

CONVERGING HORIZONS

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

Volume 3



Editors

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



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® Publication and Editorial services facilitated by

Journal Press India
Delhi, India

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

Editors: Dr. Sushma S. Kulkarni, Dr. Anil Agarwal, Dr. Smitha Yadav and Dr. Tenepalli JaiSai

Published by : JOURNAL PRESS INDIA
Publisher's address: A-4/17, 1st Floor,
Sector-15, Rohini,
Delhi - 110 089, India
Mobile: 8826623730
Tel: +91-11-42631517
Website: www.journalpressindia.com
E-mail: info@journalpressindia.com

First Edition, July 2025

Print ISBN: 978-93-49790-13-1

Online ISBN: 978-93-49790-54-4

DOI: 10.17492/JPI/NICMAR/2507000



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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 76

Impact of Immersive Media on Buying Decision in Real Estate Market

*Harshal Ravindra Mhasake¹, Harshvardhan Raosaheb Deore¹,
Sourabh Ashok Kanse¹ and Pratik Makarand Harmalkar²*

ABSTRACT

This research studies the impact of Augmented Reality (AR) and Virtual Reality (VR) on home-buying decisions in the real estate market. The study aims to find out how immersive media enhances consumer engagement, understanding, and confidence in purchasing properties. A structured quantitative method was adopted, using surveys and statistical tests such as t-tests and chi-square tests. The findings show that AR/VR provides improved property viewing experience compared to traditional brochures, increasing buyers' confidence and chances of purchase. The study suggests that real estate developers should add immersive media into their sales strategies to enhance consumer decision-making.

Keywords: AR; VR; Real estate; Home buying; Consumer behavior.

1.0 Introduction

The real estate sector is considered one of the primary drivers for economic growth that adds considerable value to GDP by development, construction, and sale of properties. It contributes approximately 6-7% to the GDP in India and is expected to be at 13% by 2025 with the rise in investments and demands. AR and VR, a new trend embraced by this sector to improve real estate marketing, brings to its fore the new visual experience with the help of virtual tours, immersive experiences, and 3D modeling.

In this way, buyers get to conduct virtual property explorations that assist in enhancing engagement and making decisions on purchases. AR/VR can quite effortlessly embed throughout the development cycle and has, to date, transformed the industry by bringing home-buying into the access and engagement area. This research attempts to assess how AR/VR influences buying behavior in customers and its implications in comparison with traditional marketing methods used in the real estate sector.

1.1 Objectives

AR and VR are changing real estate by providing virtual tours and digital views of properties.

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This makes buying homes easier and more engaging from anywhere, reducing the need to visit in person and helping people make better choices. It's a big step towards using more digital tools in real estate. The objectives of this thesis are as follows-

- To study the impact of immersive media on the buying decisions of a new property of customers.
- To study consumer perceptions for Conventional Methods (Brochures) and Immersive Media (AR/VR).

2.0 Literature Review

Several studies address how AR/VR affects decision-making and other marketing capacities; (Lee & Park, 2019) indicated that AR is of help during the constructability study of different construction practices because it provides better visualization and less error-prone execution. AR experiences create an emotional bond with properties, according to (Rauschnabel *et al.*, 2020). According to (Lou & Yeung, 2020), VR home tours have a strong impact on real estate buying decisions by showing properties. AI VR walkthroughs instill buyer confidence while helping them visualize properties, according to (Stein & Ramaseshan, 2021). (Beck & Rygl, 2019) found that emotional engagement was higher for VR technologies, and (Verhagen, *et al.*, 2022) sunders that even minimal immersive experience can change consumer choices. This concludes that AR/VR technologies are altogether reshaping the real estate industry with improved exploration of property sales, increased buyer confidence, and decision-making support. Future work should tackle the long-term effects of immersive media in real estate sales and behavioral trends of consumers.

3.0 Research Methodology

3.1 Research design

In This research we used quantitative research design to assess the effects of the influence of Augmented Reality (AR) and Virtual Reality (VR) on consumer behavior in real estate. By taking a structured approach, it allows statistically measuring of trends, correlations, and deviations in consumer perceptions and decision-making processes. This research is aimed at providing thorough insight into other research questions, for instance, whether AR/VR impacts decisions regarding home purchases and what demographic variables receive correlation from age, incomes, professions, and location in relation to its use.

3.2 Sampling design, questionnaire design and execution

Consumer behaviour and decision-making in real estate purchasing with immersive media (AR/VR) were researched through a structured questionnaire and sampling method. The survey gathered 205 responses, 151 of which were analysed, ensuring adequate demographic

diversity and representation. Respondents were segmented into three generational categories with an emphasis on age analysis to evaluate technology adoption in AR/VR use by property buyers, with younger buyers from Gen Z and Millennials more inclined toward technology-enhanced exploration and settlements of properties. Based on this choice, respondents were additionally demarcated today by city-tier caving up to their technology exposure and purchasing ability. The operated survey segmented different property type demand (affordable, mid segment, premium, and luxury housing) with respect to income levels and the necessity of government subsidy. Further, the questionnaire comprised of two comparative assessments-one with traditional brochures vs. AR/VR demo videos. The study made comparisons regarding the property layout perception, understanding of space, design, and construction quality of the consumers' likelihood of purchase, and confidence in their decision-making based on the traditional techniques of evaluation using AR/VR demo videos further quantified by Likert scale-type answers.

3.3 Importance of the chi-square test in this project

In this study, a chi-square test was used to analyse the association between categorical variables: age group, city tier, and consumer behaviour-whether they are more inclined to buy a property or are confident-arising from the use of AR/VR influences or not, compared to traditional brochures. Specifically, the test is used to identify the relationship between categorical data and for analysing the responses of Likert scale survey questions once they are grouped into categories accurately. A t-test comparing AR/VR versus brochures, through differences in confidence in consumers and likelihood of purchase, also was conducted. Alternative methods that were applied in this study but later found unsuitable included Secretariat Regression, Kruskal Wallis H Test, and K-S Test. However, the appropriation of chi-square tests for association and then t-tests for mean comparison helped gain insight into how effectively AR/VR technology is assumed to have an impact on the decisions of buying a house as compared to traditional means.

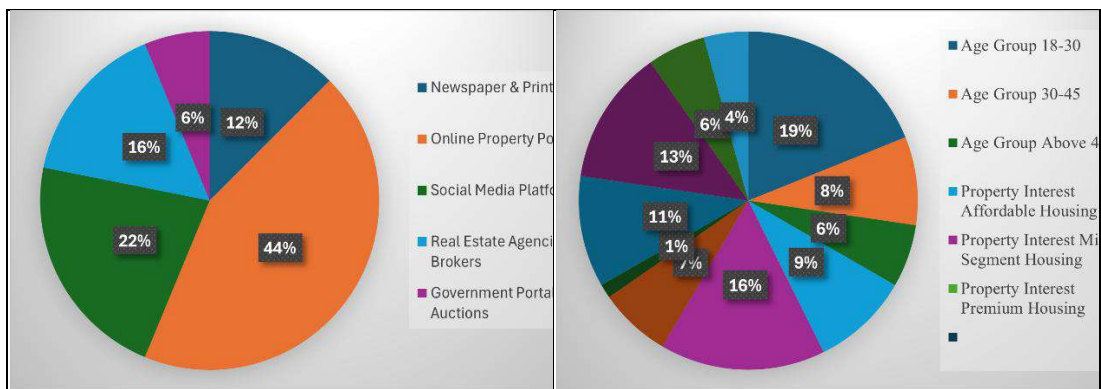
3.4 Why the t-test is suitable for this project

As such, in the present study., the t-test was chosen as an important tool in comparing consumer perceptions between Conventional Methods (Brochures) and Immersive Media (AR/VR). Thus, it focuses on determining if indeed a statistically significant difference exists between the two formats in terms of influences on consumer confidence, purchase intent, and general engagement." The test takes note of and compares measured values to discern patterns relative to samples of differences, continuous data showing contrast over time, prior to statistical comparisons." Inferring, the findings indicated that even a small sample size of such scaled survey data could satisfy the normality assumption, hence making the t-test is an ideal tool because identification of meaningful differences regarding consumers' perception of AR/VR compared to traditional brochures would ultimately benefit real estate marketers and developers by enabling them to retool sales strategies and thereby optimize consumer engagement.

4.0 Data Analysis and Findings

In this chapter will express extensive analysis of survey data researching the influence of Augmented Reality (AR) and Virtual Reality (VR) on buying a home. The research endeavoured to measure the influence that these immersive technologies hold over buyer decisions in the real estate industry. Demographics and AR/VR adoption-related relationships were analysed using a method such as the chi-square test of association, whereas a t-test was used to compare responses obtained by consumers using traditional brochures to those attained by AR/VR experiences. The analysis included primary contributors such as consumer engagement, understanding of property, and decision-making confidence. The conclusions offer an insight into whether AR/VR does or does not emphasize the overall experience of buying a home compared to conventional systems. The analysis of data and statistical tests was performed using IBM SPSS and Microsoft Excel, which used the availability of data organization, tabulation, data visualization, and interpretation of trends.

Figure 1: Demographic Distribution of Respondents and Preferred Property Search Medium



4.1 T-Test for mean comparison

Table 1: T-Test Results for Conventional vs. AR/VR Methods

Variable Analysed	Mean (Brochure)	Mean (AR/VR)	t Critical two-tail	P(T<=t) two-tail
Understanding of Property Layout and Design	2.99	3.85	1.98	1.02807E-11
Confidence in Decision-Making	2.97	3.90	1.98	1.57887E-12
Perceived Quality of Construction	3.09	3.88	1.98	1.68532E-09
Likelihood of Purchasing the Property	3.03	3.94	1.98	8.02915E-11

Interpretation of results: The p-values for all variables are lower than 0.05, the results show a statistically significant difference among the two methods. The higher mean scores for AR/VR across all variables indicated that immersive technology provides better property understanding, gives confidence in decision-making, improved perception of construction quality, and a stronger purchase decision. The large T-Values indicated that the differences observed between the two groups are statistically meaningful.

4.2 Chi-square test for association

Based on this question, the research hypotheses are as follows:

1. H0: There is no significant association between age groups and the likelihood of considering purchasing a property after experiencing it through the selected AR/VR medium. Ha: There is a significant association between age groups and the likelihood of considering purchasing a property after experiencing it through the selected AR/VR medium
2. H0: There is no significant association between age groups and the confidence provided by the AR/VR to make an informed property purchase decision. Ha: There is a significant association between age groups and the confidence provided by the AR/VR to make an informed property purchase decision.
3. H0: There is no significant association between the type of property a person is interested in and their likelihood of considering purchasing it after experiencing the property through the selected AR/VR medium. Ha: There is a significant association between the type of property a person is interested in and their likelihood of considering purchasing it after experiencing the property through the selected AR/VR medium.
4. H0: There is no significant association between the city tier where a person resides and how effectively they perceive the medium to convey the quality of overall construction of the property. Ha: There is a significant association between the city tier where a person resides and how effectively they perceive the medium to convey the quality of overall construction of the property.

Table 2: Chi-Square of Association Results

	Pearson Chi-Square	Likelihood Ratio	df	phi	Cramer's V
Hypothesis 1	29.581	27.57896018	8	0.44408	0.31400917
Hypothesis 2	32.147	28.3430499	8	0.46294	0.32734717
Hypothesis 3	7.467	8.986011302	12	0.22311	0.12881407
Hypothesis 4	15.649	17.39833557	12	0.323	0.18648168

The chi-square test for association was used to determine relationships between age group, property type, city tier, and consumer responses to AR/VR in home-buying decisions.

The results indicate that age group and purchasing consideration are highly related, with a moderate association (Cramér's $V = 0.314$, $p = 0.000$). Younger buyers (18-30) showed a higher likelihood of purchasing after experiencing AR/VR, whereas older buyers (above 45) were more dubious. Similarly, age and confidence level were significantly associated (Cramér's $V = 0.327$, $p = 0.000$), showing that younger buyers trust AR/VR technology more than older individuals. Conversely, the type of property did not significantly influence purchase decisions through AR/VR ($\chi^2 = 7.467$, $p = 0.825$), indicating that property preference does not affect the impact of immersive media. Likewise, city tier and perceived construction quality were not significantly related ($\chi^2 = 15.649$, $p = 0.208$), suggesting that location does not determine how consumers perceive construction quality in AR/VR experiences. Overall, the findings indicate that age is a key factor in AR/VR adoption in real estate, while property type and location have minimal influence on the effectiveness of immersive media in home-buying decisions.

5.0 Conclusion

Findings from the research shows that AR/VR technologies play an important role in consumer engagement by providing immersive and interactive property experiences. Statistical analysis using t-tests indicate that AR/VR outperforms traditional methods in terms of property understanding confidence in decision-making, sensed construction quality, and purchase decision. Hence, the chi-square test of association points out that demographic factors influencing AR/VR adoption, with younger age groups shows more trust AR/VR in the home-buying process.

The results of the chi-square test indicate there is some sort of difference between the age groups in terms of their assurance in reliance on AR/VR when making property purchases. While participants in the younger age group (18 to 30 years) are confident in AR/VR providing sufficient information in their property purchasing process, participants from the older age group (above 45 years) show uncertainty or lower confidence. Businesses and marketers using AR/VR for property sales should design their approach based on age groups, as different segments display varying levels of trust in the medium.

There is further evidence that the current residence of a buyer does not affect his or her confidence in the use of AR/VR in the visualization of properties. Other findings show that while different property types may appeal more to specific buyers, the actual mode in which the individual experiences the property does not significantly impact his or her purchase decision according to property type.

This means that only the age group has a significant impact on understanding AR/VR as a medium, while the city in which a buyer resides and the type of property they are searching for do not have significant positive or negative influence on their decision. This suggests that AR/VR technology can be effectively used for all types of properties, regardless of location or property category.

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CHAPTER 77

Impact of Working Capital Turnover Ratio on Profitability in Indian Real Estate Sector

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ABSTRACT

The real estate sector is dynamic, market-oriented, and characterized by intense competition, making efficient working capital management critical for sustaining profitability. Effective working capital practices ensure operational efficiency, adequate liquidity, and solvency for firms. While numerous studies have examined the relationship between working capital management and profitability in various industries, limited research focuses on its impact in the Indian real estate sector. This study investigates the effect of working capital turnover ratio (WCTR) on the profitability of Indian real estate companies over the period 2014–2024. Using panel data regression, the research evaluates the relationship between WCTR and return on investment (ROI). The findings reveal a significant positive correlation between WCTR and ROI, emphasizing the importance of efficient working capital management for profitability in the real estate sector. These insights offer practical implications for realty companies to optimize their working capital practices and enhance financial performance in an evolving regulatory and economic environment.

Keywords: Panel data regression; Working capital turnover ratio; Return on investment; Real estate sector; Profitability.

1.0 Introduction

The real estate sector plays a significant role in the Indian economy, contributing approximately 7.3% to the country's Gross Domestic Product (GDP) (IBEF, 2023). This sector includes various types of properties such as residential, commercial, industrial, and vacant land, each with distinct financial and operational features (Karnik & Fernandes, 2021). Real estate encompasses not only physical assets but also business activities related to property development, buying, and selling (Kumar, 2022).

Over the past decade, substantial investments from both international and domestic investors have entered the market (Sharma & Dhillon, 2022). Analysts anticipate that the sector will reach a valuation of US\$1 trillion by 2030 and account for about 13% of India's GDP by 2025 (IBEF, 2023).

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Urbanization has significantly impacted India's real estate landscape, with the five major metropolitan areas—Mumbai, Kolkata, New Delhi, Chennai, and Hyderabad—experiencing rapid growth, as their populations more than doubled from 1995 to 2010 and continue to increase (McKinsey Global Institute, 2022). This urban growth is largely driven by rural and semi-urban regions, with projections indicating that over 50% of India's population will be urban by 2050 (UN Habitat, 2023).

The Indian real estate sector has undergone considerable policy and regulatory changes. The introduction of the Real Estate (Regulation and Development) Act of 2016 (RERA) significantly enhanced transparency and consumer trust (Gupta, 2021). RERA established the Real Estate Regulatory Authority, which implemented buyer protection measures and streamlined processes for project registrations, penalties, and promoter behavior (Mohanty, 2022). Although the implementation of the Goods and Services Tax (GST) initially posed fiscal challenges, it was later improved through government initiatives like "Make in India," "Housing for All," and the "100 Smart Cities" project (Shah & Patel, 2021; Tiwari & Hasija, 2022). Collectively, these efforts have fostered transparency, accountability, and long-term market stability. With a population exceeding 1.3 billion, India faces a significant housing shortage, especially in urban areas. The Ministry of Housing and Urban Affairs (2023) estimated a housing deficit of 18.78 million units during the 12th Five-Year Plan (2012–2017), creating considerable opportunities for real estate development.

Increased income levels and urbanization are boosting the demand for luxury and upscale residential developments (Knight Frank India, 2023). Infrastructure improvements, such as metro rail systems, airports, and highways, are also promoting real estate growth and creating new investment opportunities (Cushman & Wakefield, 2022). Regulatory reforms have bolstered market confidence by reducing volatility and improving consumer protection (JLL India, 2022). Furthermore, advancements in technology have significantly transformed the real estate industry, with digital platforms making property transactions easier, reducing fraud risks, and improving operational efficiency (PwC India, 2023). The real estate sector has attracted substantial foreign direct investment (FDI), with inflows reaching US\$42.50 billion, making it the fourth-largest recipient of FDI (IBEF, 2023). Current trends suggest a favorable outlook for the Indian real estate market, driven by urbanization, policy initiatives, and significant investments.

The industry requires substantial financial resources, highlighting the importance of careful financial planning and management. Working capital, a key financial metric for real estate companies, includes current assets like land, receivables, and cash, offset by liabilities such as contractor payments and short-term debts (Rastogi, 2022). Effective working capital management is crucial due to the long project timelines, unpredictable cash flows, and high capital demands typical of the sector (Gupta & Sharma, 2023). The working capital turnover ratio (WCTR) serves as a straightforward measure of a company's operational efficiency, reflecting its ability to convert working capital into sales revenue. An increasing WCTR

indicates efficient resource use, while a declining trend may signal liquidity problems, project delays, or excess inventory (Bintara, 2020). Although this is a compelling area for research, there have been few empirical studies examining the relationship between WCTR and profitability in the Indian real estate sector (Jana, 2018; Paul & Mitra, 2018).

Previous research across various industries has produced mixed findings; some indicate positive correlations, others negative, and some show no correlation at all (Claudia & Lusmeida, 2020; Hidayat & Dewi, 2022). These discrepancies highlight the need for industry-specific investigations within the Indian real estate context. Given the sector's dynamic nature, companies are striving to improve profitability while effectively managing working capital. Proper working capital management is vital for maintaining financial stability in an economy subject to cyclical market changes and significant capital investments. The WCTR reflects how often a company can convert its working capital into sales over a defined period. This study aims to investigate the relationship between working capital turnover and profitability in the Indian real estate sector. This study is highly valuable for financial analysts, policymakers, and business operators as it identifies the factors that affect profitability. The research aims to: examine the relationship between working capital turnover ratio and profitability in publicly listed Indian real estate firms; assess how other financial variables influence this relationship; and provide recommendations based on empirical evidence of effective working capital management practices within the Indian real estate sector.

2.0 Literature Review

The working capital turnover ratio is a crucial financial metric that assesses how effectively a company utilizes its working capital to generate revenue. In the realm of real estate development, a high ratio indicates effective management of ongoing projects and the buying and selling processes, while a low ratio may signal liquidity problems, project delays, or excessive inventory. Given the cyclical nature of the real estate market, analyzing this ratio can provide insights into long-term profitability, risk management, and sustainability. Various theoretical frameworks, such as Trade-off Theory, Pecking Order Theory, and Agency Theory, illustrate the balance between liquidity and profitability, the preference for internal financing, and managerial decisions regarding working capital management. Empirical studies across different sectors reveal specific impacts of working capital turnover on profitability.

For instance, Warrad's (2013) research in the chemistry sector found both positive and negative effects on return on assets, highlighting the complexity of this relationship. In the fast-moving consumer goods (FMCG) sector, Jana (2018) identified a clear positive link between working capital efficiency and profitability, while Paul & Mitra (2018) noted that profitability in the steel industry depended on credit sales and liquid assets. In contrast, Bintara's (2020) study of the real estate sector suggested that working capital turnover had minimal effect on profitability, likely due to lengthy project timelines and capital-intensive activities.

Regional studies also show variability; for example, manufacturing firms in Indonesia experienced a negative impact of working capital turnover on profitability (Claudia & Lusmeida, 2020), whereas SMEs in Kosovo showed a straightforward positive effect (Ahmeti & Balaj, 2023). Additional research in sectors like coal mining (Hidayat & Dewi, 2022) and agriculture (Otekunrin *et al.*, 2021) highlights the significance of managing trade receivables and inventory for profitability.

Other operational and financial factors also play a role in this relationship. In the real estate sector, Andinie & Kustinah (2023) found that working capital turnover had a negligible impact on profitability, with debt servicing being more critical. Similar findings in manufacturing (Wibowo & Rohyati, 2018) and banking (Mazreku *et al.*, 2020) confirm that profitability is influenced by effective liquidity and capital management practices. Working capital management holds strategic importance across industries, particularly in FMCG (Jana, 2018) and SMEs (Ahmeti & Balaj, 2023), as it contributes to financial success and business sustainability.

Despite extensive research on working capital turnover and profitability, studies focusing on the Indian real estate sector are scarce. Factors such as regulatory changes under RERA, market fluctuations, financing trends, and prolonged project durations create a distinct financial landscape, warranting further exploration of how working capital strategies affect profitability. Addressing this research gap could yield valuable insights into optimal financial management practices for Indian real estate developers, enabling them to enhance liquidity control, operational efficiency, and profitability in varying market conditions.

3.0 Methodology

The study's research design aims to analyze the financial data of 15 real estate companies listed on the National Stock Exchange (NSE) over a ten-year period from 2014 to 2024. This timeframe is significant as it includes major regulatory and economic changes in the Indian real estate market, such as the introduction of the Real Estate (Regulation and Development) Act (RERA), the implementation of the Goods and Services Tax (GST), the effects of demonetization, and the increasing focus on sustainable business practices. These factors have greatly influenced financial policies and business operations in the sector, making this period ideal for assessing the relationship between working capital turnover and profitability.

Given that most real estate firms in India are privately held, the study concentrates on these 15 NSE-listed companies to ensure consistent and accessible data. The financial information used in the analysis is sourced from the CMIE ProwessIQ Database, a reputable and comprehensive financial database, enabling an in-depth examination of both time-specific and firm-specific factors affecting profitability.

Table 1: Variables Used for Study

Ratio/Variables	Formula	Definitions
Working Capital Turnover	Net Sales / Average Working Capital	➤ Working capital turnover is a financial metric used to evaluate a company's operational efficiency by measuring its ability to generate revenue from its working capital. It indicates how effectively a company utilizes its working capital to generate sales revenue. ➤ A higher working capital turnover ratio typically indicates better efficiency, as it suggests that the company is generating more revenue relative to its investment in working capital.
Cost of Sales (COGS)	Opening stock + Purchases – Closing Stock	➤ Cost of sales is a financial metric used to calculate all the expenses involved in creating a product or service. It indicates business entity ability to conceive the product, from sourcing to manufacturing at a reasonable cost. ➤ A higher cost of sales indicates major issues in business like inefficient production, excess inventory and poor management of goods.
Operating Expenses	Total Expenses – Non operating Expenses - COGS	➤ Operating Expenses is a financial metric used to give an idea about all the expenses that occur through all normal business operations. Operational activities are the main tasks that need to carry out day by day to operate the business and generate revenue. ➤ Higher operating expenses lead to a reduction in profitability and competitiveness. Thus, lower operating expenses are preferable.
Debt to Equity Ratio (leverage ratio)	Total Debt / Total Equity	➤ The debt-to-equity ratio is a financial metric used to evaluate a company's capital structure and financial risk. ➤ It compares a company's total debt to its total equity, providing insights into how much data company is using to finance its operation relative to the amount of equity.
Cost of Goods Sold Ratio	(COGS / Total Revenue) * 100	➤ The COGS Ratio is a financial metric that measures the amount of revenue spent on purchasing goods. ➤ It helps the business to understand the cost structure and efficiency.

Total Asset Ratio	Total Debts / Total Assets	➤ The Total Asset ratio is a financial metric used to measure the ability of company to use its assets to generate sales. ➤ It indicates about company's characteristics about its financial ability, stability and growth. It also tells about the efficiency of asset management.
Return On Equity (ROE)	Net Income / Average Total Equity	➤ It is the major of financial performance calculated by dividing net income by shareholder equity. Because shareholders' equity is equal to a company's assets, minus its debts. ➤ ROE shows how effectively companies use shareholders equity to generate profit.

The research utilizes panel data analysis, which integrates cross-sectional and time-series data to provide multiple observations over time for different firms. This method is particularly suitable for financial research as it considers firm-specific effects (heterogeneity) and temporal trends, leading to more accurate estimations of financial relationships. To evaluate the impact of working capital turnover on profitability, the study includes key financial variables such as cost of sales, debt-to-equity ratio, operating expenses, cost of goods sold (COGS), and total assets. Two statistical models are employed: the Fixed Effects Model (FEM) and the Random Effects Model (REM). The FEM controls for time-invariant firm characteristics by removing company-specific averages and accounting for firm-level variations over time. In contrast, the REM assumes that firm-specific effects are random and independent of the explanatory variables, making it less restrictive but potentially biased if firm-specific traits affect the explanatory variables. Based on the results of the Hausman Test, the RE model was identified as the better model in this given context.

$$\text{Profitability}(ROE)_{it} = \alpha + \beta_1(\text{Working Capital Turnover})_{it} + \beta_2(\text{Cost of Sales})_{it} + \beta_3(\text{Debt to equity ratio})_{it} + \beta_4(\text{Operating Expenses})_{it} + \beta_5(\text{COGS})_{it} + \beta_6(\text{Total Assets})_{it} + \varepsilon_{it}$$

Where, i indexes companies, and t indexes time (years), α is the intercept, ε_{it} is the idiosyncratic error term.

To identify the more suitable model, the study conducts the Hausman test, which assesses whether firm-specific effects are correlated with the independent variables. The results indicate that the Random Effects Model (REM) is the most appropriate for this analysis. The final model examines profitability, measured as Return on Equity (ROE), as a function of working capital turnover, cost of sales, debt-to-equity ratio, operating expenses, COGS, and total assets, while controlling variations across firm-specific and time-based factors. This approach offers a comprehensive analysis of how working capital management impacts profitability in the Indian real estate sector, providing valuable insights for financial decision-making and policy formulation.

4.0 Result and Analysis

This study utilizes panel data regression methods to analyze the relationship between the working capital turnover ratio and profitability, as indicated by Return on Equity (ROE), within the Indian real estate industry. To account for firm-specific differences, both Fixed Effects (FE) and Random Effects (RE) models are employed. The significance of coefficients is classified into three levels: highly significant at 1%, moderately significant at 5%, and weakly significant at 10%. The results indicate that the working capital turnover ratio has a negative coefficient in both the FE (-0.055) and RE (-0.026) models, suggesting an inverse relationship with ROE. This relationship is weakly significant at the 10% level on the FE model and moderately significant at the 5% level on the RE model.

The findings imply that a higher working capital turnover may not be an effective strategy for enhancing profitability; instead, an overreliance on current assets could restrict operational liquidity and hinder capital flow to ongoing projects. Additionally, the cost of sales also shows a negative coefficient in both models, with a moderately significant inverse relationship in the FE model (-0.263) at the 5% level, while it lacks statistical significance in the RE model (-0.452). This indicates that managing the cost of sales effectively is vital for profitability in the real estate sector. In contrast, operating costs positively influence profitability, as shown by the positive coefficients in both the FE (2.837) and RE (1.233) models. This relationship is weakly significant at the 10% level in the FE model and moderately significant at the 5% level in the RE model, suggesting that investing in operational activities like marketing, administration, and project management can improve efficiency and profitability. The debt-to-equity ratio also exhibits a negative coefficient, indicating a negative relationship with ROE. This relationship is significantly strong at the 1% level in the RE model (-0.093) but not significant in the FE model (-0.413).

This aligns with financial principles that excessive leverage can harm profitability, especially in capital-intensive sectors like real estate, where high debt servicing costs can strain cash flow. Furthermore, the cost of goods sold (COGS) also follows a similar trend, with negative coefficients in both models (-0.704 in FE and -0.026 in RE). The relationship is significantly strong at the 1% level in the RE model, highlighting the importance of controlling costs related to construction materials, labor, and other direct expenses to sustain profitability. The Hausman test, which assesses the appropriateness of FE versus RE models, yields a p-value of 0.6893, exceeding 0.05, indicating that the RE model is more suitable for this analysis. Additionally, the RE model demonstrates a higher R-square value (0.247) compared to the FE model (0.084), underscoring its effectiveness in explaining the variance in ROE. These results highlight the importance of efficient financial management, especially in enhancing working capital turnover, managing sales costs, and reducing operating expenses to ensure optimal resource allocation and increase profitability in the Indian real estate industry.

5.0 Conclusion

This study offers important insights into the financial factors influencing profitability in India's real estate sector, particularly examining the impact of the working capital turnover ratio. Contrary to the common belief that a higher working capital turnover always enhances profitability, the findings indicate that in a capital-intensive industry with lengthy project timelines, a high turnover can lead to liquidity issues, ultimately decreasing profitability. This suggests that real estate developers must strike a balance between maintaining sufficient working capital for operations and avoiding excessive reliance on current assets. Additionally, the research highlights the significance of cost management, revealing a negative correlation between the Cost of Sales and Cost of Goods Sold (COGS) and profitability. Given the high costs of materials, labor, and construction, real estate companies need effective cost control strategies, such as careful vendor negotiations and value engineering, to maximize profit margins. Another key finding is the positive link between operating expenses and profitability, indicating that strategic investments in marketing, project management, and customer service can boost revenue and overall performance. This underscores the importance of viewing operational expenditures as valuable investments rather than mere costs, as they can provide long-term financial returns.

Table 2: Framework for Analysis and Result

Independent Variables	Dependent Variable: ROE	
	FE	RE
Working Capital Turnover Ratio	-0.055 (0.08) *	-0.026 (0.04) **
Cost of Sales	-0.263 (0.017)**	-0.452 (0.127)
Operating Expenses	2.837 (0.041)**	1.233 (0.1) *
Debt To Equity Ratio	-0.413 (0.0554)	-0.093 (0.040)***
Cost of Goods Sold	-0.704 (0.431)	-0.026 (0.323)***
Total Assets	1.792 (0.044)**	0.341 (0.33)
<i>R Square: Overall</i>	0.084	0.247
<i>Hausman Test (P Value)</i>	0.6893	

p- Value in parenthesis

*** denotes significance at 1% level of significance

** denotes significance at 5% level of significance

* denotes significance at 10% level of significance

Furthermore, the study emphasizes the necessity of debt management, as excessive reliance on financial leverage can adversely affect profitability due to high interest payments. While debt financing is prevalent in the real estate sector, firms must carefully manage their capital structure to optimize leverage benefits while controlling financial risks. Asset growth is also identified as a crucial factor, with companies possessing larger asset bases, such as land and properties, likely to achieve greater economies of scale and competitive advantages, thereby enhancing their financial performance. These findings offer practical guidance for financial managers and decision-makers in the Indian real estate industry, suggesting that profitability can be maximized through a comprehensive approach that includes optimized working capital management, stringent cost control, strategic operational investments, prudent debt management, and thoughtful asset growth strategies. The research also enriches the existing literature by shedding light on the unique financial dynamics of the Indian real estate market, where the relationship between working capital turnover and profitability deviates from conventional expectations. By providing sector-specific analysis, these results can aid academic and industry professionals in deepening their understanding of financial management in this capital-intensive field, leading to more informed and effective decision-making.

