and cement waste follow at 27%, indicating major structural work material use. Waste contains 20% hazardous elements, including asbestos, posing health and environmental dangers. Timber trash is 11% and metal scraps 9%, suggesting smaller contributions. This distribution emphasises the necessity for focused plastic and concrete waste reduction efforts to enhance sustainable building.

Table 4: What Percentage of Waste from Your Projects is Recycled or Reused?

		Frequency	Percent
Valid	0–20%	14	14.0
	21–40%	23	23.0
	41–60%	35	35.0
	61–80%	14	14.0
	81–100%	14	14.0
	Total	100	100.0

Source: Compiled by authors

Construction projects recycle and reuse trash differently, according to the statistics. The majority (35%) recycle or reuse 41–60% of their garbage, showing modest sustainability efforts. trash management strategies vary, as 23% recycle 21–40% of trash and 14% each recycle 0–20% and 81–100%. A further 14% recycles 61–80% of its trash, demonstrating sustainable building. This distribution emphasises the need for better waste management to boost recycling and green building. The lack of recycling facilities, which 36% of respondents cited as a serious difficulty, is the main obstacle to construction waste recycling. For 23% of respondents, regulatory limits are important, whereas 16% worry about excessive recycling costs. Challenges include a lack of knowledge and training (14%), and inadequate incentives for sustainable activities (11%). These results show that physical, legal, financial, and educational barriers are slowing construction waste recycling programs.

Table 5: What are the Key Barriers to Effective Waste Recycling?

		Frequency	Percent
Valid	Lack of awareness/training	14	14.0
	High recycling costs	16	16.0
	Limited availability of recycling facilities	36	36.0
	Regulatory constraints	23	23.0
	Lack of incentives for sustainable practices	11	11.0
	Total	100	100.0

Source: Compiled by authors

5.0 Conclusion

This research highlights the essential issues of Construction and Demolition (C&D) waste management, especially in light of accelerated urbanization and economic development. The results indicate that plastic and concrete waste are the predominant sources of C&D waste, with recycling processes being discouraged by a lack of facilities, regulatory limitations, and high prices. The study brings out the necessity to incorporate the use of new-age technologies like Building Information Modeling (BIM) and Internet of Things (IoT) for streamlining waste management procedures. The research also points to the necessity for tighter policy guidelines, stakeholder involvement, and financial incentives in the direction of fostering sustainable operations. The first-hand experience of the on-site visit to the PCMC C&D Waste Management Plant helped identify practical realities of obstacles and operational inefficiencies, once again emphasizing the urgency to develop practical, scalable solutions. By overcoming these obstacles and applying data-driven approaches, the construction sector can cut its environmental impact significantly, become more resource-efficient, and help promote urban sustainability. This study provides a basis for further research and policy interventions to enhance C&D waste management practices across the world.

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Dr. Sushma S. Kulkarni, Vice Chancellor of NICMAR University-Pune, is a transformative civil engineering leader with over 37 years of pioneering experience. Her ground-breaking role as the first Indian Chair of the Global Engineering Deans Council (GEDC) positions her at the forefront of shaping engineering education worldwide. She has steered institutions to autonomy, secured ₹15+ crore in funding, and published 155+ papers. A recipient of 35+ awards, her influence spans research, leadership, and advocacy for women in STEM fields.



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