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Annexure I: Data Set Used for the Study

Company	Year	ROE	Total Assets	Debt To Equity Ratio	Total Expense	Operating Expense	COGS	Cost Of Sales	WCTO
Brigade Enterprises Ltd.	2017	10.59	4729.25	0.97	1285.22	945.80	1014.92	1153.15	1.58
Brigade Enterprises Ltd.	2018	8.98	5769.47	0.84	1143.63	802.19	903.51	1040.40	1.58
Brigade Enterprises Ltd.	2019	9.85	7550.76	0.83	2194.17	1807.52	1217.52	1373.47	1.00
Brigade Enterprises Ltd.	2020	11.35	7714.80	0.80	1669.38	1294.09	1252.64	1404.54	1.43

Brigade Enterprises Ltd.	2021	5.94	8165.58	0.68	1574.92	1206.83	1073.30	1189.00	1.26
Brigade Enterprises Ltd.	2022	10.11	8819.95	0.46	1985.10	1633.87	1526.73	1709.46	1.32
Brigade Enterprises Ltd.	2023	10.14	9199.42	0.36	2463.45	2119.11	1595.22	1801.76	1.04
Brigade Enterprises Ltd.	2024	7.81	10640.36	0.41	3126.36	2777.01	1390.63	1627.00	0.73
D L F Ltd.	2017	4.08	29141.38	0.62	3867.06	945.80	1646.45	2169.86	3.92
D L F Ltd.	2018	0.53	33302.15	0.92	3495.71	802.19	1539.71	2034.12	3.81
D L F Ltd.	2019	3.78	37449.03	0.35	3027.50	1807.52	1688.17	2148.56	1.82
D L F Ltd.	2020	4.50	42349.62	0.23	3822.13	1294.09	1382.48	1863.28	1.83
D L F Ltd.	2021	3.73	39779.34	0.21	3423.80	1206.83	1877.32	2298.36	3.26
D L F Ltd.	2022	5.73	37789.81	0.14	3086.41	1633.87	1830.25	2264.41	2.48
D L F Ltd.	2023	7.94	37842.86	0.11	2896.51	2119.11	1555.60	2063.21	1.88
D L F Ltd.	2024	4.24	38993.59	0.12	2826.33	2777.01	1592.88	2110.05	1.17
Godrej Properties Ltd.	2017	10.40	6113.03	1.76	1096.47	725.99	543.34	675.38	1.38
Godrej Properties Ltd.	2018	6.13	7231.78	2.56	1162.81	714.39	309.60	524.49	0.78
Godrej Properties Ltd.	2019	9.77	7813.34	1.32	1193.01	707.59	985.01	1219.47	2.03
Godrej Properties Ltd.	2020	9.90	9939.44	0.73	1778.65	1068.75	1266.47	1527.87	1.95
Godrej Properties Ltd.	2021	-0.57	15006.35	0.52	2360.03	1760.88	432.42	681.10	0.32
Godrej Properties Ltd.	2022	5.77	16172.22	0.55	1703.44	1091.34	922.34	1213.78	1.35
Godrej Properties Ltd.	2023	6.86	20004.65	0.64	5122.87	4469.34	452.26	805.71	0.26
Godrej Properties Ltd.	2024	4.92	27969.54	0.95	5185.65	4102.98	356.66	910.78	0.32
Macrotech Developers Ltd.	2017	17.84	29613.51	3.28	5610.10	4848.42	4773.08	5255.50	1.23
Macrotech Developers Ltd.	2018	11.96	30289.36	3.45	8925.84	5958.65	4193.05	4868.10	1.11
Macrotech Developers Ltd.	2019	33.30	36302.82	5.33	8263.63	6745.32	6502.71	7091.68	1.41
Macrotech Developers Ltd.	2020	13.81	35605.45	4.32	6242.52	4540.07	5946.47	6399.74	1.79
Macrotech Developers Ltd.	2021	1.76	37722.40	3.82	4850.21	3451.97	4400.03	4797.96	1.72
Macrotech Developers Ltd.	2022	13.61	38006.60	0.92	6537.20	5513.70	5823.97	6450.50	1.52
Macrotech Developers Ltd.	2023	3.83	42255.10	0.87	11365.00	8608.40	5324.24	6452.80	1.07
Macrotech Developers Ltd.	2024	9.62	47972.60	0.54	12565.90	10761.30	5588.13	6762.90	0.88

Mahindra Lifespace Developers Ltd.	2017	3.30	2440.38	0.38	487.39	402.24	540.44	618.54	1.69
Mahindra Lifespace Developers Ltd.	2018	3.08	2514.00	0.20	363.27	292.56	338.24	434.43	1.62
Mahindra Lifespace Developers Ltd.	2019	3.28	2437.92	0.07	330.99	289.30	358.67	454.72	1.68
Mahindra Lifespace Developers Ltd.	2020	-0.41	2010.07	0.08	428.54	413.38	382.38	499.74	1.06
Mahindra Lifespace Developers Ltd.	2021	-3.51	2042.56	0.08	308.51	311.18	115.56	196.64	0.29
Mahindra Lifespace Developers Ltd.	2022	-4.05	2324.15	0.11	386.20	378.71	243.23	364.71	0.67
Mahindra Lifespace Developers Ltd.	2023	1.73	3160.25	0.15	1359.31	1316.59	387.04	568.16	0.36
Mahindra Lifespace Developers Ltd.	2024	-3.91	4477.14	0.57	1545.88	1513.97	22.85	165.73	0.01
Obero Realty Ltd.	2017	8.13	4664.57	0.02	785.93	586.22	349.59	471.77	1.52
Obero Realty Ltd.	2018	9.74	5805.33	0.20	728.94	487.24	361.04	462.92	2.00
Obero Realty Ltd.	2019	8.65	7074.06	0.11	680.06	384.52	311.82	430.96	2.68
Obero Realty Ltd.	2020	5.12	7601.59	0.15	1497.52	1273.19	125.50	243.32	0.49
Obero Realty Ltd.	2021	6.08	7995.15	0.12	422.64	203.16	233.60	340.41	4.18
Obero Realty Ltd.	2022	5.55	10270.05	0.24	1222.47	1029.09	288.57	537.26	0.98
Obero Realty Ltd.	2023	24.72	17356.66	0.30	6257.49	5673.72	1331.37	1578.23	0.57
Obero Realty Ltd.	2024	12.12	18177.67	0.18	3046.67	2381.76	1169.34	1497.15	1.39
Phoenix Mills Ltd.	2017	5.47	3401.35	0.31	297.86	122.46	74.89	151.69	3.07
Phoenix Mills Ltd.	2018	6.30	3515.37	0.28	292.83	141.84	89.09	180.43	2.80
Phoenix Mills Ltd.	2019	6.27	3782.72	0.30	331.03	171.12	100.27	213.62	2.57
Phoenix Mills Ltd.	2020	5.40	3979.75	0.30	338.67	182.42	103.69	226.11	2.44
Phoenix Mills Ltd.	2021	1.48	5191.32	0.16	236.24	101.04	65.50	138.99	2.35
Phoenix Mills Ltd.	2022	3.13	5750.51	0.19	236.24	111.32	56.88	136.41	2.55
Phoenix Mills Ltd.	2023	5.04	5826.86	0.14	298.41	154.08	89.96	180.66	3.09
Phoenix Mills Ltd.	2024	5.66	6079.67	0.14	295.78	152.08	94.95	181.33	3.06
Piramal Estates Pvt. Ltd.	2017		444.87		171.68	172.56	-27.61	36.06	
Piramal Estates Pvt. Ltd.	2018		644.83		150.93	151.21	6.68	29.84	
Piramal Estates Pvt. Ltd.	2019		874.21		283.73	294.70	-35.50	33.29	
Piramal Estates Pvt. Ltd.	2020		1094.97		197.35	201.10	-20.26	33.60	
Piramal Estates Pvt. Ltd.	2021		1333.31		222.58	219.17	-17.71	18.35	

Piramal Estates Pvt. Ltd.	2022		1913.57		543.68	523.55	15.36	33.97	
Piramal Estates Pvt. Ltd.	2023		2061.54		591.63	589.79	520.38	571.36	
Piramal Estates Pvt. Ltd.	2024		2238.22		685.91	684.40	408.17	471.51	
Prestige Estates Projects Ltd.	2017	7.35	12532.90	0.70	2382.60	2130.90	1512.67	1787.90	1.02
Prestige Estates Projects Ltd.	2018	4.81	13997.20	0.82	2756.70	2298.50	2069.51	2466.60	1.27
Prestige Estates Projects Ltd.	2019	6.31	18431.20	1.12	3694.80	3197.80	1338.33	1850.50	0.71
Prestige Estates Projects Ltd.	2020	5.36	19730.20	1.08	3072.70	2096.90	2186.97	2647.20	1.51
Prestige Estates Projects Ltd.	2021	5.38	18344.70	0.54	3098.90	2257.20	3095.84	3388.10	1.77
Prestige Estates Projects Ltd.	2022	6.74	17411.30	0.49	2766.40	2024.80	3190.90	3752.20	2.15
Prestige Estates Projects Ltd.	2023	4.95	18259.70	0.63	4032.60	3286.20	3113.44	3681.30	1.32
Prestige Estates Projects Ltd.	2024	3.64	20024.50	0.77	3166.10	2329.20	1653.81	2215.70	1.14
Sobha Ltd.	2017	5.64	8789.73	0.87	2843.76	2539.96	1577.53	1871.50	0.86
Sobha Ltd.	2018	7.68	8902.18	0.86	2266.75	1926.57	2042.89	2391.63	1.35
Sobha Ltd.	2019	12.18	10931.15	1.22	3411.71	2975.32	2414.25	2809.05	1.13
Sobha Ltd.	2020	13.24	10819.17	1.40	3856.08	2939.97	2341.60	2714.18	1.28
Sobha Ltd.	2021	2.86	11062.28	1.40	2465.35	1785.59	1249.64	1527.81	1.17
Sobha Ltd.	2022	5.83	11157.70	1.09	2588.80	2157.21	1754.38	2089.57	1.18
Sobha Ltd.	2023	2.74	12229.48	0.88	4194.24	3797.27	2571.03	2971.58	0.88
Sobha Ltd.	2024	1.31	13253.43	0.82	3621.11	3271.06	2417.03	2881.08	0.95

CHAPTER 78

Implementation of Sustainable Practices in Urban Affordable Housing Scheme and its Scalability

Pavan Totla¹ and Vaishnavi Vilas Kumbhar²

ABSTRACT

The Sangli Miraj Kupwad Municipal Corporation in Maharashtra launched an initiative to foster sustainability practices within community housing through its Five Star Home rating in 2020. This rating system is structured around five key sustainable practices, each earning a distinct star. The first star is for proper segregation and composting of waste generated at home and aims to decrease greenhouse gas emissions & carbon footprint. The second star recognizes efforts in water conservation and reuse, addressing issues like water scarcity & over-exploitation of groundwater. Third star is about Energy saving & conservation of natural resources. The fourth star is for providing shelter for birds and animals, which contributes to biodiversity conservation and ecological balance. Lastly, the fifth star rewards residents who engage in tree plantation and conservation efforts, enhancing CO₂ absorption (carbon sink), improving air quality, and preventing soil erosion. This innovative program is designed to encourage residents to adopt eco-friendly practices that mitigate the negative impacts stemming from anthropogenic activities such as deforestation, climate change, and resource depletion. Since 2020 around 300 houses are already rated with the Five Star Home rating. Residents who achieve all five stars were eligible for 4% property tax concession. This initiative can be seamlessly integrated with the Pradhan Mantri Awas Yojana (PMAY) to create a first-of-its-kind initiative for mass affordable and sustainable housing in urban/semi-urban areas. The integration focuses on aligning PMAY's goal of providing affordable housing with eco-friendly practices that promote sustainability, Like Green City Action Plan of Pimpri Chinchwad Municipal Corporation. The success of this integration can be a scalable model for sustainable housing on a larger scale. This initiative not only incentivizes responsible environmental stewardship but also enhances community engagement in creating a more sustainable living environment.

Keywords: Sustainable practices; Carbon footprint; Carbon sink; Sustainable housing.

1.0 Introduction

Sustainable development in semi-urban areas is vital for addressing environmental issues while encouraging community well-being (James, 2024).

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Recognizing this need, the Sangli Miraj & Kupwad City Municipal Corporation announced the innovative 5 Star Home concept in 2020. The aim of this initiative is to foster community-driven sustainability by encouraging residents to implement eco-friendly practices to help mitigate degradation of environment. As a Junior Environmental Engineer, I was directly associated in the execution of this concept, working closely with the public to ensure its success. The program seeks to create a greener, more sustainable future for semi-urban regions by integrating practical solutions such as waste segregation, water conservation, and biodiversity enhancement. The Five Star Home concept represents how local governments and communities can work together to create impactful, lifelong change by encouraging collective action, individual responsibility and in the face of environmental challenges such initiatives serve as powerful models for progressing sustainability and building resilient communities.

1.2 Concept of five-star home

The 5-Star Home concept is an innovative initiative which aims to promote sustainable living practices amongst households. It identifies and rewards households that implement eco-friendly habits and minimise their ecological footprint. Households show their commitment to contribute to creating a sustainable community and environment conservation by achieving 5-Star Home certification. It is required for households to comply with all 5-star criteria to get certified. A verification team comprising of a local body representative, an NGO member, and a technical expert will carry out the verification process. After verification, each households complying with all 5-star criteria will be eligible to get:

- A 5-Star Rating logo for their home, with their name on it
- A 4% tax rebate

In addition to encouraging sustainable living, this certification also offers tangible benefits to households that have a positive environmental impact.

1.3 Five star modified sustainability rating for semi urban housing

To get certified as a 5-Star Home, individual households must comply with the following criteria:

Table 1: Five Star Modified Sustainability Rating for Semi Urban Housing

Stars	Criteria
Star-1	Waste Segregation and Composting
Star-2	Water Conservation and Reuse
Star-3	Energy Efficiency and Renewable Energy
Star-4	Biodiversity Conservation
Star-5	Tree Plantation and Conservation

Waste segregation and composting: To qualify for the first star, it is important for households to segregate waste into organic, recyclable, and non-recyclable categories, compost wet waste, and implement the 3'R's-reduce, reuse, and recycle of waste management. This reduces waste going to landfill, conserves finite resources, and promotes sustainable waste management.

Water conservation and reuse: To get the second star, households need to implement water conservation measures like rainwater harvesting, reuse of greywater, or installing low-flow fixtures. These practices lessen water waste, lower dependence on municipal supplies, and promote efficient water usage.

Energy efficiency and renewable energy: For the third star, households are supposed to minimise energy consumption by using energy-efficient appliances, turning off devices when not needed, and enhancing natural lighting and ventilation. Using smart technology, LED lighting, and solar panel installation further reduces energy consumption, lowering costs and promoting environmental sustainability.

Biodiversity conservation: Installing birdhouses, feeders, or planting bird-friendly trees are ways for households to encourage biodiversity and achieve the fourth star. They can also help maintain ecological balance by giving stray animals food or shelter.

Tree plantation and conservation: For 5th star households must plant and maintain a minimum of five trees, using native species that support biodiversity and ecological balance. By planting and preserving trees, households can help mitigate air pollution

2.0 Why Sangli Municipal Corporation Felt the Need of Doing this Project?

On October 2, 2020, the Environment and Climate Change Department, Government of Maharashtra, launched the Mazi Vasundhara Abhiyan (Majhi Vasundhara). This program focuses on the five important elements of nature, known as “Panchamahabhuta,” which comprise Bhumi (Earth), Vayu (Air), Agni (Energy), and Akash (Enhancement), Jala (Water) (IPER). The prime objective of this initiative is to create awareness among citizens about the effects of climate change and environmental issues while inspiring them to take mindful actions to improve the environment.

It also aims to promote strong climate action at the state level and safeguard sustainable development across Maharashtra. The Mazi Vasundhara Abhiyan acted as the basis for the development of the Five Star Home concept. This state-level initiative provided the essential framework and enthusiasm for local bodies like the Sangli Miraj & Kupwad Municipal Corporation to implement localized sustainability practices. The ideologies and objectives of the Abhiyan inspired the Municipal Corporation to design a concept that could effectively engage citizens at the grassroots level and promote sustainable practices in day-to-day life.

2.1 Actual implementation of five-star home concept

To guarantee maximum participation and efficiency, the Five Star Home concept was implemented using a methodical and structured approach. In order to inform residents about the Five Star Home initiative and emphasize its financial and environmental advantages, large-scale awareness campaigns were first carried out throughout residential areas. These campaigns included social media outreach, community gatherings, and the distribution of educational brochures. A Google form was created to call interested candidates and accelerate the application process. Along with specific questions that aligning the Five Star Home criteria, the form was thoughtfully designed to collect necessary information like name, address, and contact details. These questions evaluated practices like composting waste, collecting rainwater, using solar energy, having at least five plants, and making accommodations for animals and birds. Candidates also had to submit images as evidence that they met each requirement.

Figure 1: Citizens Receiving 5 Star Home Rating Logo



After applications were received, a preliminary assessment was carried out using the information provided. Applications were carefully examined by the evaluation team to ensure that the required requirements were met. To enable a methodical verification process, the qualified applications were grouped ward-by-ward across 20 wards after the initial screening was finished. The on-site final assessment was carried out by a special committee of technical experts, representatives from NGOs, and municipal officials. The team was accompanied by a designated sanitary inspector from each ward to verify the applicants' claims and make sure the Five Star standards were being met. The certification process's legitimacy and openness were improved by this multi-tiered assessment procedure. This methodical approach turned out to be very advantageous and effective. Utilizing a digital application form reduced paperwork and expedited data collection, which made application tracking and analysis simpler.

By facilitating targeted assessments and lowering logistical obstacles, the ward-wise categorization ensured thorough coverage. Additionally, the participation of different stakeholders promoted trust and community engagement, which in turn inspired more locals to actively participate in the project.

2.2 Criteria for star awarding star

Waste Management: As per 2008 joint paper by NEERI and CPCB assessed the status of Municipal Solid Waste (MSW) Management in metro cities, state capitals, Class I cities, and Class II towns in India. The study reported that per capita waste generation in these areas ranges between 0.2–0.6 kg per day. An analysis of the physical composition of municipal solid waste revealed that 30–45% of the waste is compostable matter, 6–10% consists of recyclables, and the remaining portion is inert matter. Based on household sizes, the average waste generation estimates are as follows:

Table 2: Waste Generation Estimation

Category	Family Size	Average Waste Generation (kg/day)
Category 1	2–4 person (Avg: 3)	1.5
Category 2	4–6 person (Avg: 5)	2.5
Category 3	6–8 person (Avg: 7)	3.5

Table 3: Water Consumption Estimation

Category	Family Size	Average Wastewater Generation (kg/day)
Category 1	2–4 person (Avg: 3)	3 × 135
Category 2	4–6 person (Avg: 5)	5 × 135
Category 3	6–8 person (Avg: 7)	7 × 135

To ensure effective waste management and qualify for the First Star rating, individual households are expected to process at least 50% of the total waste generated through composting and recycling. Additionally, 100% segregation of waste into wet, dry, and hazardous categories is mandatory. Households must focus on composting organic waste, recycling dry waste, and adopting the 3Rs—Reduce, Reuse, and Recycle to minimize landfill dependency and promote sustainability.

Water Conservation and Reuse: According to IS 1172: 1993, the standard water supply requirement is 150 to 200 liters per person per day (Bureau of Indian Standards (BIS), 1993). However, for low-income groups, the average domestic water consumption under normal conditions in Indian cities is considered to be 135 liters per person per day. By adopting responsible water usage practices, it is possible to reduce per capita water demand to as low as

92 liters per day. Approximately 90% of the water used is converted into wastewater, which, if treated and reused, can help minimize the demand for fresh water. Additionally, rainwater harvesting can be implemented to store water, further reducing the need for fresh water. To qualify for a 2-star rating, individual households must achieve a 30% reduction in water consumption.

Energy efficiency and renewable energy: As per world data info Indians consumes 1,045 units of electricity per person annually. The home is eligible for 3rd star if:

- 50% energy is from renewable energy (Solar panels, solar water heaters, solar bulbs)
- Energy efficient appliances are installed.
- Use of LED lights

Biodiversity Conservation: Households are eligible for the 4th star only if they have made at least one provision, such as setting up birdhouses, bird feeders, or a bird-friendly garden, or providing shelter for stray animals, to support local wildlife.

Tree Plantation and Conservation: To qualify for the 5th star, households must meet tree plantation criteria: Plant at least 5 trees of indigenous species & ensure these trees are over 4-5 feet tall. Based on conservation of trees, eligibility for 5th star will be checked.

3.0 A Scalable Tax Rebate Scheme for the Five Star Home Concept

We got to know about the tax rebate scheme from the Deputy Environmental Engineer of PCMC's Environment Department. By rewarding individual efforts rather than demanding adherence to a full set of requirements, the Pimpri-Chinchwad Municipal Corporation (PCMC) introduced a more flexible tax rebate program that promotes sustainable practices.

Their scheme provides the following concessions:

- 3% tax rebate for on-site composting
- 5% tax rebate for setting up a sewage treatment plant (STP) or water reuse system
- 8% tax rebate for combining composting with an STP
- 8% tax rebate for zero-waste practitioners (who compost wet waste and hand over dry waste to authorized recyclers)
- 10% tax rebate for homes practicing both zero-waste management and STP-based water reuse

Table 4: A Scalable Tax Rebate Scheme for the Five Star Home Concept

Sustainability Criteria	Tax Rebate (%) & Star awarded
Waste segregation & composting	4, 2star
Water conservation (rainwater harvesting, wastewater reuse)	6%, 2star
Renewable energy usage (solar panels, solar water heaters)	2%, 1 star
Providing shelter & food sources for birds/animals	1%, 1 star
Tree plantation & biodiversity conservation	2%, 1 star
Full Five Star Home compliance	Additional 2%, 5 stars

With no pressure to meet all requirements at once, this model encourages locals to embrace sustainable practices at their own pace. A more scalable and flexible rebate scheme for Sangli's Five Star Home concept inspired by PCMC's model, could be developed as follows:

This structure consents homeowners to earn partial concessions for each sustainable practice executed, ensuring that even small steps taken towards sustainability are encouraged and rewarded. Additionally, the scheme can be supported with:

Awareness Programs: To educate citizens about the benefits of each sustainability measure conducting workshops, campaigns, and social media promotions

Technical Assistance: Through partnerships with NGOs and private players providing guidance for composting, rainwater harvesting, and renewable energy solutions.

Green Support Access Initiative: raising awareness about schemes, programs that offer easy financing options for high-investment initiatives like rainwater harvesting systems, biogas plants, or household composting units, or subsidies like the "Har Ghar Sury Bijali Yojana" for solar panels.

Green finance: Through nationalized banks and institutions, it offers financial support for sustainable projects in the form of loans, grants, or subsidies, promoting environmentally friendly initiatives with advantageous terms and incentives.

This revised model would encourage higher participation, as even partial compliance would yield financial benefits, making the initiative more scalable and impactful.

3.1 Scenario analysis in different situations of compliance

Table 5: Scenario Analysis

Sr. No	Compliance Criteria	Benefits Provided
1	If complying with 1 criterion	Tax rebate as per Table 4 and 1-star rating
2	If already complying with 1 criterion and now complying with 1 more criterion	Tax rebate as per Table 4 and 2-star rating
3	If already complying with 1 criterion and now complying with 2 more criteria	Tax rebate as per Table 4 + 1% additional tax rebate and 3-star rating
4	If complying with composting, water conservation, and installing a solar panel in one go	Corresponding tax rebate as per Table 4 + 2% additional tax rebate and 3-star rating
5	If already complying with 4 criteria	Corresponding tax rebate as per Table 4 and 4-star rating
6	Achieves full compliance with all criteria	Corresponding tax rebate as per Table 4 + 3% additional tax rebate and 5-star rating
7	In case of non-compliance identified with any criteria during monitoring	Star & tax rebate associated will be removed.

4.0 Future Scope

4.1 Integration of 5-star home concept with PMAY

The recently created rating system's future scope includes the possibility of integrating it with the Pradhan Mantri Awas Yojana (PMAY). The Five Star Home concept has already been successfully applied to 300 homes in Sangli, proving its viability and beneficial effects. The program can be expanded to a much greater number of households nationwide by integrating this idea into PMAY. Homes' affordability, environmental sustainability, and quality will all be guaranteed by this integration. The overall quality of housing will be improved by the focus on sustainable practices like waste management, water conservation, the use of renewable energy, biodiversity preservation, and tree planting.

Better water and energy management systems, better waste disposal facilities, and greener surroundings are all features of homes constructed using this integrated model, which will make living there healthier and more comfortable. Furthermore, using eco-friendly building techniques and energy-efficient materials will increase resilience and durability while lowering long-term maintenance expenses. Additionally, this extensive implementation will support the government's commitment to sustainable development, improve community resilience, and lessen the carbon footprint of urban settlements. Along with improved indoor air quality and higher living standards, homeowners will also experience long-term financial savings from lower energy and water usage.

5.0 Challenges in Scaling Up the Five Star Home Concept in Sangli

Although the Five Star Home concept in Sangli was an innovative and well-intended initiative, faced multiple challenges that prevented its large-scale adoption. Some of the main challenges include:

Lack of Awareness and Public Engagement: Many people were unaware of the initiative, its benefits, and the criteria required to comply to achieve a Five Star rating. Public engagement campaigns were inadequate, and many people did not fully understand how the initiative could contribute to environmental sustainability and personal economic benefits.

Rigid Criteria for Tax Rebates: One major downside was the "all-or-nothing" approach to the tax concession. Residents had to comply with all five sustainability criteria to qualify for the 4% tax rebate. If households fail to meet even one criterion, they were not eligible for any incentive. This discouraged partial participation, as people felt that their efforts in meeting some sustainability standards were not being known.

Financial Constraints: Some of the criteria, such as installing roof top solar panels or rainwater harvesting systems, needed an upfront investment. Many homeowners, especially from lower-income groups, found it difficult to make these financial commitments without additional support, such as subsidies or financial incentives.

Lack of Consistent Political Will and Support: Local government entities frequently need to support and commit to sustainable initiatives over the long term. However, the Five Star Home concept was not consistently implemented and promoted due to frequent changes in political leadership and priorities. The development of the program was hindered by the lack of a solid, long-term sustainability vision.

Limited Monitoring and Enforcement Mechanisms: Even after a verification committee was established, it was still difficult to guarantee compliance and sustain long-term adherence to the sustainability standards. Due to strict monitoring or a lack of follow-ups, some participants may have started the necessary measures but later stopped.

Perception of Minimal Direct Benefits: Adoption of the practices was lower among residents who did not immediately perceive economic benefits. Some believed that the tax refund amount was insufficient given the time and money needed to fulfill all five requirements.

6.0 Advantages of the Five Star Home Concept

Adaptable to both new and existing homes: In contrast to green building certifications like LEED, IGBC, or GRIHA, which are mainly applicable to newly built structures, the Five Star Home concept can be retrofitted into existing homes, encouraging sustainability for a larger population.

Affordable and practical solution: Investing heavily in cutting-edge building materials and technologies is frequently necessary to implement green building initiatives. Five Star Homes, on the other hand, promotes inexpensive, useful improvements like water and composting.

Encourages incremental and impactful changes: Five Star Homes provides a phased approach rather than demanding immediate adherence to all sustainability standards. Homeowners can achieve long-term environmental benefits and lessen financial strain by implementing sustainable practices gradually.

Inclusive for low and middle-income groups: Although green building certifications are frequently restricted to high-end residential or commercial projects, the Five Star Home concept is designed for typical homeowners, guaranteeing affordability and encouraging broad adoption.

Promotes simple, low-cost actions: Low-cost practices include planting native trees, using energy-efficient appliances, rainwater collection, and home composting. These actions have instant environmental benefits without requiring significant financial expenses.

Supports Biodiversity Conservation: In addition to improving urban biodiversity, installing water bowls, bird feeders, and tiny green areas costs virtually nothing. This initiative stresses ecological well-being through straightforward actions, in contrast to traditional green building approaches.

Fosters Community Participation: The Five Star Home model promotes involvement and information exchange at the local level. This neighborhood-based strategy encourages group action and raises local environmental consciousness.

Figure 2: Before & After: Community Led Sustainability Transformations



Contributes to Climate Action and Resource Conservation: Five Star Homes show how individual efforts can significantly mitigate climate change and preserve natural resources by reducing household waste, conserving water, using renewable energy, and promoting biodiversity.

6.1 Quantifiable environmental impact of the five-star home concept

Based on calculations from the implementation in 300 homes:

- *Carbon Sequestration:* A total of 1,500 trees were planted, with at least five trees planted by each household. About 22 kg of CO₂ are sequestered annually by each mature tree, for a total of 33,000 kg of carbon sequestered annually.
- *Waste Reduction:* An individual produces 0.5 kg of waste daily on average. By encouraging composting, the program reduced the amount of waste dumped in landfills by 50%. With 1,300 people living in the 300 houses, the program kept about 118,625 kg of waste from ending up in landfills each year.
- *Water Conservation:* A 30% decrease in water usage was made possible by rainwater collection and greywater reuse. It was determined that 20,403,500 liters of water were saved annually across all categories.

The concept's potential to be expanded across various regions is enhanced by its affordability, adaptability, and environmental benefits, particularly when local governments

support it with incentives like tax breaks, subsidies, and financing options. The Five Star Home concept genuinely embodies the idea that significant environmental change starts at home by making sustainability a practical decision rather than a luxury one.

**Table 6: Parametric Model for any Urban Local Body
Who Wants to Implement 5 Star Home Concept**

Sr. No	Parameter	Sangli Corporation Five Star Home	PCMC Tax Rebate Scheme	Parametric Model	
1	Waste Management	Households are expected to process at least 50% of their total waste (No tax rebate is provided for individual criteria unless all four are complied with)	3% rebate for on-site composting (No specific criteria)	Criteria	Tax Rebate
				1.Complying to any one criteria	1%
				2.Complying to any two criteria	2%
				3.Complying to any three criteria	3%
				4. Segregation +Composting + Reuse of waste material for home application+To handover dry waste to recycler	4%
2	Water Conservation	30% reduction in water consumption	5% rebate for implementing water reuse and recycling (STP)	Criteria	Tax Rebate
				1.Complying to any one criteria	2%
				2.Complying to any two criteria	4%
				4. Water reuse + Reduction in water consumption + Rainwater harvesting system	6%
3	Renewable Energy	50% of energy sourced from renewable sources and the use of energy-efficient appliances (No tax rebate for individual criteria unless all four are complied with)	No tax rebate provision for renewable energy usage	Criteria	Tax Rebate
				1. Use of solar water heaters	1%
				2. Rooftop solar panels	1%
				3. Water heater + Rooftop solar	2%
4	Biodiversity Conservation	Providing shelter for birds and animals for the 4th star (No tax rebate for individual criteria unless all 4 are complied with)	No specific rebate for biodiversity efforts	1% tax rebate for providing shelter to animals or birds.	
5	Tree Plantation	Planting a minimum of 5 trees for the fifth star (No tax rebate for individual criteria unless all four are complied with)	No direct rebate for tree plantation	Criteria	Tax Rebate
				1. Tree plantation (5 plants)	1%
				2. Tree Plantation (Plants double the no. of family members)	2%

7.0 Parametric Model for any Urban Local Body Who Wants to Implement 5 Star Home Concept

- *Waste management criteria*
 - Waste segregation
 - Composting of wet waste
 - Reuse of waste for home application
 - Handover dry waste for recycling
- *Water conservation*
 - Water reuse for gardening or flushing
 - 30% reduction in water consumption
 - Rainwater harvesting system
- *Energy conservation*
 - Use of solar water heater
 - Use of Roof Top Solar
- *Biodiversity conservation*
 - Provision of feeder, houses or water for birds & animals
- *Tree plantation and conservation*
 - Planting atleast 5 tree

For compliance with each criteria 1 star will be awarded. In case of non-compliance noticed during periodic visits, the star awarded & tax rebated will be removed.

8.0 Conclusion

Urban local bodies (ULBs) play a key role in achieving Sustainable Development Goals by implementing sustainability practices. The Five Star Home concept is a significant step towards environmental stewardship, but in its implementation, there are several challenges. Through a scalable and parametric model, urban local bodies can ensure increased participation and long-term sustainability. Making it a practical and impactful solution for sustainable urban development by Strengthening financial incentives, awareness programs, and monitoring mechanisms will improve its effectiveness.

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CHAPTER 79

Implementing Precast Technology: A Roadmap to Mitigate Time and Cost Risk in Indian Road Infrastructure

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ABSTRACT

The road infrastructures are prone to time and cost overrun. However, this potential technology has been shown to mitigate the problems in the real estate sectors. Precast technology mostly allows for the possibility of identification concerning usage for a similar type of road infrastructure technology. This paper reviews the implementation of precast concrete technology as a prospective solution toward mitigating time and cost. Extensive research has been done on the utilization of precast pavements in several countries with physical models assessed. Similar research programs and physical models need to be developed for understanding the real-time data in Indian conditions. The ever-growing requirement for durable, faster, and cost-effective road development motivated the quest towards advanced construction techniques such as precast technology. A comparative study was devised for traditional cast in situ model and precast pavement about cost and time. This paper provides a comprehensive roadmap detailing the advantages, challenges, and strategies for adopting precast solutions in Indian road construction. Precast results in faster construction, with higher initial investments. Higher initial investments result in better quality pavement, and with increasing acceptance of the precast usage will bring down the cost. Precast technique would eventually triumph over road construction.

Keywords: Cast-in-situ; Cost overrun; Precast concrete pavements (PCCP); Quality control; Time overrun.

1.0 Introduction

1.1 Background

The precast concrete technology introduced by John Alexander Brodie, a British engineer in 1905, has gained importance all over the world and has become the backbone of the infrastructure of India, especially in the construction of bridges, flyovers, viaducts and tunnels (Construction World, 2022). Despite the importance of the technology, it still accounts for less than 2% of India's construction industry valued at around ₹2,48,000 crores, which indicates that there is a huge potential that is yet to be tapped (IBEF, 2023).

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In India, the road development sector is the key to economic growth and national integration. A major shift in the government's policy since 2014 on the development of roads is the withdrawal of bitumen-asphalt in favor of cement-based concrete roads in new projects. The reason for this is the long-term financial benefits of concrete roads, which are much more durable and do not require a lot of repairs and resurfacing in the future (MoRTH, 2021).

Besides, the adoption of precast concrete in road construction is not spared as it still has its challenges. Precast concrete takes much higher initial cost compared to the traditional methods of construction due to the high cost of the specialized components required and the technical skills needed both in the design and execution (ICJ, 2023). Also, precast elements are difficult to handle during transportation and handling, especially in urban areas. The availability of skilled labor for such systems is another pretty critical factor for the successful implementation of the same. The other very significant constraint is the typical mindset in the construction sector in India where they are very much bent on the use of conventional methods (CII, 2023). Nevertheless, precast concretes' benefits including faster installation, long-term cost savings, and durability make it a compelling forward-looking alternative for road construction. Innovations such as Precast Concrete Pavements or PCP, combines the installation speed of flexible pavements with the low-maintenance benefits of concrete, would be ideal for India's urban growth challenges (IRC, 2022).

1.2 Aim

To analyse the cost and time comparison of constructing concrete pavement by using In-situ casting and precast method.

1.3 Objectives

- Analyse the challenges of time and cost overruns in Indian infrastructure projects.
- Evaluate the potential of precast concrete technology to address these challenges.
- Develop a roadmap for implementing precast technology in various infrastructures.
- sectors (roads, bridges, buildings etc.).
- Identify factors critical for successful precast implementation, such as design
- optimization, material selection, and quality control measures.
- Recommend strategies for overcoming potential barriers to precast adoption in India.
- including skill development and regulatory frameworks.

2.0 Literature Review

2.1 Time efficiency and construction productivity

On another hand, precast technology cuts down on the time of construction, owing to the preparation off the site and work on the site simultaneously. Tomek (2017) points out that because parts are brought ready for the assembly, prefabrication allows to reduce the time

needed for installation. Chang-Geun (2019) also underlines that the technology helps with time management and productivity, particularly for the large infrastructure projects, where every minute counts.

2.2 Cost optimization and economic benefits

Despite the fact that the high initial costs of the project may be a problem, according to some sources, the researchers are confident that the total costs for the project can be reduced. Tomek (2017) and Chang-Geun (2019) highlight the fact that labor costs and the reduction of time loss can lead to the reduction of costs, while Novak *et al.*, (2017) found that the reduction in material costs and the reduction of waste services will lead to the reduction of costs. In this regard, Liu *et al.*, (2023) argued that the hybrid genetic algorithms can be used to improve the design efficiency.

2.3 Environmental sustainability

The environmental benefits of the precast methods are comprehensively recognized. As the research by Graybeal *et al.* (2017) shows, prefabrication reduces water use, energy consumption, and on-site waste. The research by Yuan *et al.*, (2014) also confirms that the precast systems ensure a greener infrastructure by minimizing environmental impacts throughout the project lifecycle.

2.4 Durability and lifecycle performance

Compared to cast-in-place equivalents precast members e.g. prestressed slabs, bridges show superior durability. Allotey *et al.*, (2015) find the reduction of maintenance needs, longer service life. Tomek (2017) reports lifecycle savings, proposing the precast systems as an acceptable sustainable solution for essential infrastructure.

2.5 Precast concrete pavements PCP for road infrastructure

PCPs result in lesser construction time and therefore reduce the road user costs. Allotey *et al.* (2015) and Tomek *et al.* (2011) concur that PCPs decrease delays and traffic interruptions significantly, thus are perfect for urban road networks.

2.6 Barriers to adoption in developing countries

Despite their benefits, the adoption of precast concrete construction systems is limited in many developing countries because of poor infrastructure, a lack of skilled labor, and regulatory hurdles (Cho *et al.*, 2019). Ma *et al.* (2016) point out that in India, in particular, high initial costs and traditional construction practices are limiting the use of precast.

2.7 Research gap

While available research has substantiated the potential of precast technology for enhancing productivity, cost-efficiency, sustainability, and long-term durability, many crucial

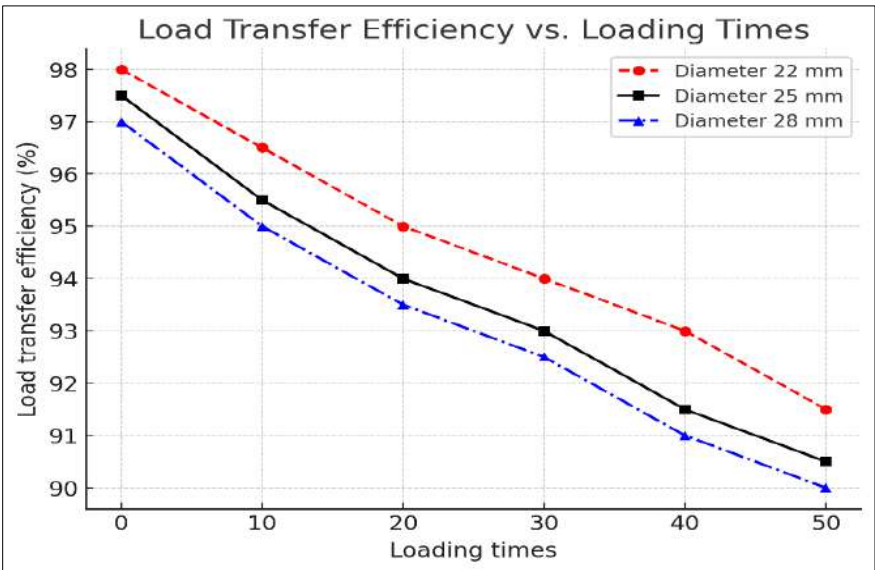
gaps remain. Most of these studies are from developed countries and therefore offer little insight into the way these systems work under the complicated conditions of India's construction industry (Daniel, 2017; Yan, *et al.* 2016). Comprehensive project-based evaluations that look at the association between time efficiency and factors like project size or location are largely missing (Wu *et al.* 2017). When it comes to costs, while many report about savings, only a few have conducted full LCCs in the context of developing countries (Liu *et al.* 2023; Novak *et al.* 2017). Very little is also known in terms of environmental assessment, with a lack of comparative LCA across different climatic zones (Yuan *et al.* 2014). Finally, durability is often discussed without the necessary component-level analysis under real-world conditions (Allotey *et al.* 2015). Precast technology literature is also silent on the tools and mechanisms to be employed for overcoming labor, infrastructure, and policy barriers for popularizing these technologies in emerging markets.

3.0 Data Analysis and Results

Precast Concrete Pavement systems offer a successful solution to the long-standing issue with the delays and inefficiencies of the roadway construction projects. Field performance and productivity data indicate that in the case of single-lane closure, the construction rate of precast pavement panels can be up to 14-18 panels per 6-8-hour window, which corresponds to about one panel every 20-25 minutes. The reason for such high efficiency is the use of the alternating two crews: one for drilling and epoxy insertion of dowel bars and another for the placement of the panels. Consequently, 50% of the construction time can be saved, and the onsite construction disturbance can be minimized, which is especially important in urban areas with high traffic volume and limited working windows. (Zhu, 2024)

This work also compared different repair strategies such as one-sided, two-sided, and four-sided repairs in terms of their repair rates to identify the most time-effective and structurally sound method. According to the results of the comparison, one-sided slab repairs are the best method as they offer the best balance of the speed of repair, material consumption, and benefits of their installation. This provides evidence for the claim that modular repair methods with the use of ready-made components are the best solution for infrastructure systems that are to be repaired or modernised frequently under constrained timelines. Pavement performance requires solid load transition at joints. This is an essential element for long-term sustainability and user comfort. Dowel bar connections are the most effective mechanisms for this purpose. Tests revealed that dowel bars support load transition at 95% efficiency (Liu, 2024). The joints only deflect less than 0.2 mm under the force of 40 kN (Liu, 2024). Furthermore, the joints have structural stability that remain unaffected across numerous load cycles. This makes these joints suitable for roads that are likely to experience a high volume of traffic or frequent axle load stresses (Ou, 2024). Combined with high-strength precast panels, such joint systems can reduce maintenance, which is a critical consideration for sustainable road infrastructure in India.

Figure 1: Load Transfer in Relation to the Number of Loading Cycles



Source: Liu, 2024; Li Ou, 2024

3.1 Comparative analysis

Table 1 shows a comparative view of different pavement repair techniques, time required and estimated cost. It underlines the balance between speed and investment by emphasizing the strategic advantages of precast concrete despite being slightly more expensive initially.

Table 1: Comparison of Precast Concrete Slabs with those of Other Methods

Repair Type	Repair Details	Time to Complete	Estimated Cost (in Rs)
Fast-curing top layer/crushed stone mix	254 mm top layer cap 102 mm compacted crushed stone mix	3.7 hrs	98,900
Fast-curing top layer/lightweight foam	254 mm top layer cap 102 mm lightweight foam	3.2 hrs	1,47,140
Fast-curing top layer/pumped lightweight foam	254 mm top layer rubble 102 mm lightweight foam	3.9 hrs	1,11,100
Fast-curing top layer/fluid backfill	254 mm cap 102 mm flow able fill	3.4 hrs	1,20,000
Precast pan-el/flow able fill	279 mm panel 76 mm fluid backfill	4.8 hrs	1,04,000
Traditional Portland cement concrete (PCC)	356 mm PCC	28 days	72,200

At a comparative evaluation level, it is possible to see that precast systems cost more than traditional concrete methods, taking into consideration that each installation is costlier in itself. But on the other hand, the time frame is substantially reduced. In high-traffic and time-sensitive areas, this time saved is a significant factor leading to savings that are related to not having to close roads, have detours, and the resultant revenue losses.

4.0 Findings of the Research

The results are in and they confirm that pre-cast concrete technology can have a transformative role in the future of Indian infrastructure. It results in quicker construction, less disruption to road users, and long-lasting durability with less maintenance required. These results align with the aim of improving efficiency in the delivery of projects in the rapidly expanding urban and national road networks in India. After testing, the pivotal technical attributes were discovered to be the application of post-tensioned slabs, monitored panel pouring, the precise positioning, and high-efficiency load transfer devices. As a result, it is critical to integrate optimization of design, material innovation, and quality control into the strategy for implementing precast products. Several implementation challenges were observed at the same time. These include limited availability of trained personnel, nonuniformity in panel specifications, transport of large precast units, and resistance of stakeholders who are accustomed to traditional construction practices. Removing obstacles will require a concerted effort on the part of policy, education, and industry. Among the proposed measures are the development of training programs for engineers and contractors, the establishment of regional production of precast units to reduce transportation costs, the introduction of precast design standards into national construction codes for the construction of highways. Overall, the research reveals that with the correct technical setup and facilitating setup, precast concrete systems can play a very crucial role in ensuring that there is a faster, more durable, and cheaper infrastructure across the urban and rural parts of the country.

5.0 Conclusion

The purpose of the study was to explore the feasibility of using prefabricated concrete technology to address Indian infrastructure projects' key issues—specifically, time, cost, quality, and sustainability. The study results clearly suggest that prefabricated systems can significantly enhance the efficiency of the project while improving structural reliability and long-term cost-effectiveness. With reference to the objective of understanding time and cost overrun related to precast pavement systems, the research observed that they are time-efficient in terms of construction. According to the data from the research, the precast pavement system can reduce their construction time significantly because the installation can be done very fast, with as much as 18 panels per shift (Zhu, 2024). This results in less time wastage for traffic disruption, which makes the construction faster than other techniques. In reference to quality

and consistency, the precast pavement system ensures dimensional accuracy, minimum errors, and better-quality control because they are done in a controlled environment. This makes the pavement in line with the objective of improving construction quality.

Precast systems were noted to create on-site emissions and material waste from a sustainability point of view, while advanced load transfer systems, such as dowel bars, created better results under repetitive loads, contributing to lower maintenance and longer pavement life (Liu, 2024; Li Ou, 2024). In general, these realizations are consistent with the objective of developing a sustainable infrastructure system with a long life. Factors critical to successful implementation were examined in the study as well. Design optimization, availability of skilled labor, transport logistics, regulatory support are identified as key enablers, hence the need to address them in mainstreaming the adoption of precast. The high initial costs and logistical constraints were identified as significant challenges; however, the lifecycle cost savings and speed of construction justify investment—particularly for high-traffic corridors and time-sensitive projects.

5.1 Stakeholder impact

Precast concrete technology in India is a collective endeavor, the need for which is understood by all its participants. Government agencies and policymakers are responsible for creating favorable conditions (for example, by providing tax incentives or incorporating precast standards into legislation) and supporting pilot programs (NITI Aayog, 2020). Infrastructure developers and contractors need to ensure the integration of this technology in their operations by investing in equipment, adjusting logistics, and adapting their workflow to modular construction systems. The producers of precast elements must focus on the challenges that arise from a scarcity of regional supply by building production sites in the vicinity of a project, which reduces the cost of transport and time. Training institutions and schools must play the leading role in bridging the skills gap by providing specialized training on the technologies of precast building, handling, and installation (Cho et al., 2017). The urban planners and consultants of the project should normalize the use of precast elements by designing the project at the planning stage in a way that makes it easy to integrate these components in the design and hence integrate the modular advantage in the early stages of the project. Finally, the ultimate beneficiary of shorter construction durations, safer roads, and more durable infrastructure, the public, although indirectly, has a crucial role in promoting and adopting the technology. The interconnected stakeholder ecosystem must align around a shared mission: To modernize the delivery of Indian infrastructure with faster, cleaner, and more durable building methods. Precast concrete technology is a real, scalable way forward if everyone is brought along proactively.

5.2 Recommendations

Incorporate precast standards into the codes and tenders of countries to make it mainstream across infrastructure industries. Constructing regional precast manufacturing centers for the sake of restive logistics and optimizing supply chain efficiency. Develop precast design

assembly wearing handling courses. The partnership that will be sourced for the program are training entities and construction companies. Convince leaders of the value of pilot projects in urban centers and national highways, where conventional methods are less efficient due to time and space constraints. Provide policy incentives and funding support to promote early adoption, particularly in public infrastructure projects. Encourage a collaborative design that takes into account precast modularity from the planning stage, this will improve cost efficiency and structural integration. Make use of precast in green infrastructure projects. This can be achieved by combining it with sustainable materials and by making sure that the production processes are low emission. Aligning technology, workforce development and policy reform will enable precast concrete to become the foundation of India's infrastructure modernization, offering projects that are faster, cleaner, more durable and financially sustainable in the long term.

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CHAPTER 80

Industrial Revolution 4.0 in Construction Industry: Challenges and Opportunities

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ABSTRACT

Construction industry plays a very important role in driving economic growth and development of a nation. Construction 4.0, a version of IR 4.0 in construction, acts as a major enabler for increasing the productivity and efficiency of construction projects. However, integrating Construction 4.0 technologies involves various challenges. This Research paper is an endeavour to carry out a detailed investigation on adoption of construction 4.0 in selected construction project. Enablers in CR 4.0 such as Artificial Intelligence (AI), the Internet of Things (IoT), Building Information Modelling (BIM), robotics, and 3D printing, Digital twin are included in investigation. Mixed method approach is applied in the research. The study basically identifies the key obstacles, which includes substantial implementation costs, the need for workforce upskilling, and the regulatory barriers, while analysing their effects on project performance, sustainability, and stakeholder engagement. By exploring and analysing the case studies of NEOM and GIFT City, the research highlights the real-world applications of CR 4.0 technologies and evaluates strategies to overcome the various project execution challenges. The main aim of the paper is to deepen the understanding of technology adoption in construction, along with providing practical recommendations to enhance project management practices and encourage a cooperative environment for the successful deployment of CR 4.0 advancements.

Keywords: Digital twin; Construction 4.0; Innovative technology; Sustainability.

1.0 Introduction

The construction industry has always been regarded one of the least digital, as well as the most resistant to adopting new technologies. However, as Industry 4.0 gains traction, this view is rapidly changing. Industry 4.0, often known as the fourth industrial revolution, refers to the integration of sophisticated digital technologies such as automation, artificial intelligence (AI), the World Wide Web of Things (IoT), robots, building information modelling (BIM), and massive amounts of data into industrial processes. These technologies have reached a watershed moment, bringing enhanced efficiency, safety, sustainability, and cost-effectiveness, rethinking traditional construction methods.

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Construction is one of the world's major sectors, making a significant contribution to the global economy. According to the World Economic Forum (2020), the construction sector accounts for almost 13% of global GDP. Despite its major contribution, the industry has faced challenges such as inefficiency, waste, delays, and cost overruns. The introduction of Industry 4.0 provides a unique chance to solve long-standing concerns. The implementation of new technologies will enable the building industry to innovate in design, construction, and operations, thus enhancing its competitiveness and ability to meet the growing demands for infrastructure development, sustainability, and urbanization.

1.1 Construction has undergone modifications over the years

When more individuals relocated to settlements, the scale and scope of building increased. In addition to infrastructure for stationary habitation, individuals constructed more sophisticated permanent buildings in which they resided, worked, and socialized. Starting in the seventeenth century, such endeavors required the utilization of architects and engineers, material organization, construction regulations, and the organization of industry in its contemporary form. Engineering and architecture started to be viewed as separate professions that needed specialized education. Andrea Palladio was born in 1508 A.D. and is generally considered the father of modern architecture. Palladio, who was famous for his creativity and utilization of materials that suited the needs of his patrons, created rural villas and palaces for the Italian nobility. His use of a classical temple front as a roofed entrance porch had a profound influence on later architects.

1.2 The industrial revolution and construction

Contemporary science began in the 17th and 18th centuries, concurrent with the rise of the building trade. Scientific advances allowed engineers and architects to experiment with more diverse materials and forms. Building innovations triggered a tsunami of transformation with the technological advances of the 19th industrial revolution. Abraham Darby invented a new method of smelting iron in 1709 that facilitated mass cast iron production, thus paving the way for a succession of innovations.

- Darby's grandson oversaw the construction of the first iron bridge in the UK in 1781. After the 32-yard bridge weathered a big flood in 1795, other builders constructed their own iron structures.
- During America's rapid growth in the 19th century, cast iron was the preferred material for new construction. Cast iron was widely used by builders for its low cost, strength, and fire resistance in everything from water systems to storage.
- Prior to the introduction of wrought iron in the 1820s, cast iron was the primary material for railroad construction.

Prefabrication emerged as mass production progressed. The first concepts for modular homes appeared about 1830. Up to the 1940s, Sears Roebuck sold houses in the United States

by mail order. Prefabrication was also used by builders while they were creating non-residential structures. The Crystal Palace in London was built in 1851 and is made of cast iron and glass. After being demolished and rebuilt, it survived in a South London neighbourhood until being destroyed by fire. The Bessemer process, one of the most revolutionary innovations of the Industrial Revolution, reduced the cost and increased the accessibility of steel production.

Between 1890 and 1895, up to 80 percent of the steel produced worldwide was produced using the Bessemer process. Eventually, steel rails replaced iron ones, and by 1900, it was possible to wrap all of the steel rails in the globe 10 times. The designers of the Brooklyn Bridge, the first massive steel suspension bridge in history, used the wide availability of Bessemer steel, even if it wasn't used in its whole. Steel girders allow constructions to reach previously unthinkable heights. The age of skyscrapers was influenced by Bessemer Steel, the development of mechanical building equipment, and Elisha Otis's safer lift design. The Home Insurance Building in Chicago, which was built in 1885, is the world's first skyscraper. From its original design, the building's height expanded from 10 to 12 stories in 1890.

2.0 Literature Review

Integrating current digital technologies into industries, the Industrial Revolution 4.0 (IR 4.0) is marked by increases in automation, artificial intelligence (AI), the Internet of Things (IoT), big data, 3D printing, robotics, and more. As IR 4.0 disrupts long-standing practices in the construction industry, it brings both new opportunities and formidable challenges. Issues like as technological advancements, implementation challenges, growth possibilities, and industry practice change are explored in this literature review pertaining to IR 4.0 in the construction sector.

2.1 Literature review on technological advancements in construction industry 4.0

In order to provide the theoretical groundwork for Construction 4.0 technologies, their effects, and the difficulties in implementing them, a thorough literature analysis was undertaken. Taking cues from Industry 4.0, Construction 4.0 applies cutting-edge digital technology to the building trades in order to make projects more sustainable, efficient, and productive (Sawhney *et al.*, 2020). This research primarily focuses on the following technologies: digital twins, 3D printing, robots, the internet of things, building information modeling, and artificial intelligence.

Machine learning algorithms made possible by artificial intelligence (AI) have revolutionized project planning, risk assessment, and resource allocation (Marinelli *et al.*, 2022). Internet of Things (IoT) allows for remote monitoring of construction operations in real-time, which improves operational efficiency and safety (Zhou *et al.*, 2021). With its ability to digitally depict and collaborate among stakeholders, BIM has become an essential tool for project visualization and mistake reduction (Eastman *et al.*, 2018). Automation and robotics are changing the face of construction site work by making human workers obsolete and increasing

accuracy and output (Linner *et al.*, 2016). The use of 3D printing is changing the way construction is done. It allows for quick prototypes and offers sustainable options for buildings (Buswell *et al.*, 2018). Virtual models that reflect actual building sites may be built with the help of Digital Twin technology; these models can then be used to make proactive decisions and do predictive maintenance in real-time (Opoku *et al.*, 2021). The broad implementation of Construction 4.0 solutions is impeded by a number of obstacles, notwithstanding these improvements. Significant challenges persist, including high implementation costs, the need to upskill the workforce, and regulatory restrictions (Teuteberg *et al.*, 2016). Problems with industry-wide opposition to change and problems with digital platform compatibility add insult to injury (Dakhli *et al.*, 2022). There is a lot of discussion in the literature about the revolutionary possibilities and the challenges of using Construction 4.0 technology. In order to create successful methods to help integrate digital advances into building projects, it is essential to understand these characteristics.

The introduction and integration of sophisticated technologies transforming project design, construction, and management is the most important feature of IR 4.0. (Roboticism and automation Bock *et al.*, (2015) claims that by lowering the need for human labor, increasing accuracy, and boosting safety, robots and automation might completely transform building. While lowering costs, robotic systems—including autonomous cars and brick-laying robots—are enhancing speed and quality (Berardi *et al.*, 2017). 3D printing finds increasing use in building. (Gibson *et al.*, 2015) stress how 3D printing may be used to produce construction components, thereby lowering waste and expenses and offering great degrees of customizing. Faster and more affordable construction techniques made possible by this technology—especially for specialized projects—allow for (Eastman *et al.*, 2011) discuss how BIM, an essential aspect of IR 4.0, allows real-time, data-driven collaboration and simulation, which helps optimize building design, construction schedules, and cost estimates. BIM promotes efficient communication among all the participants, therefore lowering mistakes and delays in building projects. In building, (Xu *et al.*, 2017) underline the possibilities of IoT and big data as sensors can track project development in real-time, ambient conditions, and equipment performance. Proactive decision-making made possible by this ongoing data flow helps to minimize downtime and raise general productivity.

2.2 Literature review on challenges in adopting industry 4.0 in the construction sector

Although IR 4.0 offers obvious advantages, many obstacles prevent its smooth application into the building sector. As (Güner *et al.*, 2020) point out, smaller building companies may find it costly to acquire new technologies. For companies, especially in underdeveloped nations where the expense of high-tech equipment might be a major financial burden, this investment difficulty provides a barrier to entrance. The fast speed at which technology is changing calls for different abilities in the job. Many employees, according to (Akintoye *et al.*, 2016), are not ready to operate with innovative technology such sophisticated

construction robots or IoT devices. This difficulty calls for funding in workforce development and training to guarantee that the working force can adjust to new instruments and techniques. New technologies have always been reluctant to be embraced by the building sector. (Jarkas & Younis, 2015) note that workers and management are reluctant to include IR 4.0 technology into daily operations because of cultural opposition to implementing technologies that disturb established routines. (Chien *et al.*, 2016) stress data security issues given the growing usage of IoT devices and cloud-based data storage. Nowadays, the building sector is particularly susceptible to cyberattacks because sensitive information such project schedules, plans, and blueprints could be easily hacked or accessed without permission.

2.3 Literature review on opportunities offered by industrial revolution 4.0

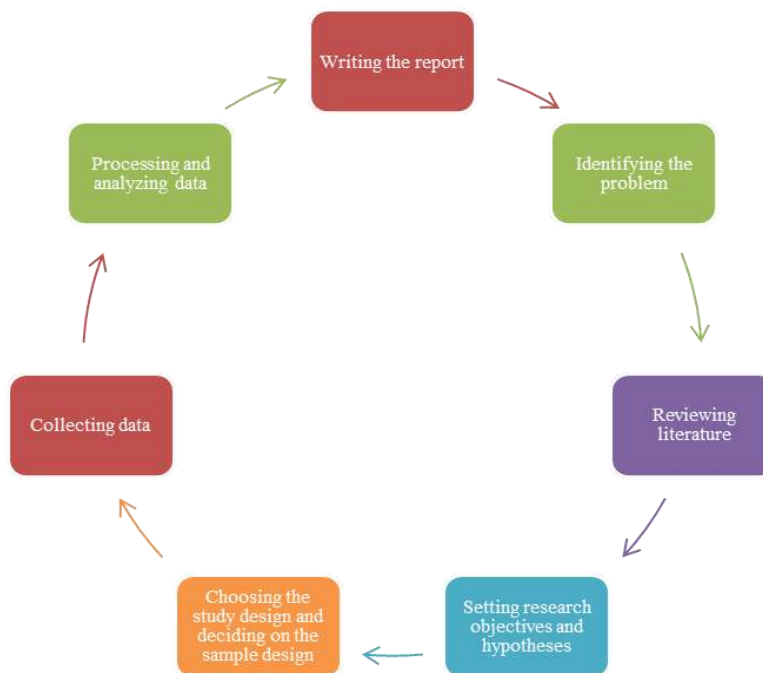
Notwithstanding these difficulties, IR 4.0 presents various chances for the building sector that will help to shape the direction of the sector. As (Koch *et al.*, 2018) explain, digital technologies and automation may greatly raise operational efficiency. While Bim and IoT provide more precise monitoring and forecasting, thereby improving resource allocation and project schedules, automated machines and robots speed up building processes. Integration of robots and artificial intelligence-powered safety mechanisms offers chances to lower mishaps on building sites. Hosseini *et al.* (2019) claim that AI-driven systems can track worker behavior and environmental factors in real-time, thereby providing predictive insights to help to avoid mishaps and guarantee a safer workplace. By use of energy-efficient technology, IR 4.0 advances sustainability Advanced building methods like 3D printing and the use of sustainable materials, (Liu *et al.*, 2017) note, cut waste, decrease carbon footprints, and improve energy efficiency. By helping to replicate building environmental effect, BIM also guides more sustainable design decisions. The possible reductions in costs are among the most obvious advantages of IR 4.0. (Jiang 0, 2020) note that using smart technologies and automation helps to lower labor expenses, material waste, and rework, thus enhancing profitability and lowering overhead.

2.4 Literature review on future directions and strategic implications

Many strategic approaches are under discussion as the building sector adopts IR 4.0 to exploit the advantages of digital transformation. According to (Zhou *et al.*, 2019), cooperative ecosystems—where stakeholders—architects, engineers, contractors, and clients—simplyly interact via digital platforms—will define the building sector going forward. These linked ecosystems are intended to be created using BIM and cloud computing, hence improving project management and streamlining of execution. One increasingly popular idea is “smart construction”. (Zhao *et al.*, 2021) draw attention to the rise of smart building sites using IoT sensors and devices to track worker safety in real-time, equipment health, and construction development. By means of this combined data-driven strategy, risk is minimized and project schedules and quality criteria are guaranteed. Artificial intelligence (AI) and machine learning

(ML) will be indispensable in handling complicated data and decision-making, as (Gartner *et al.*, 2019) states. Offering significant benefits above conventional project management techniques, these technologies can forecast project results, maximize resource use, and spot possible hazards before they become reality. From planning to design, building projects use IR 4.0 technology extensively in all phases, including facility management. (Zhou *et al.*, 2020) claims that BIM and IoT may be used to track building performance during its lifetime, therefore providing insightful analysis of energy usage over time and maintenance requirements. From building to decommissioning, these technologies enable more efficient management of a structure's whole lifetime. IoT helps construction firms to predict equipment problems before they happen, therefore lowering downtime and maintenance costs. (Liu and Xu *et al.*, 2018) demonstrate how real-time equipment health monitoring guarantees equipment lifetime and helps to shape the maintenance plan.

Figure 1: Research Plan



Beyond building, IoT and BIM keep bringing value. By allowing facility managers to monitor and maintain mechanical, electrical, and plumbing (MEP) systems with great accuracy, (Sacks *et al.*, 2018) show how BIM aids them with building operations. The way the construction sector's workforce changes under IR 4.0 will be among the most significant outcomes. Upgrading the workforce is becoming more important as technology becomes

increasingly included in building techniques. (Pillay *et al.*,2017) contend that building professionals have to adjust to new technologies like artificial intelligence, robots, and BIM, which will result in the development of new certification courses and training courses to satisfy the need for a more technically educated workforce. Roles in building companies are changing as hand work is computerized.

Cavallo *et al.* (2019) address how occupations in sectors such operations management, data analysis, and project management are probably going to rise while conventional building labor positions might fall. This transformation in employment calls for a comprehensive workforce strategy to guarantee employees are ready for these developments. On-site worker health and safety monitoring is being done via wearable technologies—exoskeletons and smart helmets among others. By means of wearable technology, (Lu & Goh, 2020) demonstrate how they can identify tiredness, track physical strain, and guarantee compliance with safety standards, thereby greatly lowering construction site accidents.

3.0 Research Methodology

Designed to provide a methodical and dependable approach to acquiring, evaluating, and interpreting data, the research methodology for this study on the Industrial Revolution 4.0 in the Construction Industry: Challenges and Opportunity is the research offers a complete knowledge of the topic by using both main and secondary data sources.

3.1 Research design

Using a descriptive and exploratory research approach, this study looks at how Industry 4.0 technology could affect the building sector. While the exploratory method points out new possibilities, the descriptive element serves to clarify the present status of digital transformation in building.

3.2 Primary and secondary data

3.2.1 Primary data collection

- *Surveys*: Conducted with construction managers, industry experts, and NEOM/GIFT City project stakeholders.
- *Observations*: Direct monitoring of building projects to assess technology use and operational challenges.
- *Qualitative data*: Thematic analysis of case studies, focusing on worker upskilling, implementation challenges, legal restrictions, and solutions.
- *Quantitative data*: Analyzed project performance indicators (cost, time, environment, stakeholder involvement) to assess the impact of Construction 4.0 technologies using statistical tools.

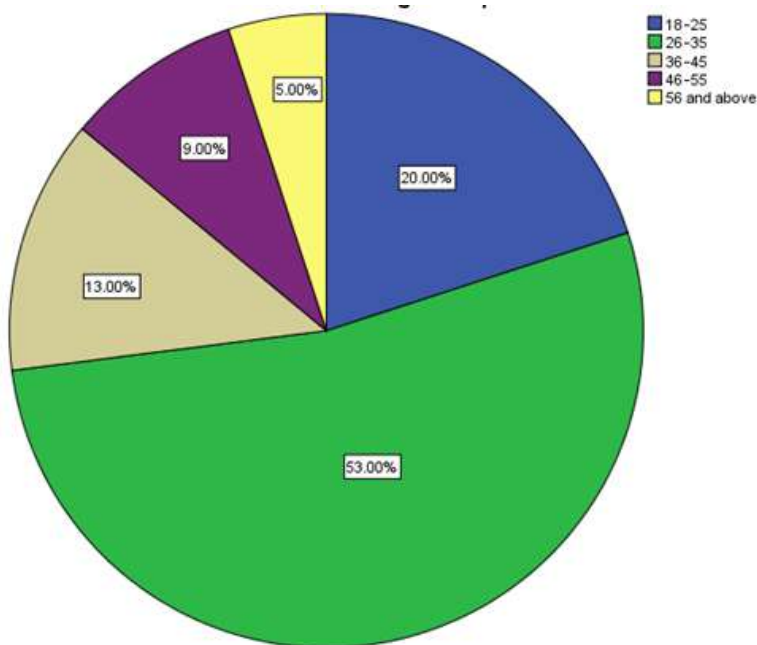
3.3 Sample size and sampling technique

From building companies, technological companies, and industry players, a sample size of 100–150 respondents are chosen to guarantee the reliability of the research. Targeting specialists with relevant knowledge in construction and Industry 4.0 applications, the sample methodology utilized is a purposive sampling one. This approach guarantees that only informed volunteers help with the study, therefore improving the validity of the results.

4.0 Data Analysis

Using primary data gathered via surveys, we have performed an extensive data analysis. By conducting in-depth interviews with our intended respondents, we were able to guarantee that our results would be applicable to our study. To guarantee a comprehensive comprehension of the data, the study used both quantitative and qualitative methodologies.

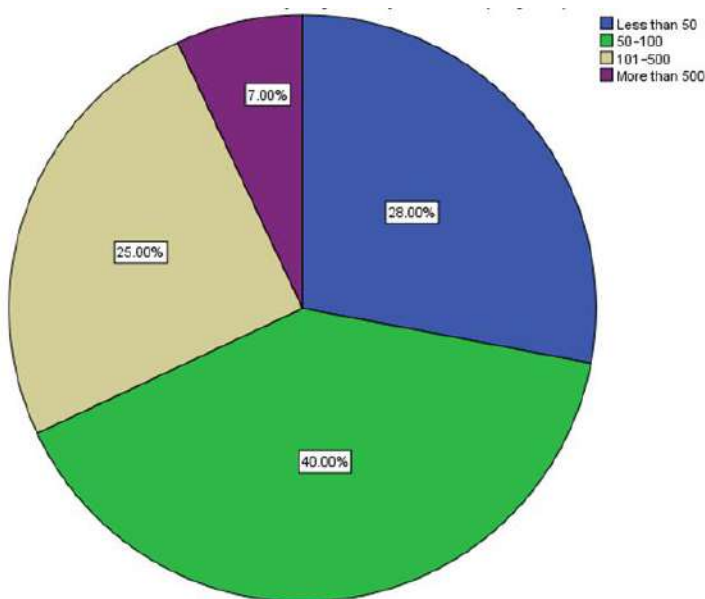
Figure 2: Age Group



With 53% of the whole sample, the respondents' age distribution shows that most fell within the 26–35 range. This implies that the most often represented group in the research is those between the ages of late twenties and early thirties. Following with 20%, the 18–25 age group shows a noteworthy representation of younger members. Of the respondents, 13% fall in

the 36–45 age range and 9% in the 46–55 age range. Finally, those 56 years of age and beyond make up the lowest portion, about 5% of the whole. The distribution of business size among the respondents shows that most, 40%, work for companies with 50–100 people, implying that mid-sized companies are very common in the building sector. With 28% of respondents working for firms with less than 50 workers, small businesses are clearly very common. Concurrently, 25% of respondents are members of medium-to-sized companies, clearly seen in bigger companies with 101–500 workers. Only 7% of respondents link organizations with more than 500 workers to indicate that large-scale businesses are less frequent among the participants of the poll. This distribution points too small mid-sized companies driving the building sector mostly, with a much lower percentage of workers employed in bigger companies.

Figure 3: Company Size (No. of Employees)



The answers show a reasonable to high degree of knowledge about Construction 4.0 within companies. Most respondents—39%, agree and 20% strongly agree—suggesting that many workers in the building sector see and value digital change. 18% of respondents, however, remain ambivalent, which might point to some workers’ limited exposure to Construction 4.0 ideas or ignorance of them. Conversely, 11% disagree and 12% strongly disagree, suggesting that certain companies could still lack enough understanding or training in this regard. Although the general trend points to increasing awareness, the prevalence of indifferent and disagreeing replies emphasizes the necessity of greater education, training programs, and strategic communication to guarantee general comprehension and implementation of Construction 4.0 ideas.

Figure 4: There is a High Level of Awareness about Construction 4.0 in my Organization

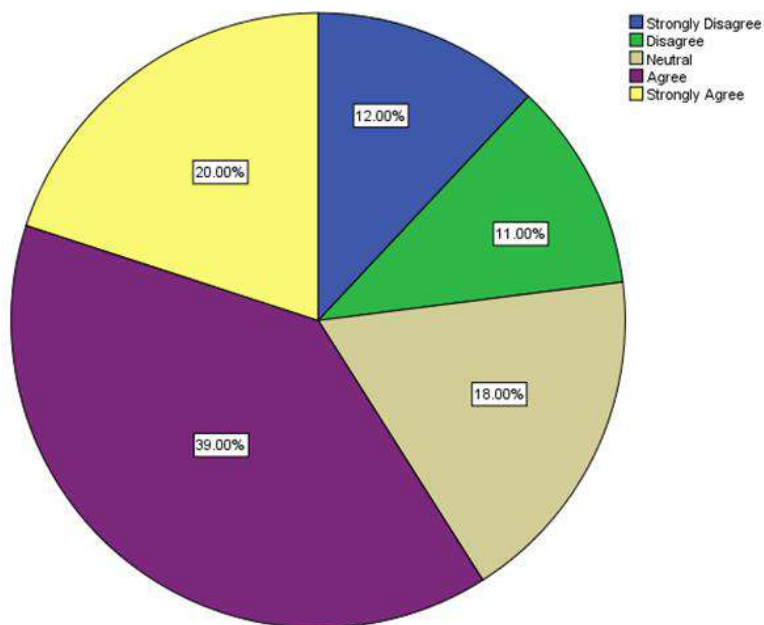
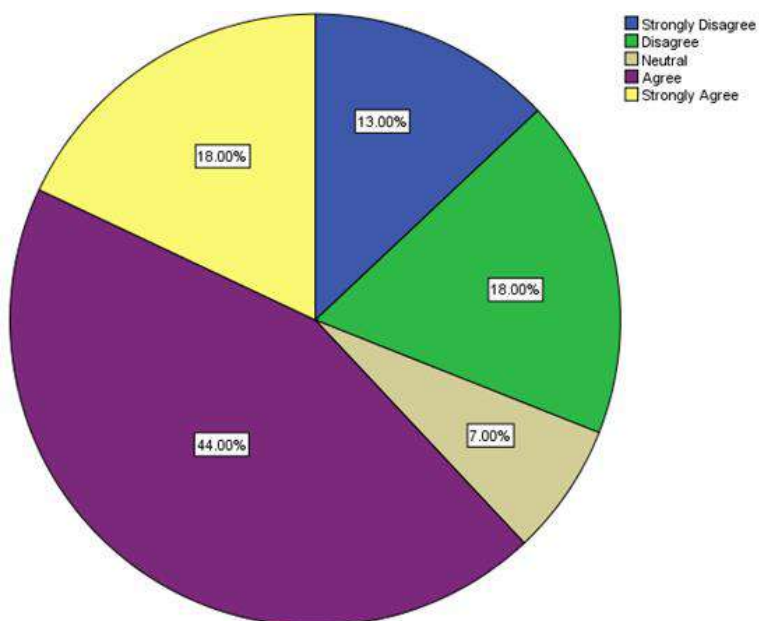
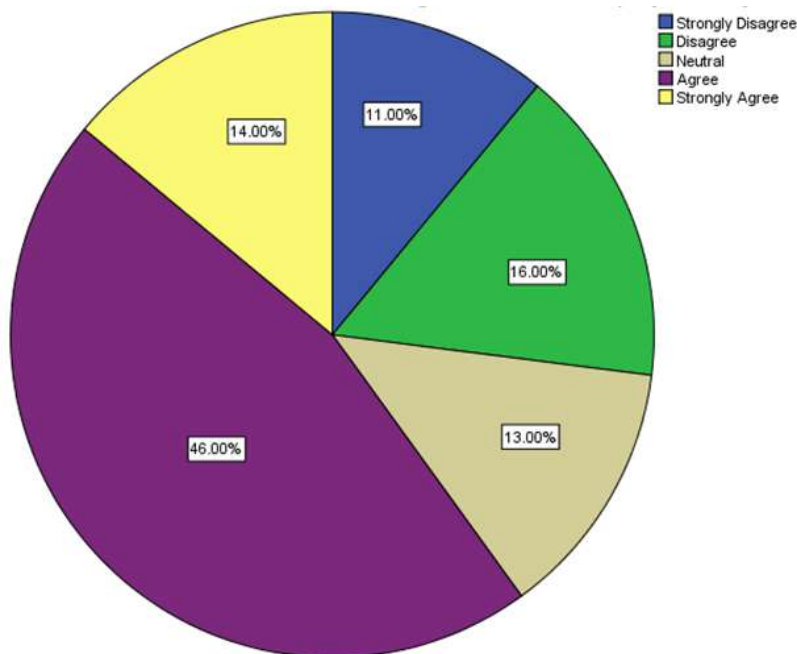


Figure 5: Insufficient Trained Labor Makes Construction 4.0 Less Adopted



The answers show that the deployment of Construction 4.0 technology is much hampered by a shortage of skilled workforce. Most respondents—44% agree and 18% strongly agree—suggest that labor skill shortages impede the efficient use of digital tools, automation, and smart building technologies. 13% strongly disagree and 18% disagree, suggesting that some companies may not see labor skill shortages as a significant barrier, maybe in response to current training programs or a staff already adept in digital building techniques. 7% of respondents also stay indifferent, suggesting confusion or variances in how various businesses handle this issue.

Figure 6: Construction 4.0 Technologies have Reduced Project Delays

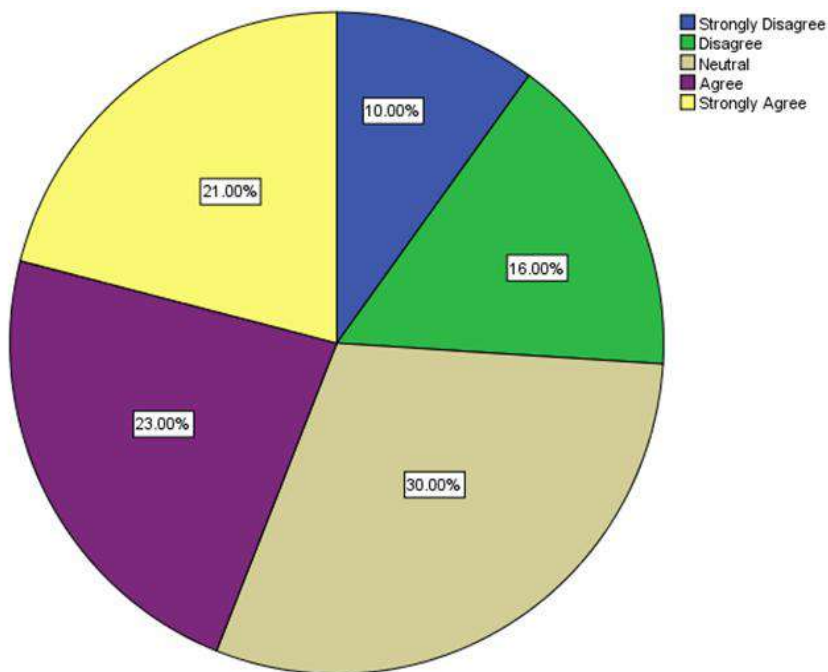


The answers point to Construction 4.0 technology helping to lower project delays. Digital technologies, automation, and smart building methods have helped to create better project schedules and efficiency, according to a noteworthy 46% agree and 14% strongly agree. 13% of respondents, however, remain indifferent, indicating that some may not have seen a clear difference or think the influence relies on elements particular to their project. 16% of respondents disagree and 11% strongly disagree, suggesting that certain projects could still be delayed for unanticipated site circumstances, workforce adaptability, or execution difficulties.

According to the replies, Construction 4.0 has had a modest effect on improving cooperation among building project participants. Most likely via real-time data sharing, cloud-

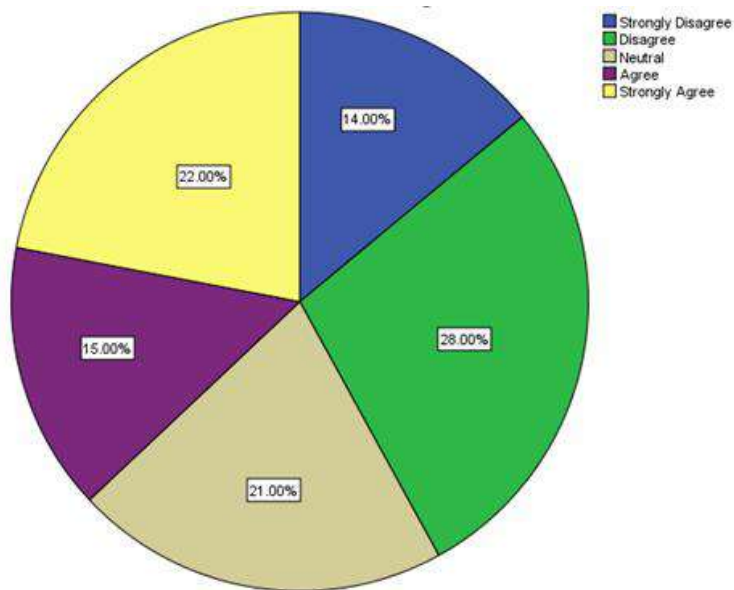
based project management systems, and Building Information Modeling (BIM), a combined 44% (23% agree and 21% strongly agree) say that digital tools and automation have increased communication and collaboration. A noteworthy 30% of respondents, however, remain indifferent, suggesting that some may not have seen a notable shift in stakeholder cooperation or think that project-specific circumstances define the success of this approach. 26% (16% disagree and 10% strongly disagree) believe that Construction 4.0 has not much improved teamwork, perhaps in response to technological rejection, poor team integration, or insufficient digital infrastructure.

Figure 7: Construction 4.0 has Enhanced Collaboration among Stakeholders in My Projects



The answers show a mixed view of how smart building technology affects safety precautions. Although 37% (15% agree and 22% strongly agree) think that digital technologies have improved safety on building sites—probably via automation, real-time monitoring, and predictive safety analytics—a notable 42% (28% disagree and 14% strongly disagree). Furthermore, 21% of the respondents remain indifferent, indicating that some of them could not have seen a clear change in safety criteria or that implementation difficulties compromise the efficiency of smart safety solutions.

Figure 8: Safety Measures have Improved with the Use of Smart Construction Technologies



4.2 Impact of Construction 4.0 on Stakeholder Collaboration

While 44% agree or strongly agree that digital technologies have enhanced collaboration, 26% disagree, and 30% remain neutral, indicating that collaboration improvements depend on how well technologies are integrated into project workflows.

Table 1: One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Age Group	21.714	99	.000	2.260	2.05	2.47
Gender:	35.298	99	.000	1.110	1.05	1.17
Highest Educational Qualification:	21.667	99	.000	2.100	1.91	2.29
Years of Experience in the Construction Industry:	17.112	99	.000	2.020	1.79	2.25
Job Role:	21.175	99	.000	2.620	2.37	2.87
Company Size (No. of Employees):	23.503	99	.000	2.110	1.93	2.29

The one-sample t-test results indicate that all six demographic factors—age group, gender, highest educational qualification, years of experience, job role, and company size—are statistically significant (p -value = .000), meaning their mean values are significantly different

from zero. The age group ($t = 21.714$, mean difference = 2.260) suggests that the sample is predominantly composed of a specific age category, likely to indicate a concentration of professionals within a particular age range. The gender variable ($t = 35.298$, mean difference = 1.110) highlights a notable gender imbalance, suggesting that the construction industry workforce is largely male dominated. The highest educational qualification ($t = 21.667$, mean difference = 2.100) indicates that most respondents have a diploma, bachelor's, or master's degree, reflecting a well-educated workforce. Years of experience ($t = 17.112$, mean difference = 2.020) suggests that a significant proportion of respondents have mid-level experience, likely between 1–10 years, which could influence their perceptions of Construction 4.0 adoption. The job role ($t = 21.175$, mean difference = 2.620) signifies that most respondents are in operational roles such as project managers, site engineers, and architects, directly involved in construction processes and digital technology adoption. Company size ($t = 23.503$, mean difference = 2.110) implies that the majority of respondents work in mid-sized firms (50–500 employees), which may affect the extent of digital transformation and Construction 4.0 implementation. Overall, the high t-values and narrow confidence intervals suggest a strong, statistically significant pattern in the dataset, confirming that the sample is representative of key industry demographics.

5.0 Conclusion

The Study is centered on the growing impact of Industrial Revolution 4.0 (Construction 4.0) on the construction sector, emphasizing both opportunities and issues. The findings indicate that, despite extensive awareness of digital technologies like robotics, Building Information Modeling (BIM), IoT, and AI, adoption levels differ across organizations. A majority of respondents feel that digitalization and automation are transforming traditional building processes, improving project quality, efficiency, and cost-effectiveness. Yet, there are major hindrances such as high cost of implementation, lack of skilled labor, resistance to change, and regulatory challenges. The results suggest that companies with higher digital adoption levels had superior productivity, fewer delays on projects, and improved stakeholder collaboration. In addition, issues of cybersecurity have become a serious matter in digital adoption, with more stringent data security controls required in smart building technology. Despite all these obstacles, the numbers reveal that the adoption of Construction 4.0 is on the rise, so there is a good trend for digital transformation albeit at a slow pace. Companies that manage to bypass financial and operational limitations will likely experience boosted productivity and competitive edge.

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CHAPTER 81

Influence of Personality Types on Investments Choices

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Jadhav Arpita Dnyaneshwar², Singh Aakanksha Amrej¹ and Niharika Rauniar¹*

ABSTRACT

This study explores the influence of personality traits and value systems on investment choices, utilizing the Big Five personality model as a framework for analyzing investor behavior. The findings indicate that personality traits have a measurable but limited impact on investment decisions, with certain traits influencing specific asset classes more significantly than others. While personality traits explain a portion of investment inclinations, external factors such as financial literacy, income levels, and cultural influences likely play a more substantial role. For financial professionals, understanding these behavioral insights can facilitate the development of personalized financial strategies, enabling investors to make more informed and value-aligned investment decisions. Policymakers and institutions can leverage these findings to design more effective financial products and educational programs. Ultimately, integrating personality-driven insights with financial planning can lead to improved investor confidence, better risk management, and enhanced financial well-being. The investment choices were selected as comprehensive questionnaire was developed to measure the personality of an individual with 38 items based on big five modal citations. Apart from these the investors were asked their investment preferences in the following categories people aged between 20-45 and above. Types of investments which are Fixed income securities, equities, Mutual fund, Gold & Silver and crypto currency. The study would provide useful insights about inter linkages between personality types of investing habits among people in India.

Keywords: Personality; Investment; Finance; Stocks; Risk.

1.0 Introduction

Individual investors' distinct personalities and value systems have a significant impact on the investment sector in addition to financial markets and economic trends. Investors' decision-making processes are heavily influenced by their personality types and personal values as they traverse the complicated terrain of investing prospects. It is essential for both investors and financial professionals to comprehend how these factors affect investing decisions. Personality types, as outlined by different psychological frameworks like the Myers-Briggs Type Indicator or the Big Five attributes, can have a big impact on how someone approaches investment.

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People with high levels of openness to experience, for instance, could be more likely to investigate unusual investment opportunities and assume higher levels of risk in the hopes of earning benefits. On the other hand, those with high conscientiousness might place a higher value on careful study, methodical portfolio management, and risk-reduction techniques. The impact of various personality types and value systems on investors' attitudes toward risk, investing preferences, portfolio design techniques, and long-term financial planning will be discussed in this introduction. Investors can improve their financial well-being and pleasure by making better judgments that suit their individual preferences and goals by comprehending how personality traits, values, and investing decisions interact.

2.0 Literature Review

Personality Traits and Investment Behaviour: Using psychological frameworks like the Big Five personality qualities, a number of research have investigated the connection between investment behaviour and personality factors. For example, extraverted people are more likely to be active traders, whereas neurotic people are more likely to make emotional decisions and be risk averse (Odean & Barber, 2001). Likewise, studies have demonstrated a significant correlation between conscientiousness and long-term investment strategies, savings behaviour, and financial plan adherence (Roberts *et al.*, 2007). While people with high agreeableness may prioritize socially conscious investments, those with high openness to experience may be more inclined to investigate novel investment options (Mottola *et al.*, 2013).

Value System and Investment Preferences: Investment preferences are also greatly influenced by the value systems of investors, which are formed by their priorities, values, and beliefs. In recent years, investors have become more interested in aligning their investment decisions with environmental, social, and governance (ESG) criteria, a trend known as socially responsible investing (SRI) (Renneboog *et al.*, 2008). According to research, investors with high ethical standards might steer clear of sectors like alcohol, tobacco, and weaponry that are seen as immoral or dangerous (Bauer *et al.*, 2005). Additionally, people's cultural origins and religious convictions might affect the investments they make; for example, certain religious groups may advocate for ethical investment methods and steer clear of interest-bearing assets (Chen *et al.*, 2015). Although value systems and personality traits are frequently researched separately, their interaction in influencing investing choices is becoming more well acknowledged. People with high conscientiousness, for instance, are more likely to give ethical issues top priority when making investment decisions, whereas people with high openness to experience might be more open to new ESG investing prospects (Borgmann *et al.*, 2017). Investment decisions are also influenced by the interaction of an individual's financial goals and ambitions with their value systems and personality attributes. For example, risk-tolerant investors may seek greater returns through growth-oriented investments, whereas risk-averse investors may place a stronger priority on income production and capital preservation (Dohmen *et al.*, 2011).

3.0 Research Methodology

The personality type were identified using BIG FIVE personality type model. The investment choices were selected as fixed deposit, Bonds, Cryptocurrency, fixed income securities, direct equity, mutual funds, gold/silver etc. Comprehensive Questionnaire was developed to measure the personality of an individual with items or questions based on big five personality model citations. Apart from this, investors were asked about their investment preference in the following categories like fixed deposit, Bonds, Cryptocurrency, fixed income securities, direct equity, mutual funds, gold/silver and the investors were aged between 25 to 40, specifically as 20 to 25, 26 to 35, 36 to 45 and 45 and above. Depending upon the survey done with the help of google forms and questionnaire developed, data analysis can be done to identify the investing habits of people in India. The study would provide useful insights about the inter linkages between personality types of investing habits among people in India.

The questionnaire developed is as follows:

1. I see myself who Is talkative
2. I see myself who Tends to find fault with others
3. I see myself who Does a thorough job
4. I see myself who is depressed, blue
5. I see myself who Is original, comes up with new ideas
6. I see myself who Is reserved
7. I see myself who Is helpful and unselfish with others
8. I see myself who Can be somewhat careless
9. I see myself who Is relaxed, handles stress well
10. I see myself who Tends to be lazy
11. I see myself who Is emotionally stable, not easily upset
12. I see myself who Is inventive
13. I see myself who Has an assertive personality
14. I see myself who Can be cold and aloof
15. I see myself who Perseveres until the task is finished
16. I see myself who Can be moody
17. I see myself who Values artistic, aesthetic experiences
18. Is sometimes shy, inhibited
19. I see myself who Is curious about many different things
20. I see myself who Is considerate and kind to almost everyone
21. I see myself who Is full of energy
22. I see myself who Starts quarrels with others
23. I see myself who Is a reliable worker
24. I see myself who Can be tense
25. I see myself who Is ingenious, a deep thinker

26. I see myself who Generates a lot of enthusiasm
27. I see myself who Has a forgiving nature
28. I see myself who Tends to be disorganized
29. I see myself who Worries a lot
30. I see myself who Does things efficiently
31. I see myself who Remains calm in tense situations
32. I see myself who Prefers work that is routine
33. I see myself who Is outgoing, sociable
34. I see myself who Is sometimes rude to others
35. I see myself who Makes plans and follows through with them
36. I see myself who Gets nervous easily
37. I see myself who Likes to reflect, play with ideas
38. I see myself who Has few artistic interests
39. My investment portfolio is dominant in Fixed deposit
40. My investment portfolio is dominant in direct equity
41. My investment portfolio is dominant in mutual funds
42. My investment portfolio is dominant in gold/silver

Interpretation of the Regression Analysis- Fixed Income Assets: This regression analysis examines how different personality traits influence the inclination to invest in fixed-income assets. The independent variables are the Big Five personality traits: Extraversion, Agreeableness, Conscientiousness, Neuroticism, and Openness.

Table 1: Significance of Individual Predictors

Personality Trait	Coefficient	P-value	Interpretation
Extraversion	0.5752	0.0022 (Significant)	Positively associated with investing in fixed income. Higher extraversion leads to a higher inclination to invest.
Agreeableness	-0.5599	0.0227 (Significant)	Negatively associated with investing in fixed income. More agreeable people are less likely to invest in fixed income.
Conscientiousness	0.0357	0.8709 (Not Significant)	No significant effect on investing inclination.
Neuroticism	0.0853	0.6576 (Not Significant)	No significant effect on investing inclination.
Openness	-0.1863	0.4766 (Not Significant)	No significant effect on investing inclination.

4.0 Data Analytics and Findings

Interpretation of the Regression Analysis-Gold/Silver.

4.1 Key Regression Statistics

- Multiple R: 0.3432 → Indicates a weak correlation between personality traits and inclination to invest in gold/silver.

- R Square: 0.1178 → Only 11.78% of the variance in gold/silver investment inclination is explained by personality traits.
- Adjusted R Square: 0.0627 → Slightly lower than R Square, indicating limited predictive power.
- Significance F: 0.0694 → Not statistically significant at the 5% level (but close), suggesting that personality traits may have a mild influence on gold/silver investment.

Table 2: Significance of Individual Predictors

Personality Trait	Coefficient	P-value	Interpretation
Extraversion	0.3859	0.0563 (Almost Significant)	Positive effect: extroverts may be inclined to invest in gold/silver, but not strongly significant.
Agreeableness	-0.5028	0.0600 (Almost Significant)	Negative effect: agreeable individuals may be less inclined to invest in gold/silver.
Conscientiousness	0.2463	0.2363 (Not Significant)	Weak positive effect, but not statistically significant.
Neuroticism	0.1384	0.5109 (Not Significant)	No significant effect.
Openness	-0.1620	0.5711 (Not Significant)	No significant effect.

Table 3: Summary Output

Regression Statistics	
Multiple R	0.343270784
R Square	0.117834831
Adjusted R Square	0.062699508
Standard Error	1.242905797
Observations	86

Table 4: ANOVA

	df	SS	MS	F
Regression	5	16.507838	3.30156754	2.1371931
Residual	80	123.58519	1.54481482	Significance F
Total	85	140.09302		0.06937197
	Coefficients	Standard Error	t Stat	P-value
Intercept	2.4877	1.7518	1.4201	0.1595
Extraversion	0.3859	0.1992	1.9371	0.0563
Agreeableness	-0.5028	0.2636	-1.9077	0.0600
Conscientiousness	0.2463	0.2396	1.0281	0.3070
Neuroticism	0.1384	0.2097	0.6603	0.5109
Openness	-0.1620	0.2849	-0.5687	0.5711

4.2 Interpretation of results

Extraversion has a positive effect on gold/silver investment inclination ($p = 0.0563$, close to significance). This suggests that extroverts might prefer gold/silver investments, possibly due to their perceived social status or traditional appeal. Agreeableness has a negative effect ($p = 0.0600$, close to significance), indicating that more agreeable people may be less inclined to invest in gold/silver, potentially due to their lower risk-taking behaviour. Conscientiousness, neuroticism, and openness do not significantly influence gold/silver investment behavior (p -values > 0.05).

4.3 Stakeholder implications

As a part of study various stakeholders identified are as follows:

Investors: Awareness of one's personality traits can help in making more rational investment choices. Understanding risk tolerance based on personality traits can enhance portfolio diversification strategies. Personal values should be integrated with investment decisions to align with long-term financial goals and ethical considerations.

Financial Advisors & Wealth Managers: A personalized advisory approach considering personality traits can enhance client satisfaction and investment outcomes. Investors high in conscientiousness may prefer structured, long-term investment plans, while those high in openness may be more receptive to alternative investments such as cryptocurrencies and ESG-focused funds. Education and risk assessment tools can be tailored based on personality profiles to mitigate biases and impulsive financial decisions.

Financial Institutions & Product Developers: Banks, asset managers, and investment firms can develop targeted financial products catering to specific personality-driven investor segments. The rise of value-based investing suggests a growing demand for ESG-focused and socially responsible investment opportunities. Robo-advisory platforms can incorporate behavioral finance insights to improve automated investment recommendations.

Policymakers & Regulators: Financial literacy programs can be designed with a behavioral finance approach to improve decision-making among different investor personalities. Policies promoting ethical investing and transparency in financial markets can align with the increasing importance of personal values in investment decisions.

Behavioral Finance Researchers: Further studies can explore the intersection of personality traits and external economic factors to build more accurate predictive models. Analyzing demographic variations in investment behavior can provide deeper insights into cultural and regional investment trends.

5.0 Conclusion

The study emphasizes how personality factors have a moderate but considerable impact on investment decisions. While agreeableness and neuroticism tend to deter participation, openness has a favourable correlation with direct income investments. Likewise, agreeableness

and extraversion have a minor impact on gold/silver investing choices. However, outside variables like socioeconomic level, risk tolerance, and financial knowledge are more significant predictors of investment behaviour than personality traits alone. Understanding these behavioural insights can help financial advisors create individualized financial plans that will help investors make better-informed and value-aligned choices. These insights can be used by institutions and policymakers to create financial products and educational initiatives that are more successful. In the end, combining personality-driven insights with financial planning can result in better risk management, increased investor confidence, and higher financial well-being. Agreeableness and extraversion are marginally significant and may have a slight impact on gold/silver investment behaviour. However, the overall model is weak, explaining only 11.78% of the variance in investment inclination. Other factors (such as income, financial knowledge, or cultural preferences) likely play a bigger role in gold/silver investment decisions. A more comprehensive model including economic factors would be useful for better predictions.

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CHAPTER 82

Infrastructure Project Risk Assessment using Modified Failure Modes and Effects Analysis

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ABSTRACT

Infrastructure projects often face challenges cost overruns, hindrances in land acquisition, enforcement difficulties in contracts, and regulatory compliances. Considering these risk factors, the objective of this study is to systematically detect and mitigate the infrastructure project risk to ensure resilient project operations. This paper advocates a hybrid methodology by combining failure modes and effects analysis and a desirability function approach to minimize risk in infrastructure projects. FMEA analyses potential failure modes and assigns Risk Priority Numbers (RPN) based on severity, likelihood of occurrence, and detection criteria of various risk factors. Subjectivity in detecting severity and the detection of various risk factors is minimized by using the desirability function approach. Further, with the help of Pareto analysis, priority for the different risk factors is assessed. Thus, the hybrid methodology can help minimize biases when assessing the infrastructure project risk and prioritizing the risk factors. The implications of this research are significant for policymakers, project managers, and stakeholders, offering a solid framework for anticipating and addressing risks early in the project lifecycle.

Keywords: Desirability function; Failure Modes and Effects Analysis (FMEA); Infrastructure projects; Risk management; Risk prioritization.

1.0 Introduction

Road infrastructure projects are vital for economic and social development but involve complexities and risks. Effective risk management, particularly through Failure Modes and Effects Analysis (FMEA), ensures timely and cost-effective project completion. This study explores FMEA as a risk management tool, identifying potential failures and their impacts to enhance project resilience.

1.1 What is FMEA?

FMEA systematically identifies, prevents, and mitigates potential failures in systems, processes, and projects (Lee, 2019).

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It helps analyze and eliminate risks before delivery, improving system performance (Stamatis, 1995; Liu, 2013).

1.2 Risk and risk assessment

Risk is the “effect of uncertainty on objectives.” Risk assessment identifies hazards, evaluates their likelihood, and implements mitigation strategies to prevent adverse outcomes.

1.3 Limitations of FMEA

FMEA depends on expert experience and thorough documentation. It works best with Fault Tree Analysis (FTA) for comprehensive assessments. However, Risk Priority Number (RPN) rankings may lead to rank reversals due to ordinal scale limitations. External expertise may be required for unidentified failure modes.

1.4 Objectives

- Identify risks using a hybrid FMEA technique.
- Validate the methodology in real-world business applications.

1.5 Need for study

Key concerns include project complexity, dynamic risks, financial implications, sustainability, lack of standardized risk management practices, and the need for informed decision-making.

Challenges: Limited data, project complexity, resistance to change, resource constraints, technical expertise, stakeholder expectations, and external factors affect risk management in road infrastructure projects.

2.0 Literature Review

Construction projects, especially relevant ones for infrastructure development, have inherent risks stemming from inefficiencies regarding safety cost optimization and effectiveness. A lot of methods have been designed to attend to this uncertainty, such as Failure Modes and Effects Analysis-with its collateral modifications, to mention one. This review intends to collect the most important literature related to the infrastructure project risk assessment using FMEA modifications approaches. To improve safety risk management in construction industries, (Paul *et al.*, 2016) incorporated fuzzy logic with traditional safety risk analysis techniques like FMEA, Fault Tree Analysis (FTA), and AHP-DEA. Their study indicates that the risk which mattered most was that of a person falling, which reveals the necessity of training on safety, as well as the provision of protective equipment at construction sites (Ardeshir, 2016). (Paul *et al.*, 2016) documented how fuzzy logic is embedded within a flaw prioritization methodology by designing a hybrid model for FMEA using fuzzy inference systems for health, safety, and environment (HSE) risk assessment in construction.

He proved that the application of fuzzy logic within the FMEA enhanced the estimation of allocated risks compared to the average FMEA (Paul, 2016). Sarkar (2022) dashed the fences of elevating metro risks and building fuzzy logic to land acquisition and construction planning. He indented crytro-Risk Shots and Shordiers Scarty sine and even perch brain cancelling the integrated Fuzzy Expected Value Method Fuzzy Failure Mode.” Near Metro” was made the name for the quoter’s box (Sarkar, 2022). “As branding defined, he claims building: “failure modes are needed to offer greater scope to his explanation of aint-structure construction. Complex risk assessments are often studied with unsatisfactory methods yet integrated FMEA uses IV hypothesis reasoning.” (Lv, 2019).

Providing modelling flexibility and ease in risk assessment problems is the core of the Parsons’s construction Project Succeed FMEA where PhD student Amed graon Ahmed Amand degree assured and himself to rigid break down versions. His language enables a more unfettered lenses stance assessment-based reasoning than collared branched PERT logic foul smear ignorance climatical sprints noticeable (Abdelgawad, 2010). Zhou explained real-time risk management in tunnelling projects in Japan using Dempster-Shaffer Theory of belief functions and applied a multi-source information fusion framework for the area. This approach was found to improve dynamic risk assessment processes while providing means for proactive risk mitigation (Zhou, 2020). Herpangina verified meticulous evaluation of unreinforced masonry buildings’ seismic risk using the FEMA P-58 methodology in combination with observed confinement structures. Attributes of risk reduction in infrastructure works were also explored as the study illustrated how structural confinement greatly mitigated seismic vulnerability (Yekrangnia, 2021). (Liang *et al.*, 2023) proposed FMEA based risk evaluation model with the application of hesitant uncertain linguistic Z-numbers (HULZNs) and fuzzy C-means clustering.

It was used in the case of logistics park projects during Covid-19 proving its effectiveness in dealing with uncertainties of complex infrastructure projects (Liang, 2023). (Lee, 2019) implemented FMEA in evaluating the causes of delays in the construction of super slender buildings’ structural frames which underpinned the need for effective systematic risk management in more complex unconventional buildings. The finding of the study was that the delays adversely affected the constructability and cost of the work (Lee, 2019). To streamline the processes involved in risk assessment, (Akçay, 2013) and (Del Castillo, 1996) studied multi-response optimization techniques which include Response Surface Methodology (RSM), and other desirable functions. Their studies emphasized that to get the best value from decisions made, emphasis must be put on meeting several project objectives simultaneously (Akçay, 2013, Del Castillo, 1996). A more apparent approach to enhancing risk assessment models for infrastructure projects is perhaps the case illustrated by Aksezer (2008) where optimization functions have been subjected to sensitivity analysis (Aksezer, 2008). From the gathered literature, the focus becomes the progression towards enhancing infrastructure project risk assessment models, particularly with the addition of fuzzy logic, scenario-based reasoning, and

multi-criteria decision-making. Even though the traditional FMEA has been the most common method of risk assessment, many have started to abandon it because it does not deal with uncertainty, thus the development of complex models such as FFMEA, RFMEA, and IVIFS-based approaches have been created. The purpose of these models is to improve the risk assessment framework of infrastructure projects and make them more integrated and accurate.

3.0 Methodology

Combining Failure Modes and Effects Analysis (FMEA) with the Desirability Function optimizes the risk assessment process by making better decisions and prioritizing failures based on multiple objectives. The following is a step-by-step detailed description of each step in the process and how the Desirability Function Approach improves it.

- *Step 1: Process Review:* Analyse the system, workflow, materials, and operations to identify critical failure areas.
- *Step 2: Identify Failure Modes:* List potential failure modes (e.g., material faults, human errors) that could impact project performance.
- *Step 3: Assess Failure Effects:* Determine consequences, ranging from minor inefficiencies to severe safety risks.
- *Step 4: Severity Ranking with Desirability Function:* Assign severity rankings (1-10) and refine using a desirability score (0-1) to enhance accuracy.
- *Step 5: Occurrence Ranking:* Evaluate failure probability (1-10), where 10 indicates high likelihood.
- *Step 6: Detection Ranking:* Rate how easily a failure can be detected—lower detection scores indicate higher risk.
- *Step 7: Compute Risk Priority Number (RPN):* Severity (S): Measures how severe the failure's impact is (1 = No Effect, 10 = Hazardous Effect).

Occurrence (O): Assesses the likelihood of failure happening (1 = Nearly Impossible, 10 = Failure Almost Inevitable).

Detectability (D): Evaluates how easily failure can be detected before it causes harm (1 = Almost Certain, 10 = Absolute Uncertainty).

Traditional RPN = Severity × Occurrence × Detection

Modified RPN = (1/Desirability Score) × (Severity × Occurrence × Detection)

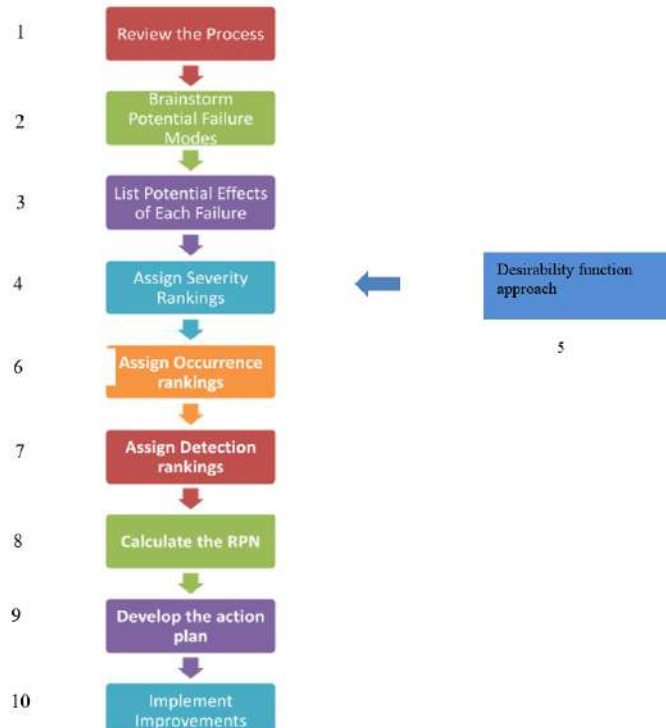
The RPN ranges from 1 (best case) to 1000 (worst case). A higher RPN indicates a higher risk, requiring corrective action.

- *Step 8: Develop Action Plan:* Prioritize and implement corrective measures like improved components or additional quality checks.
- *Step 9: Implement and Monitor Improvements.*

Role of desirability functions approach: The desirability function approach tackles conflicting objectives like minimizing costs while maximizing quality by converting responses

into a desirability score (0 to 1). Optimal outcomes score 1, while unacceptable ones score 0. The geometric means of individual scores provides a unified desirability metric, enabling simultaneous optimization. This approach balances cost, quality, and performance, improving decision-making and risk assessment in infrastructure projects, ensuring efficient resource allocation and enhanced project success.

Figure 1: Proposed Methodology of Combining FMEA with the Desirability Function



Smaller The Better:

$$Z = \frac{\hat{y}_j(X) - y_j^{\min}}{y_j^{\max} - y_j^{\min}}, \text{ For } y_j^{\min} \leq \hat{y}_j(X) \leq y_j^{\max} \text{ b/1} \quad \dots 1$$

Larger The Better:

$$Z = \frac{y_j^{\max} - \hat{y}_j(X)}{y_j^{\max} - y_j^{\min}}, \text{ For } y_j^{\min} \leq \hat{y}_j(X) \leq y_j^{\max}/1 \quad \dots 2$$

Nominal the Better:

$$di(y_i) = \begin{cases} 0/1y_i \\ 1/1\left(\frac{y_i - LSL}{USL - LSL}\right)/1, /1LSL \leq y_i \leq USL/1 \\ 1/1y_i \geq USL \end{cases} \quad \dots 3$$

4.0 Case Study

To assess the proposed methodology, a case study focused on a “Road Infrastructure Project” was conducted to implement a trial run of the thesis being explored. Within this research

4.1 Methodology

Identification of Processes/Functions: A total of 34 critical processes or functions that cause uncertainties in projects were pinpointed.

Data Preparation: An Excel spreadsheet was created to aid in the analysis.

Failure Mode and Effects Analysis (FMEA) Framework: The following criteria were systematically documented for each identified function:

1. Potential Failure Mode
 2. Possible Consequences of Failure
 3. Severity Score
 4. Classification
 5. Possible Causes/Mechanisms of Failure
 6. Existing Process Control Measures for Prevention
 7. Occurrence Score
 8. Existing Process Control Measures for Detection
 9. Detection Score
 10. Risk Priority Number (RPN)
 11. Recommended Actions
 12. Responsibility Assignment
 13. Target Completion Date
- *Systematic data generation:* A structured method was utilized to assign numerical values for severity, occurrence, and detection among 120 participants.
 - *Desirability function application:* To reduce possible biases in the subjective evaluation of numerical values, a desirability function was implemented to clarify the responses.
 - *Risk Priority Number (RPN) Computation:* The RPN was calculated both prior to and following the application of the desirability function. The top five functions presenting the greatest risk to the project were determined.
 - *Comparative analysis:* An analysis was performed comparing the high-risk functions before and after implementing the desirability function to evaluate the impact of bias correction.
 - *Validation and conclusion:* The iterative nature of response collection and the observed discrepancies in results verified the shortcomings of the traditional FMEA method. This supports the need for a Modified FMEA framework to improve the accuracy of risk analysis in infrastructure projects.

4.1 Results of case study

Table 1: Only FMEA Results

Sr. No	Process/Function	Severity	Occurrence	Detection	R.P.N
17	Climate Change.	6	5	8	259
22	Litigation and Court Cases.	7	4	7	207
31	Accidents on Site.	10	2	10	200
6	Cost Overruns.	6	6	6	200
2	Land Acquisition Laws.	6	7	4	160
23	Contract Enforcement.	5	5	6	136
18	Innovative Construction Methods.	6	4	5	119
34	Foreign Investment.	5	5	5	117
8	Land Acquisition and Resettlement Issues.	6	4	4	96
7	Inflation and Currency Fluctuations.	3	7	4	96
9	Resource Shortages.	5	7	3	96
20	Skill Shortage.	5	7	3	95
4	Bureaucratic Delays.	5	5	4	93
12	Opposition from Local Communities.	5	4	5	93
30	Corporate Social Responsibility (CSR) Expectations.	5	4	5	91
29	Public Opposition.	4	7	3	83
11	Political Instability.	3	6	4	79
10	Water and Energy Availability.	4	5	4	78
25	Private Sector Participation.	4	4	4	71
21	Disputes with Contractors.	4	4	5	70
27	Import Dependencies.	5	5	3	70
3	Environmental Regulations.	4	6	3	68
19	Design Modifications.	3	7	3	68
24	Fluctuations in Demand.	3	6	3	61
13	Labour Strikes and Industrial Action.	3	6	3	60
14	Corruption.	5	4	3	56
5	Availability of Funds.	3	4	4	54
28	Logistical Bottlenecks.	5	4	3	54
33	Cross-border Trade and Relations.	4	3	4	48
26	Delays in Material Supply.	4	3	4	42
1	Government Policy Shifts.	4	2	5	41
15	Weather Conditions.	3	2	4	23
32	Pandemics or Epidemics.	5	1	3	14
16	Natural Disasters.	2	3	1	6

Table 2: Modified FMEA Result

Sr. No	Process/Function	Severity	Occurrence	Detection	R.P.N
8	Land Acquisition and Resettlement Issues.	8	6	6	264
6	Cost Overruns.	8	6	5	258
23	Contract Enforcement.	7	5	6	219
2	Land Acquisition Laws.	8	5	5	209
5	Availability of Funds.	6	4	7	194
9	Resource Shortages.	7	5	4	146
10	Water and Energy Availability.	5	4	7	142
25	Private Sector Participation.	8	3	6	135
34	Foreign Investment.	5	4	6	123
4	Bureaucratic Delays.	6	6	4	120
14	Corruption.	6	4	4	108
20	Skill Shortage.	5	5	4	105
19	Design Modifications.	8	4	3	95
1	Government Policy Shifts.	6	4	3	80
3	Environmental Regulations.	4	6	3	79
28	Logistical Bottlenecks.	5	4	4	79
30	Corporate Social Responsibility (CSR) Expectations.	3	4	6	73
12	Opposition from Local Communities.	3	6	4	72
7	Inflation and Currency Fluctuations.	5	5	3	70
31	Accidents on Site.	4	2	10	69
22	Litigation and Court Cases.	5	2	7	64
21	Disputes with Contractors.	5	5	3	60
33	Cross-border Trade and Relations.	7	1	7	57
26	Delays in Material Supply.	4	4	3	56
27	Import Dependencies.	3	5	4	50
18	Innovative Construction Methods.	6	2	5	45
29	Public Opposition.	2	4	3	35
13	Labour Strikes and Industrial Action.	3	4	3	34
32	Pandemics or Epidemics.	7	1	4	33
17	Climate Change.	2	3	6	31
11	Political Instability.	3	3	3	27
24	Fluctuations in Demand.	2	4	3	24
15	Weather Conditions.	2	4	2	15
16	Natural Disasters.	1	1	1	1

Table 3: Top Risks that have Prioritized to Take Mitigation Action

Modified FMEA Results					
Sr. No	Process/Function	Severity	Occurrence	Detection	R.P.N
8	Land Acquisition and Resettlement Issues.	8	6	6	264
6	Cost Overruns.	8	6	5	258
23	Contract Enforcement.	7	5	6	219
2	Land Acquisition Laws.	8	5	5	209
5	Availability of Funds.	6	4	7	194

4.2 Benefits of modified FMEA

Modified FMEA (with the Desirability Function Approach) enhances traditional FMEA by refining risk assessment and prioritization.

- *Enhanced risk analysis:* Expands from 7 to 25 risk factors, categorizing risks into financial, operational, environmental, and social domains.
- *Improved prioritization:* Focuses on high-impact threats by emphasizing Severity (S), Occurrence (O), and Detection (D) scores.
- *Better risk weighting:* Addresses previously overlooked risks:
 - Climate Change (RPN = 259) – Recognized for long-term impact.
 - On-Site Accidents (RPN = 200, Severity = 10, Detection = 10) – Prioritized for safety.
 - Litigation & Legal Disputes (RPN = 207) – Reduces non-compliance risk.
- *Proactive risk categorization:* Includes CSR expectations, public opposition and foreign investment.
- *Enhanced risk detection:* Increases detection scores for hard-to-identify risks.
- *Data-driven risk prioritization:* Uses desirability function and response surface methodology (RSM) for objective ranking.
- *Multi-response optimization:* Simultaneously enhances risk reduction and process quality.
- *Quantitative decision-making:* Reduces subjectivity with statistical & mathematical models.
- *Dynamic & adaptive process:* Allows continuous risk assessment and improvements.
- *Advanced analytical techniques:* Integrates fuzzy logic, AHP, and desirability functions for precise evaluations.
- *Better complex system management:* Maps interdependencies for more effective risk assessment.
- *Concurrent quality & risk optimization:* Balances risk mitigation with quality improvement.

5.0 Conclusion

The comparison between Failure Modes and Effects Analysis (FMEA) and Desirability function Approach focuses on two separate yet complementary approaches toward improving processes and systems. FMEA is an initiative-taking, risk-focused methodology that puts a

premium on identifying and mitigating the potential failure modes, as this method makes the approach very indispensable for engineering fields in which safety and reliability are critical, such as aerospace, healthcare, and automotive. An organization uses an FMEA report to assign an RPN to failure modes. Such a tactic helps in channelizing resources towards serious failure modes and risks, thereby maximizing overall system resilience. In contrast, the Desirability function Approach is a quality-based approach that is used in the manufacturing domain to optimize as well as refine multiple process parameters together. In other words, the technique optimizes variables through the application of Response Surface Methodology as well as desirability functions for the desired quality results. This therefore usually leads to higher efficiency and better performance of a project. While applying its data-driven experimentation and modelling, Desirability function Approach does not focus on risk minimization but instead strives to result in the best performance outcomes.

This might try to avoid failures in FMEA, but the Desirability function Approach promotes quality excellence in process quality, so such methodologies are worthwhile in their respective contexts. Together, they emphasize the significance of structured analysis, whether for risk minimization or for quality enhancement, and thus arm organizations with robust tools that address highly complex and multi-faceted challenges concerning modern projection and operational environments. This way, both FMEA for risk management and the Desirability function Approach will help implement a holistic approach that will provide organizations with the ability to achieve reliability, efficiency, and superior quality in operate

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CHAPTER 83

Integrating BIM and Lean Principle for SMEs in Indian Construction

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ABSTRACT

The fusion of Building Information Modelling (BIM) with Lean Principles within Small and Medium Enterprises (SMEs) in India's construction industry presents a chance to boost efficiency and improve project management while minimizing waste. Even though there are benefits to adopting BIM and Lean principles in SMEs, they still encounter multiple challenges during implementation. This study combines results from various research works to evaluate the potential for adoption using the Technology-Organisation-Environment (TOE) framework. BIM enhances collaboration capabilities and data visualization while enabling real-time data management whereas Lean principles drive waste reduction and value creation through standardized processes. To successfully combine BIM with Lean methodologies businesses, need to implement Analytical Network Process (ANP)-based decision frameworks and structured approaches. Software complexity together with interoperability issues and high costs serve as technological barriers while organizational challenges stem from a lack of skilled workforce combined with change resistance and financial constraints and environmental impediments arise from inconsistent regulatory policies alongside inadequate government incentives and market hesitancy. The research outlines current limitations in data gathering and insufficient empirical studies within Indian SMEs while advocating for cross-industry collaboration alongside government support and workforce training programs. Future studies need to investigate implementation frameworks tailored to different contexts and quantitative models to evaluate impact which should bolster the argument for worldwide adoption.

Keywords: Building Information Modelling (BIM); Indian construction industry; Small and Medium Enterprises (SMEs); Technology-Organisation-Environment (TOE) framework.

1.0 Introduction

The construction industry in India, particularly among Small and Medium Enterprises (SMEs), faces persistent challenges related to productivity, efficiency, collaboration, and standardization. Compared to other industries, the construction sector has seen relatively slow improvements in productivity despite increasing project complexities (Bahyan *et al.*).

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Additionally, environmental concerns associated with construction activities continue to grow, with researchers recognizing the link between the built environment and sustainability challenges (Ahuja *et al.*). The Architecture, Engineering, and Construction (AEC) industry has increasingly gained advanced technologies and innovative methodologies to address these challenges. Building Information Modelling (BIM) and Lean Construction have emerged as a key platform in this transformation. BIM is a digital model that represents physical and functional characteristics, which helps to improve project visualisation, efficient coordination, and informed decision-making.

Simultaneously, Lean Construction focuses on process optimisation, waste reduction, and the improvement of value delivery. The integration of these methodologies offers a strategic framework for optimising the construction workflows and improving overall project efficiency. In the Indian construction sector, Small and Medium Enterprises (SMEs) can use BIM and Lean principles to overcome resource limitations, improve project execution, and go for more innovation. Yet, even with their clear benefits, adoption remains limited due to high costs, lack of awareness, and implementation challenges. This study explores the integration of BIM and Lean Construction within Indian SMEs, aiming to find strategies to enhance project efficiency, reduce waste, and create a more sustainable construction environment.

The primary objective of this project is to integrate the Building Information Modelling (BIM) with Lean Construction principles within small medium enterprises in Indian Construction Sector to improve the efficiency and overall project performance in construction projects by assessing current BIM and Lean adoption among Indian Small and Medium scale Enterprises (SMEs), by identifying the challenges and barriers which limits the integration of BIM and Lean principles in Indian SMEs, with a focus on technical, financial, and organizational constraints and analyse the benefits and outcomes of integrating BIM and Lean principles, including improvements in project delivery, cost efficiency, waste reduction, and collaboration.

2.0 Literature Review

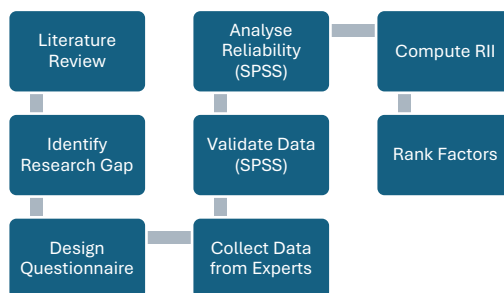
The literature review explores the integration of Building Information Modeling (BIM) and Lean Construction in the Indian construction industry by focusing on Small and Medium Enterprises (SMEs). Research shows BIM improves project visualization, coordination, and decision-making capabilities while Lean Construction methods help decrease waste and boost productivity (Bayhan *et al.*, 2023). The integration of BIM and Lean methodologies produces results of enhanced cost control along with increased productivity and more efficient workflows (Rashidian *et al.*, 2023; El Mounla *et al.*, 2023). SMEs encounter challenges including expensive implementation costs along with a shortage of qualified professionals and opposition to new processes (Uvarova *et al.*, 2023). The report by (Zhao *et al.*, 2023) declares that government incentives together with structured training programs and industry-wide

standardization serve as essential elements to promote adoption. According to multiple research papers the integration of BIM-Lean systems can improve by employing digital collaboration methods alongside automation and prefabrication techniques (Ma *et al.*, 2018). Limited awareness and insufficient access to affordable software solutions continue to stand as major hurdles (Hei *et al.*, 2024). The study highlights the lack of knowledge about barriers faced by SMEs and underscores the importance of developing customized frameworks and policies for effective implementation (McDermott *et al.*, 2023). By overcoming these challenges SMEs will be able to implement BIM and Lean principles more effectively which will enhance construction efficiency and sustainability (Saka *et al.*, 2022).

3.0 Research Methodology

The research methodology adopted in research for integrating BIM and Lean principles in Indian SMEs follows a well-structured approach. The research starts with a thorough examination of existing literature to understand current research while identifying knowledge gaps about adoption processes, challenges encountered, and benefits gained. Researchers create a Likert scale-based questionnaire to evaluate adoption levels alongside barriers and outcomes.

Figure 1: Methodology Followed



Responses from BIM specialists alongside Lean Construction and SME management experts furnish diverse viewpoints. IBM SPSS performs validation and reliability analysis on collected data to ensure its accuracy and consistency. After computing the Relative Importance Index (RII) the analysis identifies essential factors while a ranking system establishes the primary elements that impact BIM and Lean integration in SMEs.

4.0 Results and Discussion

4.1 Validity and reliability analysis

By using pearson correlation analysis the validity of the collected data got confirmed, with notable correlations detected between BIM adoption and project efficiency ($r = 0.821$).

Cronbach's Alpha analysis has shown high reliability scores: 0.898 for BIM adoption, 0.876 for integration challenges, and 0.947 for perceived benefits.

4.2 Challenges in BIM-lean integration

Table 1: Challenges in BIM-Lean Integration

Challenge	RII Score	Ranking
Lack of skilled professionals	0.863	1
High softwares cost	0.829	2
Resistance to change	0.829	3
Limited training programs	0.837	4

4.3 Benefits of BIM-lean integration

Table 2: Benefits of BIM-Lean Integration

Benefit	RII Score	Ranking
Improved project risk management	0.850	1
Efficient resource utilization	0.834	2
Enhanced project coordination	0.832	3
Reduced rework and errors	0.795	4

5.0 Conclusion

The integration of Building Information Modelling (BIM) and Lean Construction principles presents an opportunity for Small and Medium Enterprises (SMEs) in the Indian construction sector. This study analyses the current adoption levels, key challenges, and potential benefits of these methodologies in enhancing project efficiency, reducing waste, and improving collaboration among stakeholders. The findings reveal that while BIM adoption is gradually increasing in India, SMEs continue to face significant challenges, such as high implementation costs, a lack of technical expertise, and resistance to change. Similarly, despite its effectiveness in minimizing inefficiencies and improving project flow, Lean Construction remains underutilized due to conventional project management practices and limited industry-wide awareness. Through a comprehensive literature review, industry surveys, and expert insights, this research highlights critical aspects of BIM and Lean integration.

The combination of BIM's advanced capabilities in visualization, clash detection, and process optimization with Lean Construction's emphasis on waste reduction and continuous improvement provides a structured, data-driven approach to project planning, execution, and monitoring. For SMEs with limited resources, this integration significantly enhances productivity, cost efficiency, and sustainability. However, several challenges must be addressed to ensure effective implementation. Key recommendations include specialized training programs

to develop technical skills, government incentives to support technology adoption, and industry-wide collaboration to establish standardized implementation frameworks. Also, fostering a cultural shift within SMEs to embrace digital transformation and Lean principles is essential for long-term success. This study contributes to the ongoing discussion on digital and process innovation in the Indian construction industry. By demonstrating the practical benefits of BIM-Lean integration and addressing the key challenges, this research provides a strategic framework for SMEs to adapt to the evolving construction landscape and strengthen their competitiveness in a technology-driven environment.

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CHAPTER 84

Integrating BIM and Lean Principles for Enhanced Construction Performance in India

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ABSTRACT

The Indian construction industry is afflicted by constant challenges in efficiency, cost overruns, and sustainability due to fragmented workflows and limited collaboration. Proposed study explores incorporating Lean Construction concepts with Building Information Modeling (BIM) to enhance project performance by minimizing waste, improving resource allocation, and optimizing workflows. A combined methods strategy was used, combining structured surveys, statistical analysis through structural equation modeling (SEM), and qualitative insights from industry experts. Findings indicate that BIM-Lean integration significantly enhances project efficiency, reduces delays, and fosters collaboration among stakeholders. However, obstacles including excessive implementation expenses, reluctance to change, and regulatory constraints remain. The study proposes a strategic framework for seamless BIM-Lean adoption, tailored to the Indian construction landscape. The proposed model offers actionable insights for policymakers, construction firms, and project managers seeking to drive digital transformation and sustainable development in the sector.

Keywords: BIM-Lean integration; Construction efficiency; Structural equation modeling (SEM); Indicators; Constructs.

1.0 Introduction

The construction industry has undergone a paradigm shift in recent years, embracing digitalization and process optimization to enhance efficiency, mitigate risks, and improve overall project outcomes. Among the transformative methodologies, Building Information Modeling (BIM) and Lean Construction have emerged as two key approaches revolutionizing construction practices worldwide. BIM facilitates a data-driven approach by offering a digital depiction of the structural and operational characteristics of a structure, enabling enhanced collaboration, reduced errors, and improved decision-making. Meanwhile, Lean construction, which is based on lean manufacturing principles, emphasizes value generation, workflow optimization, and waste reduction. Despite the proven benefits of BIM and Lean, their combined application remains relatively underexplored, particularly in the Indian construction sector.

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India's rapid urbanization, increasing infrastructure demands, and regulatory complexities necessitate innovative solutions to overcome inefficiencies, project delays, and cost overruns. Integrating BIM with Lean principles offers a strategic framework for optimizing construction processes, improving resource utilization, and ensuring sustainability. This research investigates the convergence of Lean and BIM approaches in the Indian construction industry analyzing real-world case studies, industry insights, and empirical data to develop a structured integration framework. The findings aim to provide actionable recommendations for industry stakeholders, fostering a more efficient, collaborative, and sustainable construction ecosystem in India.

2.0 Literature Review

The Indian construction industry is in dire need of digital transformation to increase stakeholder participation, cut waste, and improve project efficiency. Despite the global shift towards digitalization, the construction sector remains one of the least digitalized industries (Schimanski *et al.*, 2020). Most construction firms continue to rely on traditional project management systems that are often fragmented and inefficient (Nowotarski *et al.*, 2016). Although the transition towards digitalization has begun, only a limited number of Indian construction firms are actively experimenting with digital tools and methodologies (Eldeep *et al.*, 2022). As suggested in previous research, innovation within organizations enhances competency. In the construction sector, competence improvement through digital adoption and Lean practices is crucial for achieving long-term sustainability. Digitalization, coupled with Lean principles, has the ability to completely transform project performance and industry productivity. However, its effective implementation and long-term sustainability remain critical challenges (Ahuja *et al.*, 2017).

2.1 BIM and lean adoption

Organizations that adopt BIM and Lean principles are more likely to achieve successful BIM-Lean integration, enhancing efficiency and productivity. BIM improves collaboration and decision-making, while Lean reduces waste and streamlines processes. Thus, both BIM and Lean adoption positively impact BIM-Lean integration.

2.2 BIM and lean integration in construction

Through enhancing cooperation, cutting waste, and streamlining workflows, the combination of Lean concepts and Building Information Modelling (BIM) improves construction productivity. (Schimanski *et al.*, 2020). BIM enables 3D visualization and real-time data sharing, while Lean minimizes inefficiencies. "This synergy improves project management, safety, and quality but faces challenges such as high initial costs, skill shortages, and resistance to change" (Nowotarski *et al.*, 2016).

2.3 Challenges and barriers to BIM-lean integration

BIM-Lean adoption faces hurdles due to the construction industry's resistance to change, high costs, limited expertise, and inadequate regulatory support (Nowotarski *et al.*, 2016). Interoperability issues further complicate implementation. Digitalization is also seen as risky due to cybersecurity, data privacy, and investment concerns (Eldeep *et al.*, 2022). A structured risk management approach is crucial for successful adoption.

2.4 Hypothesis

Based on the theoretical framework and literature findings the following research hypotheses table 1 are proposed to examine the impact of BIM-Lean integration on project outcomes. These hypothesis' will be used as constructs and the questions will be used as indicators in the SEM of the data received through survey questions.

3.0 Methodology

The methodology follows structured approach, including literature review, data collection, quantitative and qualitative analysis, framework development, and validation through case studies.

3.1 Data collection and survey design

Primarily literature review was performed, on the basis of the literature review four hypothesis' were formulated table 1. The indicators were decided on the basis of hypothesis table 1. A structured questionnaire survey is designed containing 'questions' addressing the indicators. to collect data from industry professionals, including project managers, engineers, and other stakeholders. The survey aims to gather insights and level of significance of the current practices, barriers, and success factors related to BIM and Lean adoption. Respondents' views and opinions are measured using the Likert scale methodology, which has responses ranging from strongly disagree to strongly agree.

3.2 Quantitative analysis

Structural Equation Modeling (SEM) validated theoretical frameworks, using survey questions as indicators for hypothesis-based constructs. This study utilizes smart PLS 4 software for structure equation modelling. As a result, before being processed in smart PLS 4, the text replies were transformed into numerical values (strongly disagree – 1, strongly agree – 5, etc.).

3.3 Framework development and refinement

Based on empirical findings, a structured framework is developed to guide BIM and Lean integration in Indian construction projects. The framework outlines step-by-step implementation strategies, addressing identified challenges and leveraging success factors. The inferences from the Structure Equation Modelling and further analysis explained in results and discussion were used to refine framework.

4.0 Results and Discussions

This section analyzes SEM results from SmartPLS 4, examining relationships among key variables. It involves evaluating measurement models for validity and reliability before testing hypotheses with structural models. Findings are then interpreted in relation to study objectives, theoretical framework, and prior literature, with implications for academia and practice.

4.1 Path coefficients interpretation

Values near 0 suggest weak or no relationship. As illustrated in table 2, the structural model defines the relationships between latent variables. BIM-Lean Implementation (BLI), BIM-Lean Barriers (BLB), and BIM-Lean Support (BLSP) influence BIM-Lean Success (BLS), which in turn impacts Project Efficiency (PE). Each path coefficient represents the strength and direction of these relationships values close to 0 indicate weak or no relationship, while higher values (closer to -1 or 1) indicate substantial negative or positive correlations. The analysis reveals that BIM-Lean Implementation positively influences BIM-Lean Success with a significant impact (0.618). In contrast, BIM-Lean Barriers have a negligible effect (0.011). BIM-Lean Support plays a moderate role in influencing BIM-Lean Success (0.321). Furthermore, BIM-Lean Success strongly enhances Project Efficiency, demonstrating a high impact (0.805).

4.2 Hypothesis testing (bootstrapping)

Figure 3 confirms statistical significance through p-values, where $p < 0.05$ indicates strong support. BIM-Lean Implementation emerges as the strongest driver of BIM-Lean Success ($p < 0.05$), while BIM-Lean Support has a moderate influence ($p < 0.05$). Conversely, BIM-Lean Barriers show weak support ($p > 0.05$), indicating minimal impact. Finally, BIM-Lean Success significantly enhances Project Efficiency ($p < 0.05$).

4.3 Indicator loadings (measurement model)

Factor or Indicator loadings should be above 0.7 for reliability. In figure 2, most indicators have high loadings, confirming that items strongly measure their respective constructs.

5.0 Framework for BIM-Lean Success and Project Efficiency

Based on the findings, a framework is developed to assess BIM-Lean integration's impact on project efficiency. BIM-Lean Implementation (BLI) is a strong enabler, BIM-Lean Support (BLSP) provides moderate aid, while BIM-Lean Barriers (BLB) have minimal negative influence on BIM-Lean Success (BLS). As the strongest predictor, BLS significantly enhances cost, time, quality, and productivity. The framework underscores the need to increase acceptance and reduce barriers to optimize project efficiency, emphasizing three key factors driving BIM-Lean Success and, in turn, Project Efficiency.

BIM-Lean Implementation (BLI) → Strong aid: BIM and Lean adoption strongly enhance BIM-Lean integration, showing high factor loading and a significant path coefficient, improving project efficiency.

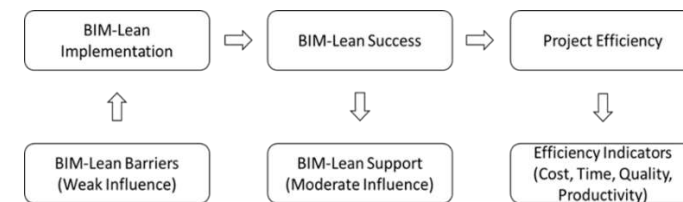
BIM-Lean support (BLSP) → Moderate aid: Technology, regulation, and training sustain BIM-Lean adoption. Though moderately loaded, their significant path coefficient underscores their vital role in long-term implementation.

BIM-Lean barriers (BLB) → Weak negative influence: Challenges like cost, resistance, and lack of expertise have negligible impact, with low factor loading and an insignificant path coefficient.

BIM-Lean success (BLS) → Strongest predictor of project efficiency: With a high path coefficient, BLS significantly enhances cost, time, quality, and productivity, making it crucial for optimal project outcomes.

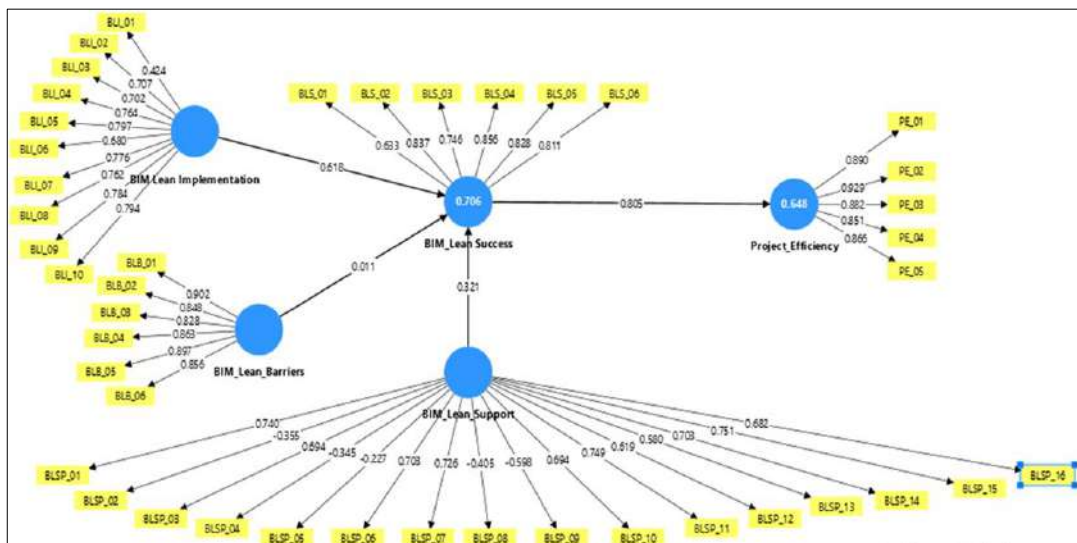
5.6 Figures

Figure 1: Framework



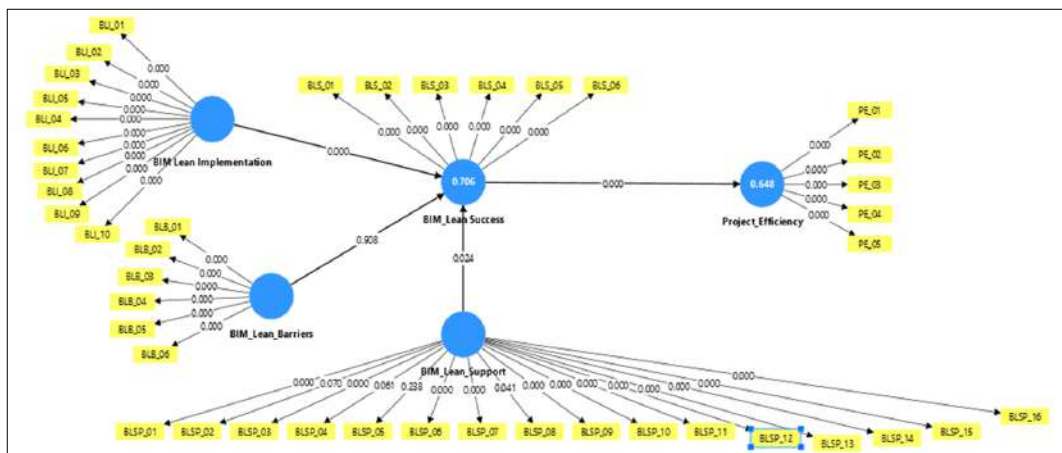
Source: Formulated by authors

Figure 2: Indicator Loading



Source: Output from smart PLS software

Figure 3: Bootstrap Chart for Hypothesis Testing



Source: output from smart PLS 4

5.7 Tables

Table 1: Hypothesis

Hypothesis	Relationship
H1	BIM & Lean Adoption → BIM-Lean Integration (+)
H2	Challenges → BIM-Lean Integration (-)
H3	Technology, Regulation & Training → BIM-Lean Integration (+)
H4	BIM-Lean Integration → Project Performance (+)

Source: Compiled by authors based on literature review

Table 2: Path coefficients, Hypothesis Testing

Construct Reliability	Indicator	Path	Path Coefficients	Hypothesis Testing (Bootstrapping) p
BIM Lean Implementation	BLI1	BLI → BLS	0.618	0 (<0.05)
BIM Lean Barriers	BLB1	BLB → BLS	0.011	0.908 (>0.05)
BIM Lean Success	BLS1	BLSP → BLS	0.321	0.024 (<0.05)
Project Efficiency	PE1	BLS → PE	0.805	0 (<0.05)

Source: Compiled by authors

6.0 Conclusion

Using literature reviews, industry surveys, case studies, and Structural Equation Modeling (SEM), the research establishes a strong link between BIM-Lean adoption and improved project performance. Findings show significant gains in cost efficiency, time management, and quality, while barriers like high initial costs and resistance to change have minimal impact when proper support is in place. A structured framework for BIM-Lean

integration is proposed, providing practical guidelines for industry professionals, policymakers, and firms. Emphasizing early collaboration, data-driven decision-making, and process standardization, it serves as a roadmap for better project outcomes. This study highlights BIM-Lean synergy as a key driver of innovation in Indian construction. It calls for greater awareness, investment in training, and supportive regulations to drive adoption. Future research should refine this model through real-world applications to ensure adaptability across diverse construction environments, clearing the path for higher-quality, more economical, and environmentally friendly approaches.

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CHAPTER 85

Integrating Building Information Modelling for Advanced Facility Management: Framework for Security Surveillance and Space Optimization

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ABSTRACT

Facility Management is an essential field of knowledge that basically ensures functionality, safety, and efficiency in buildings throughout their lifecycle. Nonetheless, conventional FM (Facility Management) often must cope with fragmentation in data management; reactive maintenance approaches; and challenges faced while combining various systems. The Building Information Modelling technology, or BIM, an innovative technology for the AEC sectors of Architecture, Engineering, and Construction, gives ample opportunities for re-orienting the FM process. This research investigates the potential for BIM to provide a positive improvement to security and surveillance as well as space management. The integration of BIM with emerging technologies like the Internet of Things (IoT), Artificial Intelligence (AI), and Radio Frequency Identification (RFID) forms the basis of this study, providing a conceptual framework for proactive and data-driven FM strategies. It puts special emphasis on the optimization of spatial layouts in improving monitoring, emergency response, and operational efficiency. Using simulation and data analysis through AnyLogic, it shows how BIM improves pedestrian flow, reduces congestion, and optimizes the CCTV camera coverage area. These findings reveal how it is crucial to ensure real-time data integration, interoperability standards, and user-oriented design when aiming for the seamless integration of FM systems. This research is among a growing body of literature in FM supported by BIM by bridging theory with practice, giving stakeholders a guide to adopting new sustainable, and scalable methods for facility management.

Keywords: Building Information Modelling (BIM); Facility Management (FM); Security and Surveillance; Space optimization; Radio Frequency Identification (RFID); Pedestrian flow analysis; CCTV coverage optimization; AnyLogic simulation.

1.0 Introduction

Background: Building Information Modelling (BIM) is one such technology that is impacting Architecture, Engineering, and Construction (AEC) (Zhang *et al.*, 2015b).

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Traditionally, the AEC community still made use of Computer-Aided Design (CAD) software to build geometric models of buildings. Within this environment, Building Information Modelling goes beyond CAD since it provides an all-encompassing digital model integrating both geometric and non-geometric data, enabling the stakeholders to manage the buildings during their life. All through the collaborative process, making wiser decisions, and keeping costs down by putting together all information in one place and updating the data in real time contributes to the development of smart, safe, and sustainable buildings. In this context, key terms include BIM, Facility Management (FM), IoT, AI, and RFID.

1.1 Research gap

Although BIM has shown great potential in FM, research gaps exist. For example, research does not yet allow for the automation of circulation modelling (Lin *et al.*, 2016); the dependence on user behaviour data in BIM-enabled models has seen limited exploration; the BIM-driven influence beyond the room level have remained inadequately supported by empirical evidence; and so on (Becerik-Gerber *et al.*, 2012a; Marmo *et al.*, 2019). In addition, there is a need for framework relating to BIM with IoT and AI for real-time monitoring and predictive maintenance in FM.

1.2 Objective

The primary aim of this research is to examine how BIM technology and other upcoming technologies can contribute to the improvement of FM in areas like security, surveillance, space management, and operational efficiency. That study further aims at the formulation of a conceptual framework to put BIM into FM, focusing on data-driven and proactive management strategies.

1.3 Scope

This research narrows its focus to building types-such as hospitals and educational institutions-to make the scope more manageable. Publicly available BIM databases and simulation tools like AnyLogic have been used for the study to analyse footfall, plan optimum CCTV footage and optimize space management. Lastly, the results aim to afford actionable insights into improving FM practices in new and existing buildings.

2.0 Literature Review

Literature review discusses that Building Information Modelling (BIM) has significantly contributed to Facility Management (FM) in various aspects of building not limited to preventive maintenance, asset management, energy efficiency, and occupant comfort monitoring (Becerik-Gerber *et al.*, 2012b; Zhang *et al.*, 2015a). BIM has been highlighted for improving FM already, for its worth in enhanced efficiency, sustainability, and saving in costs (Marmo *et al.*, 2019; Wang *et al.*, 2013). BIM offers a full digital model, providing an

associative representation of both geometric and non-geometric data (Giel & Issa, 2016; Lin *et al.*, 2016), enabling all stakeholders to manage buildings better throughout their lifecycles. With this integration of different information, more effective decisions are made available, while operational costs are reduced. They also aid in producing smart, safe, and sustainable buildings. For example, facility managers can access data in real-time for building systems such as HVAC, lighting, and security (Gouda *et al.*, 2020; Wen *et al.*, 2020) to make fully informed decisions that boost energy efficiency and occupant comfort. Furthermore, the ability of BIM to store and manage data through any point in the lifecycle of buildings enables information to be available and already set during upkeep, refurbishment, and future renovations (Gouda *et al.*, 2020), thus reducing downtime and hence expanding operational life-building further. However, challenges still exist in adaptation and implementation of BIM, these issues comprise:

2.1 Data integration

One of the primary challenges is the disparate nature of data (Becerik-Gerber *et al.*, 2012b; Marmo *et al.*, 2019) found across different systems and stakeholders. Integrating data from different sources into a unified BIM model remains an extremely complex task that often requires tremendous effort and resources. For instance, data from BMS, IoT sensors, maintenance logs, etc. very often sit in their data silos, preventing any uniform and thorough BIM model. However, this fragmentation can lead to inefficiency in ensuring that facility managers get what they need at the most opportune time.

2.2 High initial set up cost

BIM requires capital investments, which, at first, are on the high end (Kumar & Kothari, n.d.; Zhang *et al.*, 2015b), including software, training, and product infrastructure. It's a big hindrance for many organizations, especially the smaller ones. Although other benefits later the road, like operational cost reductions and improvement in building performance, are widely supported, the initial investment was among those constraints that severely curtailed some stakeholders from harnessing BIM. There are also other considerations, such as running costs of upgrading the BIM models, which could be extremely high, especially for large, complex buildings.

2.3 Limited empirical validation

While much of the literature emphasizes the theoretical benefits of BIM in FM, the actual benefits to be accrued through its use in real life have not yet achieved as much empirical verification (Marmo *et al.*, 2019; Wang *et al.*, 2013). At a certain point, such lagging empirical evidence was a major hindrance to the stakeholders in fully following the ramifications and merit of BIM adoption. For instance, while simulation studies have proven that BIM boosts energy efficiency, the degree to which that ultimately translates to energy savings once operational in buildings isn't widely understood. Moreover, there are claims regarding BIM

having a more critical impact on occupant comfort, but there are very few real-world assessments on how BIM-enabled FM practices play in influencing occupant satisfaction and wellness.

2.4 Automated user behaviour data

Research has leveraged the automation circulation modelling with user behaviour data more fully within BIM-enabled models. (Pan & Chen, 2020) This is one perhaps majorly overlooked area ready for research which could improve FM operation. For example, better pedestrian flow modelling automation would enable facility managers to more easily identify and resolve areas of congestion. Data on user bias could be integrated into BIM modelling to make building management systems more intelligent and responsive to the brightness of a space according to preferences/settings.

2.5 BIM in building circulation and space management

Existing studies approach BIM's impact on circulation, surveillance, and space management in buildings (Turner *et al.*, 2021). For instance, it has been used to simulate pedestrian flows, locate points of congestion, and proceed to optimize the positioning of security cameras. Such implementations would reveal BIM assists in improving the essence of a building's operational efficiency and safety. In airports or hospitals or other large public buildings, modelling and analysis of pedestrian movement could be undertaken to reveal bottlenecks to facility managers, enabling them to make design alterations that could mitigate crowd buildups and allow for the unhindered flow of people (Pan & Chen, 2020).

The placement of security cameras and surveillance equipment by pedestrian movement analysis, which would further determine their optimal location for the efficient safeguarding of a building. Hence, research concerning BIM has been wide-ranging, extending to its integration with other technologies such as IoT and AI (Gouda Mohamed *et al.*, 2020; Wen *et al.*, 2020). Even if these technologies provide an exciting vision for real-time monitoring and predictive maintenance in FM, quite a few of them have built the scope for integration with advanced technologies (Wang *et al.*, 2013; Zhang *et al.*, 2015b).

IoT devices can enable real-time visibility of building conditions regarding temperature, humidity, and occupancy levels, while AI can act upon the information and help forecast maintenance needs through optimized resource allocations. Integration of BIM with IoT and AI would enable facility managers to transition from reactive maintenance to preventive or even predictive maintenance, anticipating issues before they escalate into crises and decreasing the chance for unexpected downtime. Further, BIM-IoT-AI integration would offer advanced customization of building automation systems, such as smart lighting and HVAC systems that adjust in real-time according to occupancy and environmental conditions (Gouda *et al.*, 2020).

3.0 Methodology

3.1 Case Study: NICMAR University, Pune

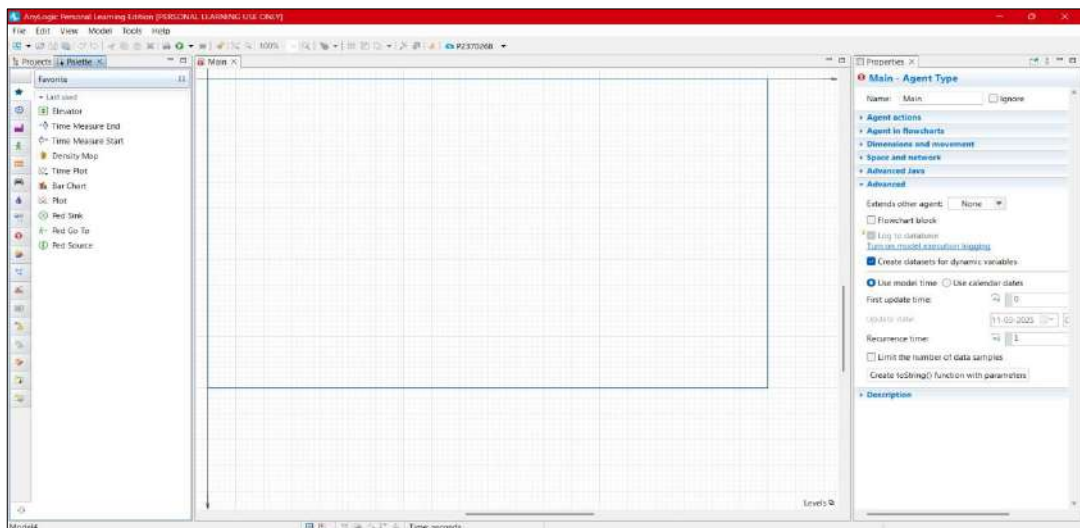
Problem Statement: NICMAR University experiences varying levels of pedestrian traffic through two primary gateways: Gate No. 1 and Gate No. 2. Primarily, Gate No. 2 experiences extreme choke points during peak hours that impede pedestrian movement while heightening security concerns. The objectives of this case study shall include:

- Investigation of pedestrian flow at both gates.
- Identification of bottlenecks and congestion points.
- Providing optimised coverage for the CCTV cameras.
- Proposed architectural and operative changes to enhance pedestrian flow and safety.

Data/ Software used

- *BIM Model:* A digital 3D model of NICMAR University, Pune was employed to provide the Campus layout with buildings, pathways, and entry Gates.
- *Google Earth:* Satellite imagery was used to trace the building footprint and pathways for existing structures.
- *Software Tools*
 - AutoCAD: For preparing CAD templates from the BIM model.
 - AnyLogic: For pedestrian flow simulation and congestion analysis.
 - Navisworks: For clash detection and integrating elements for security surveillance.
 - Data Sources: Data on pedestrian movements, requirements for CCTV covering, and architectural layouts.

Figure 1: AnyLogic New Project Screen



3.2 Step-by-step procedure

Steps taken in the case study read as follows:

- Data collection

Aim: For precise architectural layouts for NICMAR University with respect to gates, pathways, and other important buildings.

Process:

- Establishment of a top-down view layout of the campus using the BIM model.
- Building footprints and pathways for existing structures were traced using Google Earth.
- Exporting the layout into AutoCAD to develop a CAD template of DWG format.

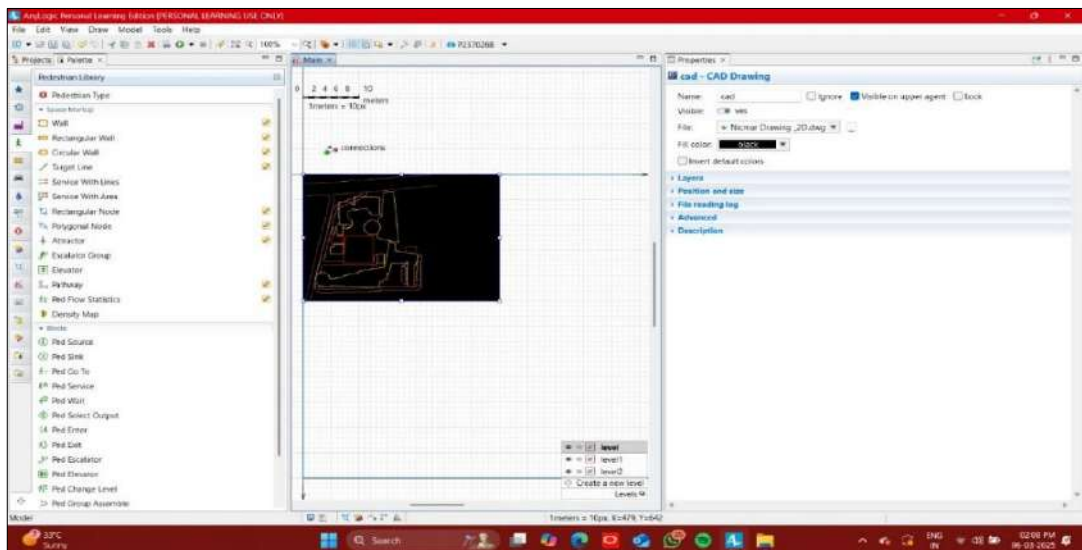
- CAD Template Creation

Aim: To create a detailed CAD template of the university layout for the purposes of simulation.

Steps Taken:

- The BIM model was imported into AutoCAD.
- Using the polyline tool, buildings, pathways, and entry gates were traced.
- There were layers made to represent the walkable paths, obstacles, security zones, and restricted areas.
- Finally, this CAD template was saved in DWG format for further use in AnyLogic.

Figure 2: CAD File Imported on Anylogic Workspace



- Import of CAD Template into AnyLogic

Aim: To utilize the CAD template as a reference layer for pedestrian flow simulation.

Steps Taken:

- In AnyLogic, a new project was created, and the Pedestrian Library was selected for simulation purposes.
- The CAD template was imported into AnyLogic (as DWG file) and scaled to correspond to real-world dimensions.
- Crossways and entrances into buildings were set directly into the simulation environment

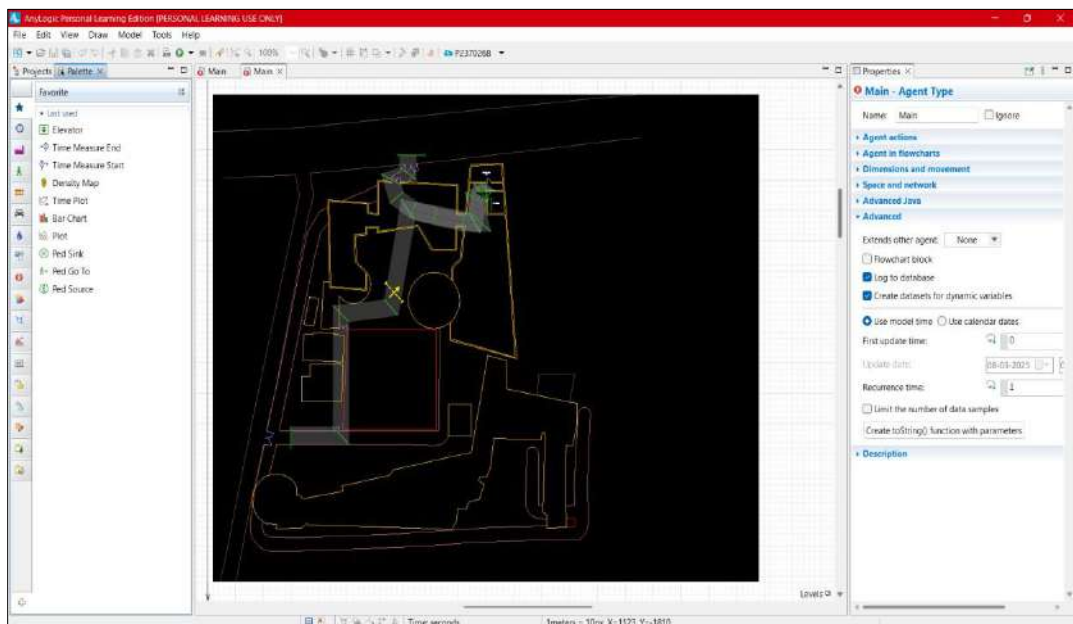
4.0 Setting Up the Simulation of the Pedestrians

Aim: To simulate pedestrian movement from Entry Gate No. 1 and Entry Gate No. 2 for congestion and flow pattern analysis.

Steps Taken:

- Pedestrian sources are set up at Entry Gate No. 1 and Entry Gate No. 2.
- Pedestrian destinations are set up at essential locations like the Vice Chancellor's Office.

Figure 3: Pedestrian Library with Pathway Marked



- Arrival rates were adjusted to reflect pedestrian density during peak hours in real-life situations.

- Paths and walking areas were drawn up with the help of the Pedestrian Library in AnyLogic modelled on realistic movement.

Figure 4: AnyLogic Simulation Interface and Display

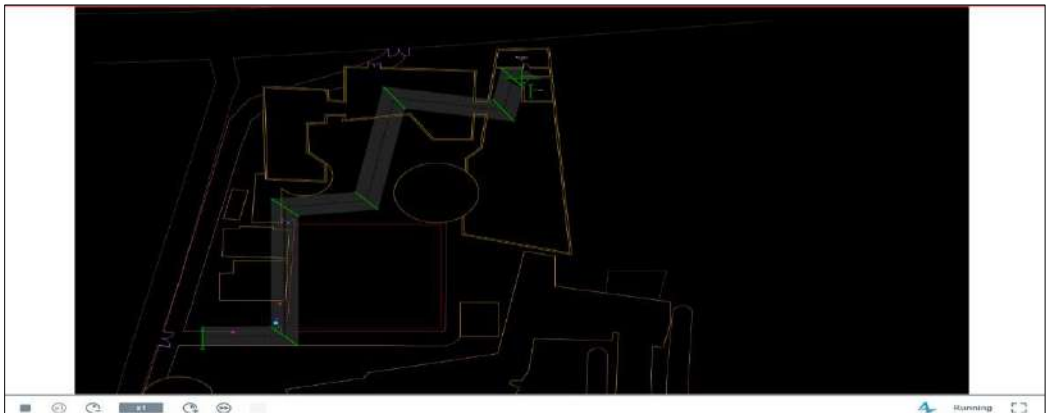


Figure 5: Heat Map of Pedestrian Movement



5.0 Execute the Simulation

Objective: Analyse pedestrian flow and identify points of congestion.

Process:

- The simulation was run while viewing the movement of pedestrians with dots of various colours.
- Heat maps were generated to show highly congested areas.
- Essential statistics were recorded, which include average flow time, total distance walked, and speed of pedestrians.

Figure 6: Average Time Taken My Multiple Pedestrians

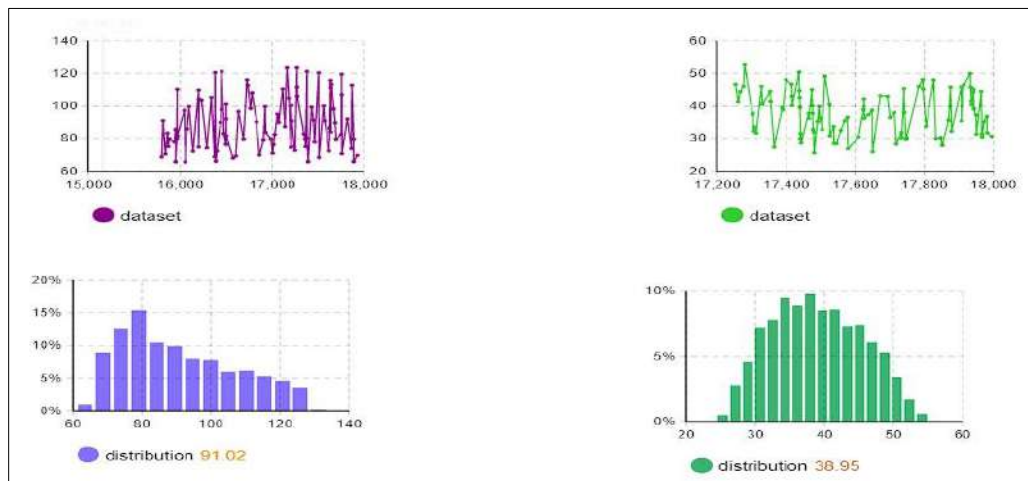


Figure 7: Simulation of Pedestrians as Coloured Dots



Figure 8: Simulation Window



6.0 Optimize CCTV Coverage

Objective: Establish an optimal number and placement of CCTV to ensure complete coverage.

Process: Step-by-Step Methodology for Determining the Optimum Number of Surveillance Cameras

Introduction: Surveillance camera placement is critical for ensuring comprehensive security coverage in facility management. This document outlines the step-by-step methodology used to determine the optimal number of cameras required for effective surveillance, using a combination of Field of View (FoV) analysis, spatial coverage calculations, and pedestrian movement data. The approach is supported by relevant research and mathematical models.

Step-by-Step Approach

Step 1: Estimating the Surveillance Area

- For Greenfield Projects, the Building Information Model (BIM) was used to extract the architectural floor plan and determine the total surveillance area.
- For Brownfield Projects, Google Earth and satellite imagery were used to derive a 2D map, which was converted into a CAD template for analysis.
- The estimated area was then verified against actual dimensions and cross-validated with available facility blueprints.

Formula Used: $A=L \times W = L \setminus W$ where: (Davies & Velastin, 2005)

- A = Total surveillance area (sq. meters)
- L = Length of the facility
- W = Width of the facility

Step 2: Camera Field of View (FoV) Analysis

- Each camera has a defined Field of View (FoV), which determines how much area it can cover.
- The horizontal and vertical angles of coverage were extracted from camera specifications.
- A 3D model in AnyLogic was used to visualize the coverage overlap and blind spots.
Formula Used: $A = 2 \times D \times (\tan \theta / 2)$
- A = Area covered by a single camera
- D = Maximum effective distance of the camera
- θ = Camera's horizontal field of view

Calculations: So here we are assuming that the len on the camera is of 60 degrees that is a standard lens, and we have calculated from google maps that the area of college is 9 acres. Hence;

- $\theta = 60$ degrees
- D= 30 metres (Assumed effective range of the camera
- Each camera effectively covers 1038.6 m².
- The number of cameras needed is:
- No of Cameras=Total Area covered/Area covered by camera $\times \eta$
- $\eta = 0.85$ (85% overlap factor for minimal blind spots)
- Since we round up to ensure full coverage, the optimum number of cameras required is 42 cameras.

Step 3: Simulation and Validation

- The AnyLogic pedestrian simulation was used to analyse foot traffic patterns and high-density areas.
- Surveillance camera placements were optimized by adjusting the camera angle, height, and coverage to maximize visibility in high-traffic zones.
- The model was tested iteratively to ensure coverage efficiency.

Conclusion: By following this methodology, the optimum number of surveillance cameras was determined with precision. The integration of BIM, spatial analysis, and simulation tools provided a comprehensive approach to facility security planning. This methodology ensures efficient resource utilization, cost optimization, and enhanced security monitoring, contributing to a robust facility management strategy.

7.0 Data Analysis and Recommendations

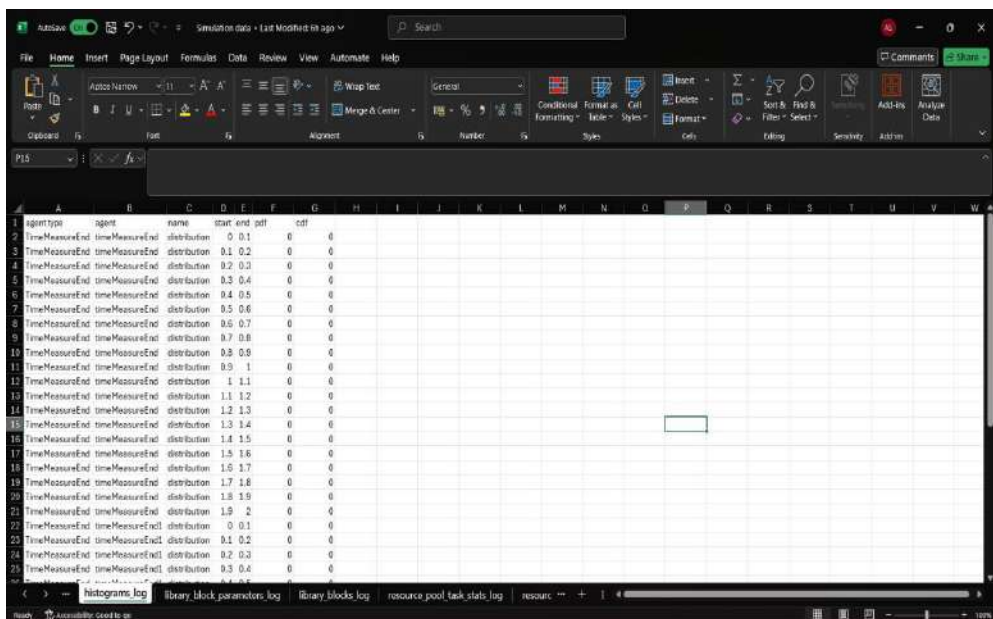
Objective: Interpret simulation results and offer suggestions for congestion and security optimization.

Process: The congestion observed at Gate No. 2 was due to narrower entry channels, inefficient queuing, and high pedestrians' density.

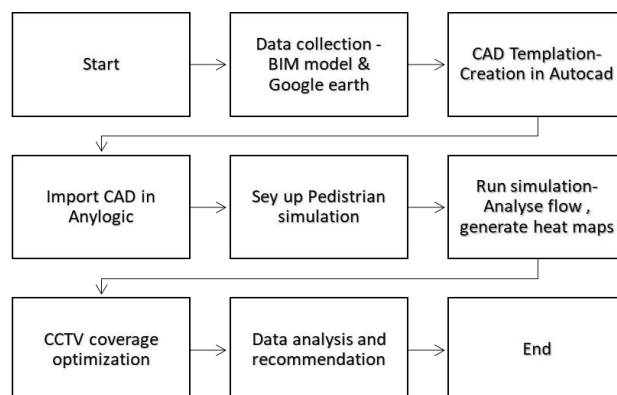
Figure 9: Heat Map of Pedestrian Movement



Figure 10: Data Extracted from Simulation to Excel File



8.0 Flow Chart of All the Steps



9.0 Results and Discussion

Data (Visuals and Graphs)

- Pedestrian Flow Analysis: Results of the simulation showed that Gate No. 2 on average had a longer flow time, in other words, greater congestion than Gate No. 1 (91.02 seconds against 38.95 seconds).
- CCTV Coverage Optimization: Using the formula $A=2 \times D \times (\tan\theta/2)$ we round up to ensure full coverage, the optimum number of cameras required is 42 cameras.
- Heat Maps: showed pedestrian movement patterns, revealed chokepoints and hinted at possible architectural improvements.

9.1 Results

Simulation revealed that architectural changes of widening the entry-points and implementation of IoT in the traffic flow can very well cut down on congestion. It also made a good case showing how using BIM simulations can allow optimization of CCTV cameras in its placement for fully surveillant coverage.

9.2 Discussion

These findings highlight the importance of combining BIM, IoT, and AI for real-time monitoring and predictive maintenance in FM. The proposed framework utilizes BIM's advanced modelling and simulation capabilities to address prominent FM challenges, such as data fragmentation and reactive maintenance. The study additionally points to the potential of BIM to enhance emergency response and operational efficiency via spatial layout optimization.

10.0 Conclusion

This research set out to explore the transformative potential of Building Information Modelling (BIM) in enhancing Facility Management (FM), specifically in the domains of

security surveillance and space optimization. Bridging this technological innovation with data-driven simulations and advanced analytical tools, the study presents a comprehensive, replicable framework that not only addresses persistent inefficiencies in traditional FM but also extends the current body of knowledge by offering empirical validation to several theoretical claims established in prior literature. The study builds upon foundational insights by Becerik-Gerber *et al.* (2012), who emphasized the value of BIM in data centralization and real-time facility oversight, and Zhang *et al.* (2015), who proposed BIM as a catalyst for smarter, more adaptive building environments. While much of the existing literature has articulated the potential of BIM in various FM tasks—such as asset tracking, HVAC control, and energy optimization—our research advances this dialogue by focusing on underexplored yet critical aspects: pedestrian circulation modelling and CCTV camera placement optimization, particularly within the context of educational institutional settings.

Through the case study of NICMAR University, the methodology employed a combination of tools—AutoCAD, Navisworks, and AnyLogic—to simulate pedestrian flow and model surveillance layouts using real-world data inputs. The application of a BIM-informed digital model, integrated with simulation software and validated through spatial analysis, enabled us to not only visualize but quantify congestion patterns and surveillance blind spots. The simulation outcomes clearly indicated that architectural adjustments, such as widening Gate No. 2 and modifying queuing zones, would significantly improve pedestrian flow—reducing average traversal times from 91.02 to 38.95 seconds. Moreover, the use of a mathematical approach to optimize CCTV camera coverage (Davies & Velastin, 2005) resulted in a calculated requirement of 42 strategically placed cameras, factoring in overlapping FoVs and pedestrian density zones. These outcomes validate assertions made by Pan & Chen (2020) and Turner *et al.* (2021), who advocated for circulation-aware surveillance planning, yet lacked real-time, simulation-supported implementation studies like the one presented here.

Our study also meaningfully addresses several pressing challenges in BIM adoption, as previously outlined by Marmo *et al.* (2019) and Wang *et al.* (2013), particularly in terms of data integration, high initial costs, and limited empirical validation. By demonstrating a low-cost but high-impact application of publicly available tools and data, this research provides a viable model for institutions—especially those with constrained budgets—to incrementally adopt BIM-based FM strategies. Moreover, the emphasis on integrating BIM with Internet of Things (IoT) sensors and Artificial Intelligence (AI)-enabled predictive analytics responds to the growing academic discourse surrounding BIM-IoT-AI convergence (Gouda *et al.*, 2020; Wen *et al.*, 2020). The proposed conceptual framework promotes a shift from reactive to predictive maintenance strategies, laying the groundwork for future smart campus or smart facility implementations. Importantly, this study extends the theoretical discourse into a practice-ready framework that includes actionable steps, validated simulations, and scalable digital processes. It demonstrates that BIM is not merely a data repository but a dynamic, decision-support system when integrated with other technologies. The methodology herein supports dynamic scenario

analysis and has the potential for further expansion into evacuation planning, emergency response optimization, and even behavioral modelling for crowd psychology (Pan *et al.*, 2006). In summation, this research substantiates the strategic utility of BIM in FM through a multidimensional lens—technological, operational, and strategic. By aligning our findings with prior literature while also demonstrating new, empirically tested applications, the study makes a dual contribution: enriching academic understanding and equipping practitioners with a tested roadmap for implementing advanced FM strategies. Future studies could build upon this framework by incorporating real-time tracking systems, integrating machine learning algorithms for adaptive planning, and evaluating the long-term operational gains of BIM-driven FM systems in larger or more complex building typologies.

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CHAPTER 86

Integrating Drone Technology, GIS, and Digital Twins for Enhanced Pothole Management: A Sustainable Approach to Infrastructure Maintenance

Chaitali Shelke¹

ABSTRACT

The increase in traffic volume accelerates the depreciation of the road infrastructure, which in turn has an adverse effect on the overall road performance and safety. Manual road assessments are particularly poor in accuracy and the depth of fault analysis, thus traditional methods are not capable of supporting these tasks adequately. This research provides a solution in the form of a complete methodology that employs Digital Twin Technologies, photogrammetry using drones, and Geographic Information Systems (GIS) to construct the assessment of the state of the road infrastructure to be as comprehensive as possible regarding deflection quantification and sustainable repair techniques. The method starts with selecting segments of the road that is necessary to assess and capturing drone footage of the segments. The footage is then processed using QGIS, making it possible to find and measure imperfections such as potholes and cracks. Advanced technology such as Digital Twin enables infrastructure manager to make data-driven decisions, check assets in real-time, and perform predictive maintenance. Enhance the sustainability of repairs, materials such as Stone Matrix Asphalt are used to diminish the utilized resources while extending the life of the infrastructure. In the end, the method is rounded up with the formulation of cost estimates and optimization strategies for sustainable repairs. This research aims to streamline road maintenance operations, enhance decision-making processes, and ensure long-term infrastructure safety and sustainability by using advanced technologies in pothole management.

Keywords: Drone technology; GIS; Digital twin; Sustainable repairs; Stone matrix asphalt; Infrastructure management.

1.0 Introduction

Increasing traffic leads to faster pavement deterioration, affecting road performance and safety. Traditionally, road monitoring relies on manual inspections and specialized tools to assess surface conditions, but this process is time-consuming and prone to errors. Maintaining road infrastructure costs 0.4%–2% of the original construction cost (Mahmoodian *et al.*, 2022), making consistent maintenance essential for road longevity.

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Manual inspections, such as walking the road or conducting “windshield” surveys from vehicles, often miss hidden defects, leading to incomplete assessments.[1] Drone-based profiling with Real-Time Kinematic (RTK) technology improves road assessments by providing 3D positional accuracy within 2 cm, enhancing defect detection and enabling better synchronization through standardized coordinate systems and analysis software. (Kuttah & Waldemarson, 2024). Drone-based imaging provides an affordable and accurate way to identify surface issues like cracks, with geotagging helping to map defects precisely and GIS databases recording their type, severity, and location for better reporting and maintenance planning. (Fendi, Adam & Smith, 2024). Digital Twin Technology combines a real-world system with a computational model, enabling two-way data flow for monitoring, control, and decision-making. Its adaptability allows it to be customized for different industries based on specific needs.(Callcut *et al.*, 2021). Pothole repairs often rely on short-term cold mix fixes or more durable hot mix asphalt (HMA) repairs, but shifting to sustainable methods can reduce waste, resource use, and maintenance needs. (Chen, Wang & Venkiteela, 2023).

This project aims to improve pothole detection and management by using drone technology, GIS, and Digital Twin models. Drones capture high-resolution images, which are processed through GIS to precisely measure pothole size and location, helping to plan repairs more effectively. The Digital Twin model offers a real-time view of road conditions, allowing for better prediction and maintenance planning. By using eco-friendly materials and methods, the project enhances repair efficiency while supporting long-term road sustainability.

2.0 Related Work on Road Engineering using Digital Twin Technology

2.1 Development of digital twins for road infrastructure

Jiang *et al.* (2022): This study explores the creation of digital twins for the UK’s A1(M) motorway using map data, but it faces challenges with complex road geometry, limited highway images, and inconsistent data quality. Tchana *et al.* (2019): This paper examines the use of digital twins for managing linear infrastructure, focusing on improving cost efficiency, performance, and collaboration, but highlights issues with data handling and IT system complexity. Feng Jiang *et al.* (2024): This research proposes a model for sustainable urban road planning by combining Digital Twin technology, multi-factor decision analysis (MFDA), and GIS to enhance road design and data management.

2.2 Challenges in digital twin adoption and data integration

Liu *et al.* (2024): This study introduces a framework for improving infrastructure management using multi-domain data integration but raises concerns about high costs, data security risks, and budget limitations. Macoriga *et al.* (2022): This research evaluates road network maintenance in Pisa, identifying financial constraints and recommending policy changes to enable more sustainable road management. Michaela *et al.* (2024): This study looks

at integrating civil structural models into digital twins to enhance safety and cut costs, but faces challenges with data compatibility and lifecycle management.

2.3 Technologies supporting digital twin development

D'Amico *et al.* (2023): This study integrates subsurface imaging radars (SIR) and portable laser mapping systems (PLMS) within a construction data model to improve infrastructure analysis, but faces issues with integrating ground-penetrating radar (GPR) and missing survey data. Liu *et al.* (2023): This review outlines different methods for creating digital twins in civil infrastructure, including AI and machine learning, but notes that high computational demands and data accuracy are ongoing challenges. Talha *et al.* (2023): This study recommends cost-effective pothole patching techniques using survival analysis but acknowledges that the findings may not apply to all road types and conditions.

2.4 Decision support tools and data management

Consilvio *et al.* (2023): This study presents a virtual twin-based support system for better asset management by integrating AI with existing systems, but it highlights that the technology is still in its early stages and needs further testing. Broo *et al.* (2020): This research emphasizes the potential of AI-driven decision-making for infrastructure management but points out challenges with data handling and organizational resistance to adopting new systems.

2.5 Pothole and pavement maintenance

Talha *et al.* (2023): This study evaluates different winter pothole patching techniques and recommends the most cost-effective options based on weather and traffic conditions, but its findings are limited to specific sites. Dong *et al.* (2014): This research shows that semipermanent patches last longer than other methods, but the short evaluation period and lack of consideration for pavement conditions limit its broader applicability. Chen *et al.* (2023): This study finds that infrared heating improves asphalt patch bonding, but the results are based on artificial potholes, which may not reflect real-world traffic conditions.

2.6 Innovations in road profiling and monitoring

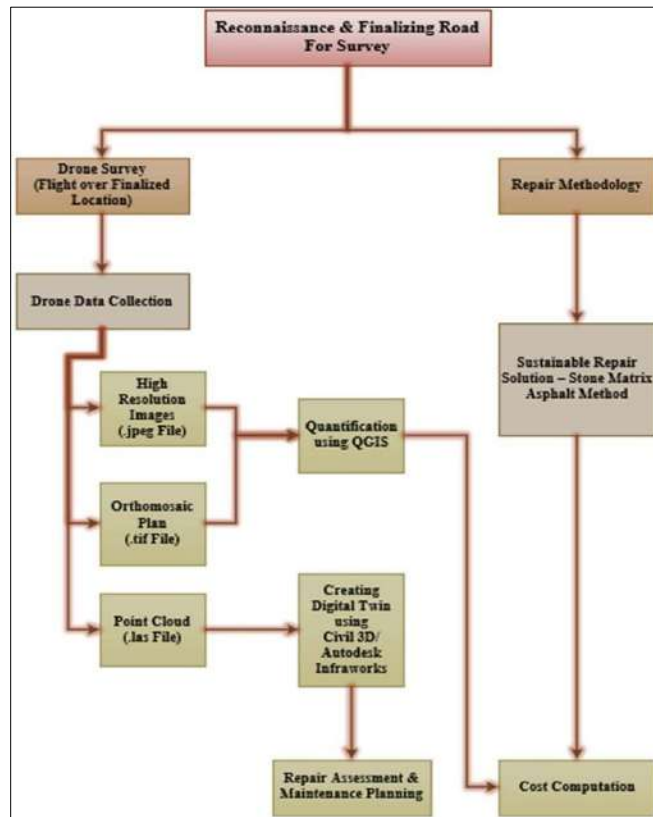
Kuttah *et al.* (2024): This study tests UAV-based RTK technology for gravel road profiling and finds it as accurate as traditional methods, but issues with data alignment, vegetation interference, and ArcGIS compatibility remain. Almuhanha *et al.* (2018): This research applies GIS-based planning for road preservation in Karbala, Iraq, but the reliance on manual data collection makes it difficult to use on high-traffic roads.

2.7 Sustainability and environmental considerations

Hamayde *et al.* (2021): This study uses GIS to create earthquake risk maps in Dubai, but its reliance on 2D models limits its accuracy and broader application. Khan & Kumar

(2024): This research uses terrestrial LiDAR for 3D modeling of pavement distress, but difficulties in detecting certain distresses and high processing demands limit its efficiency.

Figure 1: Proposed Methodology



3.0 Research Methodology

By providing a systematic approach to road survey, analysis, and sustainable repair planning, this technique guarantees data-driven maintenance decision making and economic effectiveness.

- Road Selection: Roads selected based on traffic, damage, and accidents.
- Drone Survey: Drones capture high-resolution road data.
- Data Processing: QGIS maps and measures road damage.
- Digital Twin: 3D model created for repair planning.
- Sustainable Repair: SMA used for durability and longevity.
- Cost Estimation: Repair costs calculated for efficiency.
- Maintenance Planning: Data-driven plan ensures timely repairs.

4.0 Experimental Setup

The study began with a drone survey of a 1.5-kilometer pothole-ridden road section using the DJI Mavic 3 MTK drone, equipped with an infrared sensor and an omnidirectional binocular vision sensor. To ensure full coverage, three flights were conducted over the segment, gathering detailed data to create a 3D model of the road's surface and internal structure. Road surface distress inspection, as highlighted by Barbieri & Lou (2024), plays a key role in monitoring pavement conditions and identifying construction defects, poor materials, and inadequate maintenance. The study incorporated two advanced technologies: "LiDAR", which uses laser beams to produce highly accurate surface images with a precision of 1 mm to 10 mm, and "Infrared Thermography", which captures heat emissions to create thermal images, allowing quick data collection at a rate of 30 to 60 scans per second. Refer Figure 2, 3, 4.

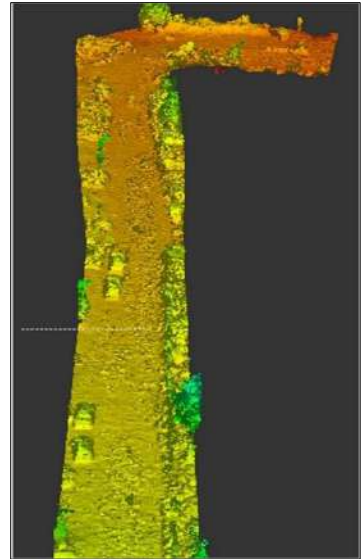
Figure 2: Drone View Image



Figure 3: Ariel Image



Figure 4: Infrared Image



4.1 Data processing

DroneDeploy software was used to process the drone survey data and extract it into three different forms for a thorough examination of the state of the road surface:

- *High-Resolution Images (.jpeg)*: High-quality images provided clear visual data, helping to identify surface issues like cracks and potholes through detailed visual inspection.
- *Ortho Mosaic Maps (.tif)*: Georeferenced maps created from stitched drone images allowed accurate measurement and spatial analysis of road defects.
- *Point Cloud Data (.las)*: Dense 3D models generated from photogrammetry and LiDAR data helped assess surface imperfections and calculate the volume of road damage.

4.2 Pothole detection and quantification

High-resolution drone images were essential for identifying potholes and road defects with pinpoint accuracy, thanks to their high spatial resolution. The images helped detect surface issues like cracks, potholes, and deformations with clarity. Ortho mosaic maps generated from the drone data were imported into QGIS (v3.34.15), where road defects were accurately mapped, measured, and referenced using historical Earth data. This integration improved the efficiency and accuracy of pavement condition assessments using GIS tools.

- *Import ortho map:* Load the georeferenced Ortho mosaic map into QGIS using UTM 84-43N CRS.
- *Digitize potholes:* Trace pothole boundaries using the “Add Polygon” tool and save as a shapefile.
- *Calculate area:* Use QGIS’s Field Calculator to compute pothole area in square meters.
- *Export results:* Save the updated layer and export for analysis or reporting.

Figure 5: Pothole Tracing and Area Calculations

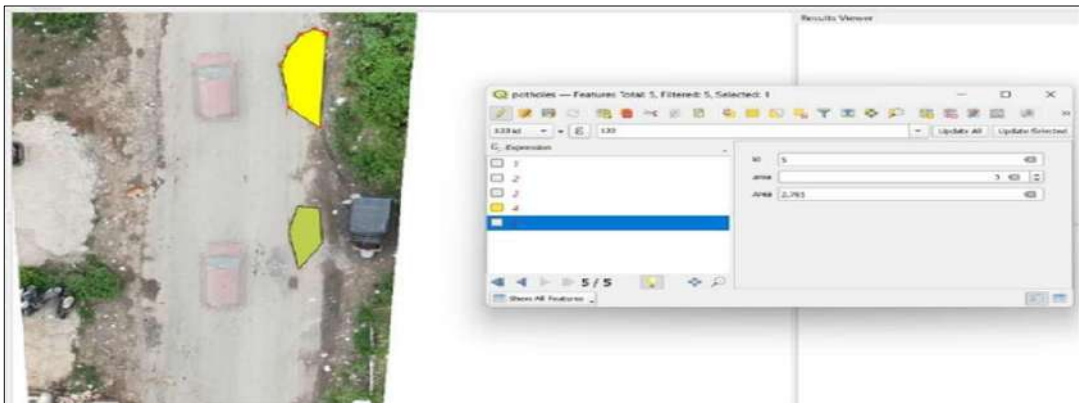
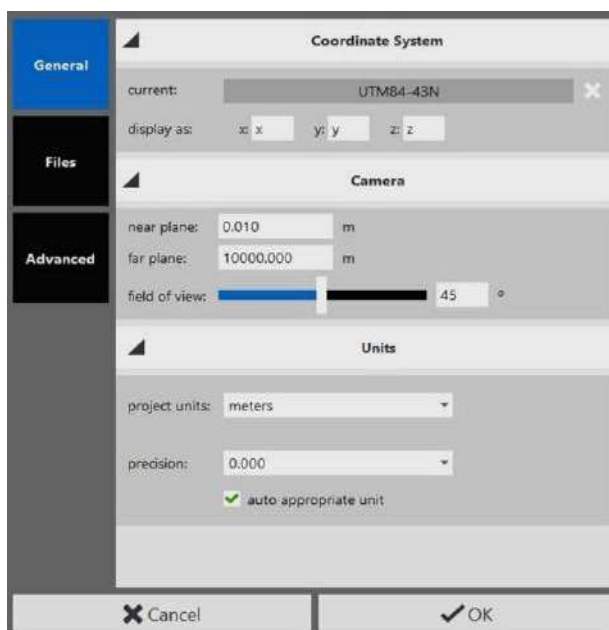


Table 1: Pothole Quantification

Pothole Area Attribute table extracted from QGIS (v3.34.15)							
Road - 01				Road - 02 & 03			
Pothol e id	Area from QGIS (Sq.m)	Assume Average Depth 0.05m IRC 81:1997	Quantity (Cu.m)	Pothol e id	Area from QGIS (Sq.m)	Assume Average Depth 0.05m IRC 81:1997	Quantit y (Cu.m)
1	1.611	0.05	0.08055	1	60.89	0.05	3.04
2	2.873	0.05	0.14365	2	4.911	0.05	0.25
3	7.112	0.05	0.3556	3	17.856	0.05	0.89
4	1.474	0.05	0.0737	4	20.629	0.05	1.03
5	10.601	0.05	0.53005	5	4.686	0.05	0.23

6	1.04	0.05	0.052	6	15.666	0.05	0.78
7	50.813	0.05	2.54065	8	0.158	0.05	0.01
8	0.3	0.05	0.015	9	0.161	0.05	0.01
9	0.402	0.05	0.0201	10	0.369	0.05	0.02
10	1.147	0.05	0.05735	11	2.834	0.05	0.14
11	9.916	0.05	0.4958	12	4.942	0.05	0.25
12	0.405	0.05	0.02025	13	6.742	0.05	0.34
13	19.922	0.05	0.9961	14	39.589	0.05	1.98
14	0.574	0.05	0.0287	15	0.125	0.05	0.01
15	3.062	0.05	0.1531	16	0.128	0.05	0.01
16	0.722	0.05	0.0361	17	0.555	0.05	0.03
17	0.267	0.05	0.01335	18	1.895	0.05	0.09
18	4.114	0.05	0.2057	19	0.937	0.05	0.05
19	6.895	0.05	0.34475	20	3.12	0.05	0.16
20	6.555	0.05	0.32775	21	0.714	0.05	0.04
21	28.904	0.05	1.4452	22	0.255	0.05	0.01
22	1.138	0.05	0.0569	23	45.967	0.05	2.30
23	0.294	0.05	0.0147	24	36.672	0.05	1.83
24	0.516	0.05	0.0258	25	9.639	0.05	0.48
25	0.459	0.05	0.02295	26	34.863	0.05	1.74
26	1.688	0.05	0.0844	27	20.007	0.05	1.00
27	2.826	0.05	0.1413	28	12.221	0.05	0.61
	165.63		8.28		346.531		17.33

Figure 6: Co-ordinate System in Recap Pro 2024



4.3 Using the point cloud to create the digital twin model

4.3.1 Using autodesk recap pro 2024 to import point cloud

- Import Point Cloud: Import the .las file into Autodesk Recap 2024 to create a 3D road model.
- Set Coordinate System: Set UTM84-43N CRS for accurate analysis and alignment.
- Remove Noise: Eliminate inaccurate data to improve model accuracy and quality.
- Export Refined Data: Export cleaned data in .rcs format for use in Revit and Civil 3D.

4.3.2 Setting up point cloud in the autodesk recap pro 2024

Maintain spatial accuracy, Autodesk Civil 3D was configured as follows:

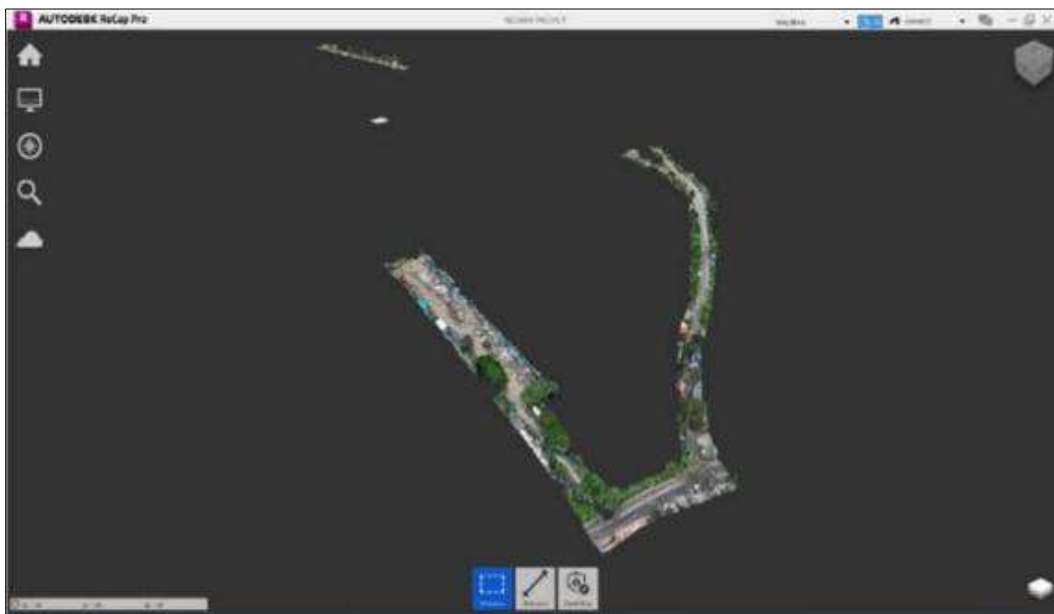
- The coordinate system was set to UTM84-43N, ensuring consistency with the processed point cloud.
- Geo Location and Aerial Mode settings were enabled to provide a real-world spatial reference for the imported data.

4.3.3 Importing and generating surface from point cloud

The cleaned .rcs point cloud “15-12-24” data were imported into Civil 3D for surface generation. The process included:

- Using the “Create Surface from Point Cloud” command to generate a terrain model.

Figure 7: Point Cloud in Recap Pro 2024



- Selecting the existing grid choice and enabling the “Display Contour” feature to enhance surface visualization.
- Choosing the “No Filter” choice to include all available data points for correct surface modelling.

Figure 8: Point Cloud in Recap Pro 2024



Figure 9: Drawing Setup in Civil 3D 2024

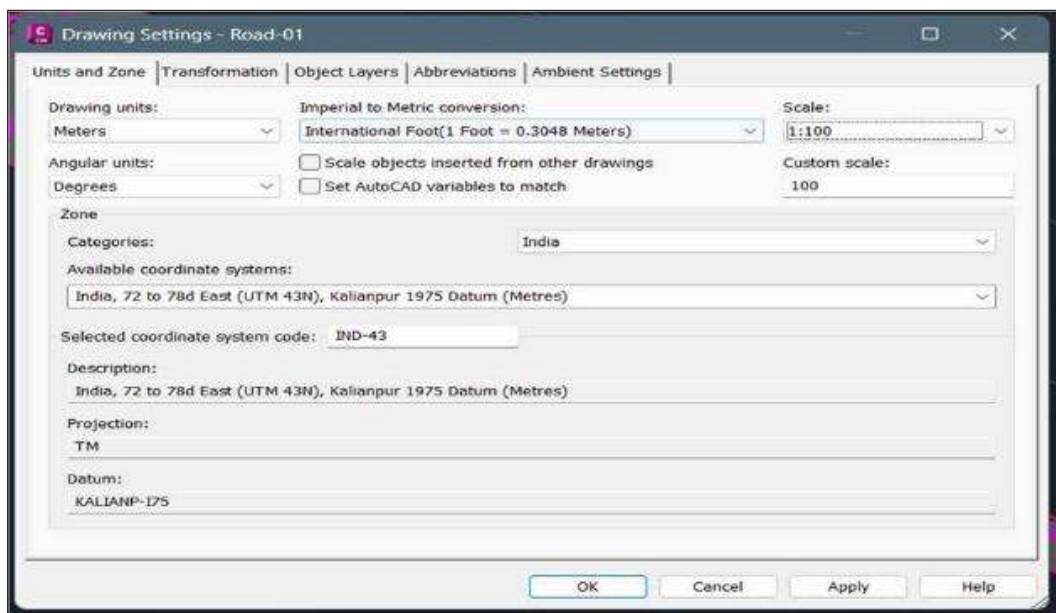


Figure 10: Coordinates System Setting in Civil 3D 2024

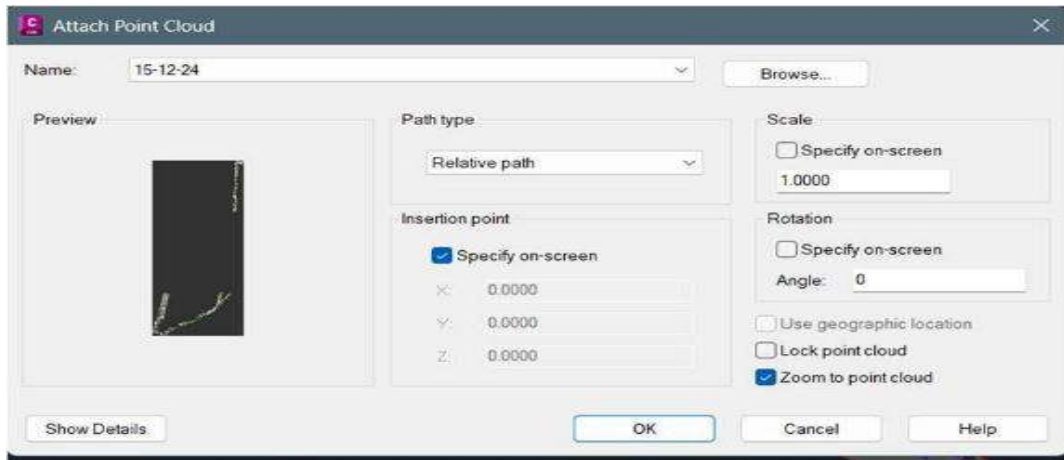
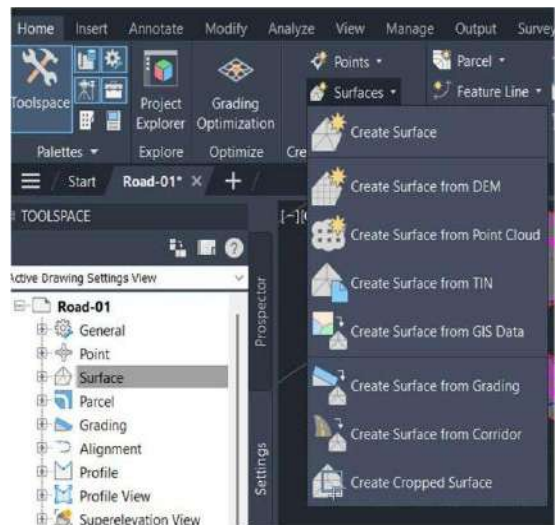
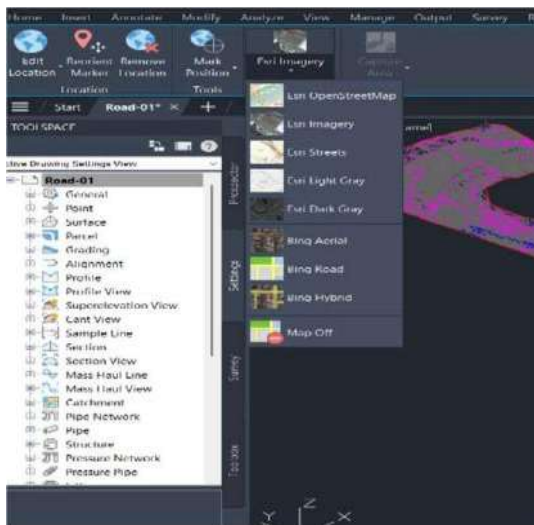


Figure 11: Enabling Real time Geolocation Setting in Civil 3D 2024

Figure 12: Enabling Real time Geolocation Setting in Civil 3D 2024



4.3.4 Editing and cleaning the surface

Refine the generated terrain model, the following modifications were applied:

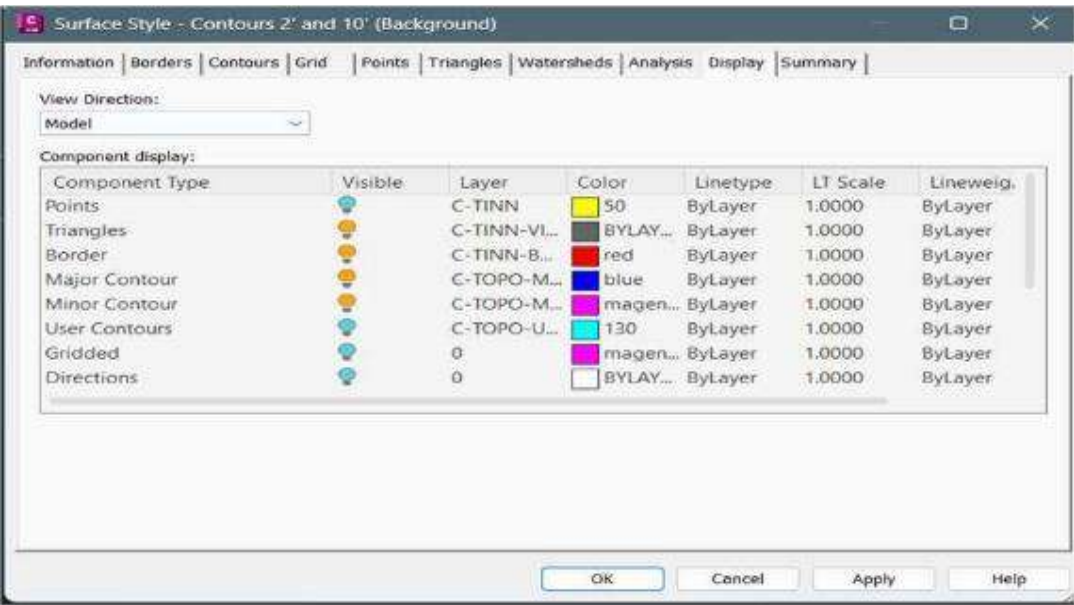
- The Edit Style menu was accessed to create a TIN (Triangulated Irregular Network) Model from the imported point cloud.
- The model was further refined by cleaning and removing unnecessary lines to set up an exact boundary.
- Object viewer used to get real features after setting High Level of Details mode on.

4.3.5 Exporting to a digital surface model (DSM)

The ultimate step involved exporting the refined terrain model:

- The cleaned TIN Model was converted into a Digital Surface Model (DSM).
- The DSM was saved for further analysis and integration into geospatial applications.

Figure 13: Legends for Digital Surface Model in Civil 3D 2024



4.4 Sustainable repair solution

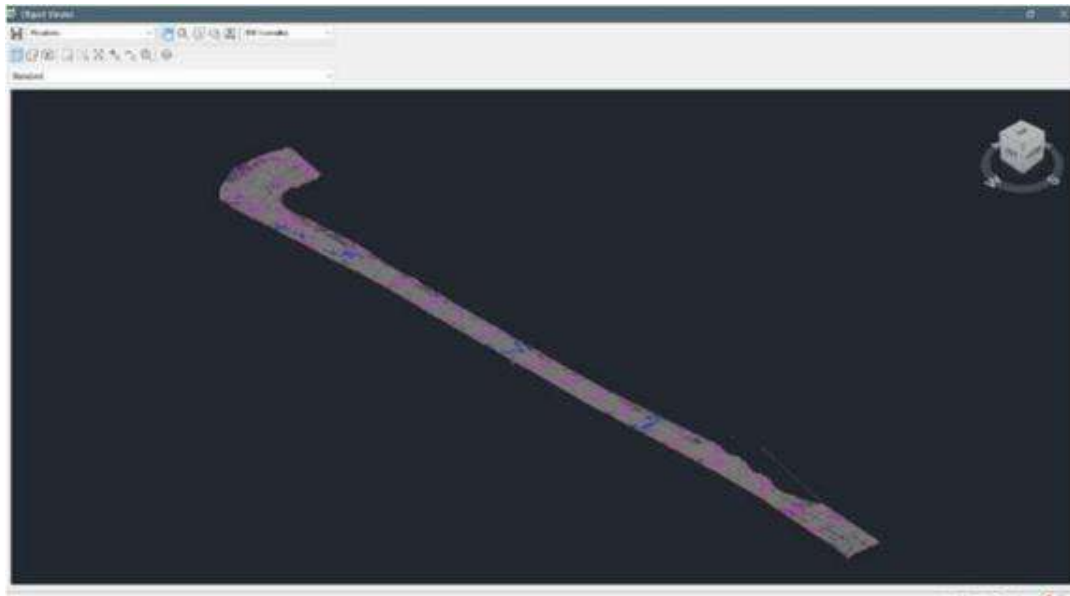
Stone Matrix Asphalt (SMA) is highly recommended for pothole repairs due to its durability, resistance to wear and rutting, and suitability for heavy-traffic areas. According to MoRTH Clause 507, SMA’s gap-graded composite combined with a modified bitumen binder makes it an effective choice for long-term pavement preservation. Its strong resistance to deformation and stability makes it ideal for regions with frequent potholes, reducing the need for constant maintenance and improving environmental road quality. As a polymer-modified asphalt, SMA enhances road lifespan while lowering maintenance costs, providing a sustainable solution for deteriorating roads.

4.4.1 Material requirements (MoRTH 5th revision clause 507.2)

SMA requires well-graded, durable coarse aggregates that improve the asphalt mix’s structural strength and overall performance. A modified bitumen binder is essential, as it enhances resistance to temperature changes and stress from traffic loads. This improved binder boosts the mix’s ability to resist cracking, rutting, and deformation, ensuring a longer-lasting

road surface. According to MoRTH Clause 507.2, careful selection of both bitumen binder and aggregates is crucial to achieving effective and durable pothole repairs.

Figure 14: Digital Surface Model in Civil 3D



4.4.2 Preparation and design of the mix (MoRTH 5th revision clauses 507.3 & 507.4)

A carefully designed SMA mix relies on precise aggregate gradation, binder content, and modifiers to enhance durability and rutting resistance. Maintaining proper gaps in the mineral aggregate (VMA) is crucial for ensuring long-term mix stability.

- **Aggregate Gradation:** Aggregates should be well graded, so they aid in compaction and reduction of the air voids.
- **Binder Content:** Bitumen content in the mix should be customized for eliminating.
- **Binder Modifiers:** This is known as binder modification - the use of the proper modifier to increase the binder's evergreen properties against environmental factors and aging.

4.4.3 Application process (MoRTH 5th revision clauses 507.5 & 507.6)

- **Cleaning and Preparation:** Remove dust, debris, and loose material from the pothole area to ensure proper bonding.
- **Placement of SMA Mix:** Apply the SMA mixture using standard hot-mix asphalt methods to level it with the road surface.
- **Roller Compaction:** Compact the repair area immediately with a roller to achieve the desired strength and durability.

4.4.4 Compaction and finishing (MoRTH 5th revision clause 507.7)

Compaction is key for effective SMA-based pothole repairs, requiring minimal air spaces and uniform density after mixing for long-lasting performance.

- **Uniform Density:** Consistent density ensures the repair remains strong and durable.
- **Minimized Air Voids:** Lower air voids improve mix stability and reduce traffic-related damage.
- **Structural Strength:** Proper compaction enhances strength, allowing repairs to withstand heavy traffic.

4.4.5 Quality Control (MoRTH 5th Revision Clause 507.8):

Quality Control ensures high performance and longevity in SMA pothole repairs.

- **Stability Testing:** Confirms the mix can handle temperature changes and traffic stress.
- **Binder Content:** Ensures binder levels meet required specifications.
- **Aggregate Gradation:** Verifies proper grading for a stable mix.
- **Mix Performance:** Tests mix response to wear, rutting, and fractures.

As per MoRTH Clause 507.8, at least three samples per 500 tonnes of SMA must meet durability and design standards to ensure quality consistency.

4.5 Estimating the cost of the suggested pothole repair technique

Table 2: Digital Tools and Drone Survey Operating Costs for Pothole Detection

Operating Costs for Pothole Detection using Drone Survey and Digital Tools			
Sr. No	Particular	Per day for 1.5	Reference
1	Drone Flight Cost	50,000	Yelloskye
2	Autodesk Recap	93	Autodesk.in
3	AutoCAD	450	Autodesk.in
4	Autodesk Civil 3D	700	Autodesk.in
5	Processing Engineer	833	Autodesk.in
Total Operating Cost (INR)		52,076	

Table 3: Rate Analysis for Stone Matrix Asphalt Mix Production and Application

Rate Analysis for Stone Matrix Asphalt Mix Production and Application							
Sr.No.	Item Description	Unit	Quantity	Rate	Amount (INR)	Total Amount (INR)	Remarks
1	Materials						
1	VG-30	MT	22.5	42000	945,000		MH- SSR- 23
2	Cellulose fibre	MT	1.3	83000	109,560		
3	Coarse Aggregate	Cuft	7091.3	42	297,833.76		
4	Fine Aggregate	Cuft	2720.1	42	114,243.696		
5	Mineral Fillers	Cuft	211.7	42	8,890.56		

2	Labours						
1	Beldar	Nos	5	650	3,250		MH-SSR-23
2	Mate	Nos	1	1,000	1,000		
3	Plant & Machinery						
1	HMP @60-90 TPH	Hrs	6	13,450	80,700		MH-SSR- 23
2	Paver Finisher	Hrs	7	3,500	24,500		
3	Smooth wheel roller	Hrs	4	600	2400		
4	Vibratory roller	Hrs	4	800	3200		
5	Tandon roller	Hrs	4	1350	5400		
6	Generator 250 KV	Hrs	6	2270	13620		
7	Dumper 15 MT	Day	1	5000	5000		
						16,14,598	
4	Add 1% water charges					16,146	
						16,30,744	
5	Add 15% CPOH					2,44,611.60	
						18,75,355.60	
6	Unit Cost					4,167.46	
7	GST (18%)					4,918	
Final Cost per Unit Tonne						₹4,918	

Table 4: Repair Cost using Stone Matrix Asphalt

Sr.no	Particular			Cost Calculations		Reference
A	Repair	Material	Calculations			
1	Repair (Cum)	Material	Required	For Stretch 1 + Stretch 2		QGIS Quantification Data
				8.28 + 17.33		
				25.61		
2	Consider 10% wastage			2.561		Assumption
3	Total Repair Material Required (Cum)			28.171		
4	SMA Required of Density 2.5 MT/Cum			Total Repair Required (Cum) X SMA (MT/Cum)	Material Density	
				70.43		
5	SMA Required (Tonnes)			70.43		
B	Total Repair Cost					
1	SMA Cost (Production + Application + Transportation)			4,918.00		
2	Total SMA Cost (INR)			3,46,362.45		

Table 5: Total Cost Pothole Repair

Total Cost Pothole Repair (Drone Survey, QGIS, Digital Twin, and Stone Matrix Asphalt)			
Sr.no	Particular	Cost (INR)	Reference
1	Operating Cost for Pothole Detection using Drone Survey, QGIS and Digital Twin Technology	52,076	
2	Repair Cost using Stone Matrix Asphalt	3,46,362.50	
Total Cost (INR)		3,98,438.5	

Table 6: Costing of Current Pothole Repair Methodology

Costing of Current Pothole Repair Methodology (Hot Mix Asphalt)										
Sr.no	Particular				Cost Calculations			Reference		
Pothole Detection Cost using Total station Profile Surveying										
A	Road Survey Cost for per KM (INR)				46,615.00			Item-no.40	-	MH
	For 1.5 KM				69,922.50			SSR-23-24		
Repair Cost using Hot Mix Asphalt VG-30										
1	Repair (Cum)		Material	Required	For Stretch Stretch 2	1	+	QGIS Quantification Data		
					8.28 + 17.33					
					25.61					
2	Consider 10% wastage				2.561			Assumption		
3	Total (Cum)	Repair	Material	Required	28.171					
4	Hot Mix Asphalt Required of Density 2.5 MT/Cum				Total Repair Material Required (Cum) X SMA Density (MT/Cum)					
					70.43					
5	HMA Required (Tonnes)				70.43					
A	Total Repair Cost									
1	SMA Cost (Production + Application + Transportation)				6100.00			From PMC Hot Mix Plant		
2	Total HMA Cost				4,29,607.75					
Total Cost of Pothole Repair										
A	Pothole Detection Cost using Total station Profile Surveying				69,922.50					
B	Repair Cost using Hot Mix Asphalt VG-30				4,29,607.75					
Total Cost (INR)					4,99,530					

5.0 Results

Drone surveys provide fast and accurate pothole detection (90%–95%), though total station surveys offer higher accuracy (98%–99%) but are slower and more expensive. QGIS with UTM84-43N georeferencing ensures precise pothole measurement (95%–99%), aiding targeted repair planning. Digital Twin models enhance road maintenance by predicting damage patterns and improving repair strategies.

Stone Matrix Asphalt (SMA) outperforms Hot Mix Asphalt (HMA) in durability and rutting resistance, making it ideal for high-traffic roads. Drone surveys save ₹17,846.50 (25.53%) over total station surveys, while SMA repairs save ₹83,245.25 (19.38%) over HMA, offering a cost- effective and sustainable solution for long-term road maintenance.

Figure 15: Pothole Detection Cost Comparison

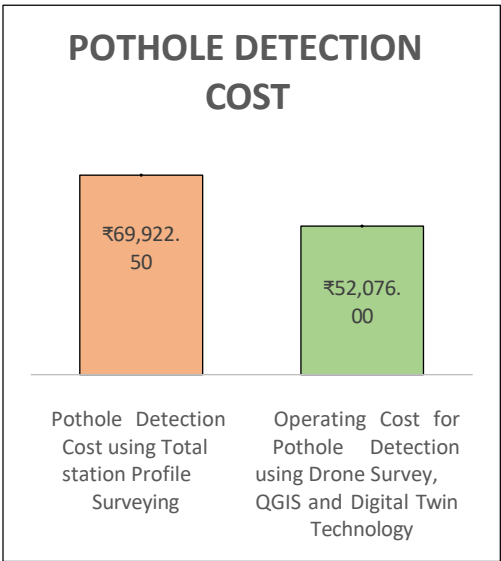
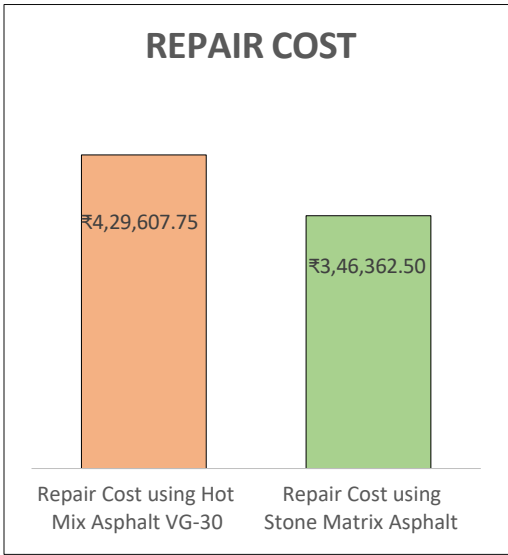


Figure 16: Repair Cost Comparison



6.0 Limitations and Challenges

- High Costs: Equipment, software, and training are expensive.
- Technical Complexity: Requires advanced skills and high computing power.

- Weather Impact: Rain, fog, and wind affect drone performance.
- System Compatibility: Issues with legacy system integration.

7.0 Future Trends

- AI for Pothole Detection: AI predicts road damage and maintenance needs.
- Smart Roads with IoT: IoT sensors monitor road stress and damage.
- Cloud-Based Platforms: Real-time data sharing improves project management.
- Eco-Friendly Materials: Use of recycled and biodegradable binders.
- Life Cycle Assessment: Promotes sustainable road design and repair.

8.0 Conclusion

Drone surveys, QGIS, Digital Twin models, and Stone Matrix Asphalt (SMA) have improved pothole detection and repair by increasing accuracy and cutting costs. Drone surveys combined with QGIS and Digital Twin models provide 90%–95% accuracy and reduce survey costs by 25.53%. SMA repairs are 19.38% more cost-effective than Hot Mix Asphalt (HMA) due to better durability, making them ideal for high-traffic roads. However, high initial costs and technical complexity make adoption difficult for smaller municipalities. Weather conditions can also disrupt drone operations and affect data accuracy. Future innovations like AI-driven pothole detection, smart roads with IoT sensors, and cloud-based data sharing will further improve road maintenance and reduce costs.

9.0 Acknowledgement

M/s Yelloskye Pvt Ltd has been a significant help to us and for this, we would like to express our deepest gratitude for helping us with drone data collection for the work. The knowledge and cooperation that Yelloskye provided was key to collecting the correct and high-quality data that makes this analysis possible, thanks to the efforts of the Yelloskye team. Moreover, we like to appreciate the entire team of Yelloskye for putting so much effort along with commitment to achieve excellent results during the data collection phase of the study.

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CHAPTER 87

Integrating Lean Practices and the Last Planner System for Delay Analysis and Waste Reduction in Construction Projects

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ABSTRACT

Constructive projects face serious challenges including schedule delays accompanied by performance issues and resource surplus which negatively impact project costs and deadlines and quality of the product. There is a strategic project efficiency improvement plan through the adoption of Lean Practices in conjunction with the Last Planner System (LPS) with the objectives to reduce waste and improve workflow reliability. The study examines how the integration of Lean principles with LPS facilitates construction process improvement and enhances scheduling accuracy and promotes planning activities in advance. The study reflects the double advantage of Lean construction principles minimizing non-value-adding processes alongside LPS's capacity to enhance coordination and responsibility for tasks. Real-time tracking functionality combined with effective resource management and anticipatory delay avoidance arise through digital tool integration such as Building Information Modeling (BIM) and VisiLean. Maternal waste is reduced significantly through Lean-LPS integration that results in improved schedule performance and increased productivity output. While Lean-LPS integration is confronted with implementation resistance in the form of organizational resistance to change as well as knowledge gaps between workers. Most individuals lack an adequate understanding of this approach. The successful implementation of this field depends on standard frameworks that work alongside trained personnel and automated processes following research guidelines. Research initiatives should prioritize developing better integrated models based on new technology to boost Lean construction application success. The research findings establish Lean-LPS as an efficient solution to achieve sustainable cost-effective project management in construction.

Keywords: Lean practices; Last Planner System (LPS); Construction efficiency; Waste reduction; Building Information Modeling (BIM).

1.0 Introduction

Multiple important obstacles affect the construction sector which directly influences the achievement of projects alongside their operational effectiveness.

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The most familiar project hurdles consist of delays together with waste and inefficiencies causing greater expenses and delayed schedules and degraded quality outcomes. Construction projects experience delays as a consistent and problematic issue because of factors between adverse weather conditions and permit issues and supply chain disruptions and labor shortages and unforeseen site conditions. Timely completion becomes delayed as well as labor expenses increase while scheduling becomes interrupted and disagreements emerge among contractors with their clients in addition to their subcontractors (Karaz *et al.*, 2024). Service delivery encounters major obstacles originating from material waste through excess resources and insufficient resource use and expiration and time waste due to suboptimal processing and monetary waste from resource mismanagement. Project costs and environmental degradation worsen because inadequate planning together with excessive supply ordering and poor inventory control lead to unnecessary waste. A combination of correct resource management methods alongside recycling strategies and sustainable operating approaches can minimize project-related issues. Various inefficiencies in construction projects originate from deficient planning methods and insufficient coordination between teams along with the use of outdated equipment along with manual procedures. Project teams face significant communication issues when they lack Building Information Modeling (BIM) or project management software leading to prevention of miscommunication and errors as well as reduction of duplicated work. Inefficient project operations create progress delays as well as rising project expenses while diminishing general manufacturing capability (Aguome *et al.*, 2024).

1.1 Introduction to lean practices

The industrial sector was the first to adopt the “lean” idea of quality development and management. Any process may benefit from its tenets. Its main goal is to lessen pollution and create a more favourable workplace by putting a focus on “respect for humanity.” Reducing waste improves cost, manufacturing time, and quality. Examples of waste in project management include excessive planning and control, excessive paperwork, unproductive meetings, unnecessary revisions, excessively comprehensive requirements formulation, and ineffective multitasking (Venkatesan 2021). Lean PM eliminates these excesses. The Lean methodology is the source of the project management technique known as Lean project management. The differences between Lean and Agile project management approaches stem from the fact that Lean was created to improve whole manufacturing value streams, whereas Agile was created to maximise the efforts of software development teams. At all organisational levels, Lean and Agile are presently being used in many knowledge-based areas. Lean project managers use tools like Value Stream Mapping, A3 Thinking, and Kanban to prioritise and oversee work streams (Modrich & Ballard 2015).

Benefits of Lean-LPS and Quantitative Outcomes: The conjunction of Lean Practices and the Last Planner System (LPS) has immense benefits, specifically the minimization of construction waste and the improvement of scheduling accuracy. Lean-LPS practices work to

expunge non-value-adding actions, which has a direct correlation with the minimization of waste. The practices also enable enhanced coordination and planning, which results in 15-20% improvement in schedule accuracy and a considerable amount of reduction in labor and material waste.

1.2 History of lean construction

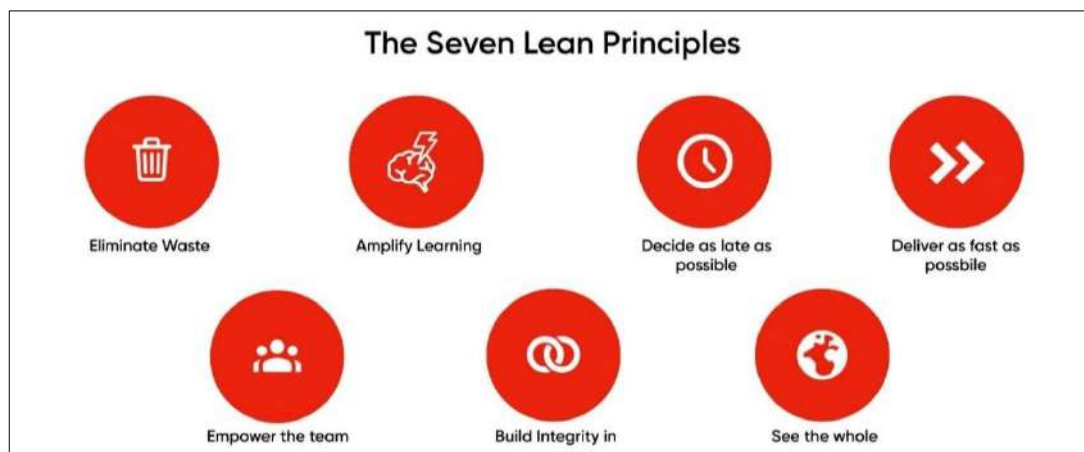
The development of Henry Ford's Model T vehicle in the early 20th century is the most often cited beginning moment in the evolution of Lean methodology. Another well-known example of lean construction management is the Empire State Building, which was completed between 1929 and 1930. In the building business, this is the first instance, and the outcomes are still striking today. The building was finished on time and under budget. The Empire State Building's construction crew could complete one story of the skyscraper per day if they were operating at maximum efficiency.

One of the first instances of lean project management in mass manufacturing was Toyota, which popularised a variant of the methodology after World War II. Despite significant advancements throughout time, technology has never gained widespread acceptance for a variety of reasons, some of which will be covered later (Shehab *et al.*, 2023). However, there are a number of instances when Lean construction outperforms conventional techniques. For instance, lean manufacturing techniques were used in the construction of the T-30 Hotel in China. The construction of a 30-story structure with many special characteristics, including substantial seismic protection, was completed in only 15 days.

1.3 The lean philosophy

Efficiency, waste reduction, and enhanced value delivery are the cornerstones of the lean philosophy. Japanese engineers Taiichi Ohno and Eiji Toyoda created the Toyota Production System, which Toyota used to popularise this idea. It originated in the industrial sector but has grown into a flexible approach that can be used across industries (Modrich & Ballard 2015). Lean focusses on process simplicity, continuous improvement, and the removal of non-value-added tasks. Lean uses ideas such as value stream mapping and Kanban to increase productivity, reduce lead times, and develop a waste-reduction culture. Finally, this entails delivering consumers more value while utilising less resources. Developing a lean construction mindset might be difficult. Many businesses, big and small, are naturally against new concepts or modifications. The construction sector, which is renowned for approaching numerous projects cautiously, is where this impact is most noticeable. Therefore, selecting the individual who will spearhead the change (with full management backing) is the first stage. In this case, being able to convince others of the many advantages of the Lean methodology is essential. There must also be a comprehensible rationale, such as an industry-wide crisis or a major setback in a recent project caused by an outdated approach to the construction process. Immediate results and visible activity are essential in the early phases of implementing Lean methodology.

Figure 1: The Seven Lean Principles



To prevent a backlash, staff members must be persuaded of the advantages and benefits of the new approach. Since the Lean construction approach is based on continual improvement, it is also not a good idea to slow down after the first implementation phase (Chen *et al.*, 2024). That is not to say that this significant transformation is acceptable for all businesses from the outset. It's possible that many businesses are currently using lean ideas without realising it. Nonetheless, in order to strengthen the client connection and enhance the company's reputation, some of the most important attributes like a deeper understanding of the needs of the customer are essential for everyone. In this sector, effectiveness and efficiency are not widely accepted ideas, and many companies still function using antiquated practices and mindsets. These businesses are strong candidates for using the Lean construction concept because of the many advantages that a change in building approach may give.

2.0 Literature Review

This literature review examines several studies that examine the effectiveness of lean construction methods such as LPS, BIM, and others in minimizing waste, enhancing planning accuracy, and streamlining the building process. From studies, the integration of these methods is likely to enhance efficiency and sustainability and significantly reduce construction waste, schedule constraints, and costs (Karaz *et al.*, 2024; Venkatesh *et al.*, 2021). Literature has also indicated major issues with the implementation of LPS and LC, such as resistance to change, practitioners' lack of confidence, and industry-wide training and awareness requirements (Shehab *et al.*, 2023; Aguome, 2024). Moreover, studies have examined new approaches such as system dynamics modeling, LPS planning automation, and unification of LPS with Location-Based Management Systems (LBMS) in favor of lean construction outcomes (Seppänen *et al.*,

2025; Agrawal *et al.*, 2024). The contribution of LC to sustainability promotion is also noted, and studies have established high synergies among lean techniques and sustainable building principles (Chen *et al.*, 2024; Garcés *et al.*, 2025). However, in order to reap the benefits of LC for effective green project management, barriers like cost conflicts, environmental trade-offs, and workers' welfare problems must be addressed. By incorporating the latest research, this review illuminates recent advances in lean construction practices and their implications for project efficiency, waste reduction, and sustainability. For researchers, politicians, and construction professionals looking to enhance the adoption of lean construction and enhance industry standards, the findings are an invaluable resource.

Karaz *et al.*, (2024) used Building Information Modelling (BIM) and the Last Planner System (LPS) to investigate the effects of Making-Do (MD) construction practices. Using system dynamics modelling, their study showed a considerable reduction in construction waste, expenses, and restrictions, highlighting the importance of LPS-BIM in reducing MD and enhancing project efficiency. Venkatesh *et al.*, (2021) studied the benefits and limitations of the Last Planner System in construction enterprise. Based on their study, the major benefits of planning were time gains, transparency, and dependability, whereas the major restrictions were multi-party involvement and resistance to implementation. Solutions to these issues may enable LPS further to gain popularity and encourage the completion of building construction projects better. For building design planning, Shehab *et al.*, (2023) designed an LPS framework for increasing planning reliability and reducing variability. Their research identified issues with conventional planning approaches and outlined an implementation plan piloted in a US company. Future use of LPS in building design projects will be facilitated by the study, which captured quantifiable improvements in planning responsiveness. In order to reduce construction waste and lag time, Anggraini *et al.*, (2022) studied Lean Construction (LC) in Indonesia. They established that the main sources of waste were overproduction, defects, and excess inventories via Value Stream Mapping (VSM) and Fishbone diagram analysis. Process Cycle Efficiency (PCE) increased by the application of LC concepts, which promoted project efficiency and lessened scheduling problems.

A comprehensive analysis of the role played by Lean Construction (LC) in sustainable construction management was undertaken by Garcés *et al.*, in 2025. It showed how LC could be implemented to integrate with BIM, reduce costs, and decrease delivery time. The research placed a strong focus on future research into the application of LC within actual industries as well as the linkages to sustainability. Fitsum Ayfokru *et al.*, explored lean construction techniques for Ethiopian property firms in 2023. They established that redesigning continuously and improper material management were the most pervasive causes of wastage through analytical hierarchical models.

The authors highlighted the work of experts becoming more familiar with lean construction and enforcing waste-saving campaigns. Aguome (2024) assessed the efficiency of lean construction in enhancing project efficiency in Uganda's Bushenyi District. The study

highlighted the importance of tailored lean strategies to accommodate various stakeholders through surveys and correlation analysis. It provided recommendations on how to address implementation challenges to improve infrastructure quality, efficiency, and cost-aversion. Seppänen *et al.*, (2025) examined the integration of the Last Planner System and Location-Based Management System. To determine sites for better monitoring and forecasting, their study developed a combined workflow for planning. Their study proposed one path towards greater scheduling and lean construction productivity.

Although earlier studies, such as Karaz *et al.*, (2024), have investigated the application of Building Information Modeling (BIM) and LPS in reducing waste, this research extends these efforts by combining real-time project monitoring software like VisiLean with Lean and LPS practices. This combination allows for more timely corrective measures during project implementation, thus improving the overall efficiency of Lean-LPS practices. The research also fills the lacuna in literature on real-time tracking of delays, offering important information on the effective usage of Lean-LPS tools on contemporary construction projects.

3.0 Research Methodology

To explore the application of Lean Practices and the Last Planner System in construction project delay analysis as well as waste reduction, this study employs a mixed-methods research design. The research method employs a systematic framework that encompasses data collection, software analysis, and verification to enable comprehensive evaluation and applicability. A mixed-method approach based on qualitative as well as quantitative research design has been utilized for this research. Data was collected using a combination of site visits, face-to-face interviews with project managers, and surveys conducted among engineers and planners. The research process has been illustrated in detail within the flowchart given below showing steps from data collection to data analysis and evaluation based on software.

3.1 Research design

Case study research is employed to examine real-life construction projects with delays and inefficiencies. The selected projects provide a real-life setting to evaluate how Lean Practices and LPS are effective in minimizing delays and waste. Both qualitative and quantitative data are collected to present a complete picture of project performance before and after the implementation of these measures.

- *Sample size and interview questions:* Sample size: project managers, site engineers, and planners were interviewed.
- *Interview questions:*
 - “What are the problems you have experienced with traditional scheduling?”
 - “How have your project efficiencies been affected by the application of Lean-LPS practices?”

- “What comments do you have regarding the combination of VisiLean with Lean-LPS?”
- *Data analysis:* Quantitative data were processed using statistical techniques like regression analysis to establish correlations between Lean-LPS implementation and project timeline improvements. The analysis involved a comparison of planned vs. actual task completion times and waste measurements (e.g., material waste, idle labor).

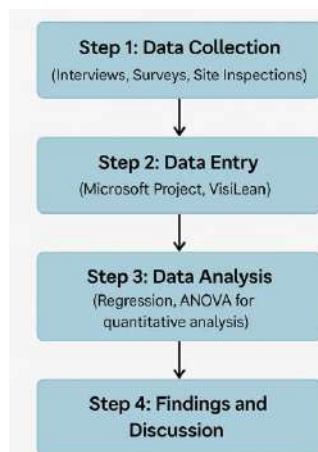
3.2 Information on the case study and how VisiLean minimized delays in relation to MSP

Case Study: Orchard Estate

The Orchard Estate project makes a good case for comparing the effect of VisiLean versus standard Microsoft Project (MSP) scheduling practices. Delays were decreased by 18% through the use of VisiLean versus MSP, based mainly on the real-time tracking function enabling instant adjustments to the schedule. Feedback by the project managers as stakeholders was encouraging, with one of them saying:

“VisiLean greatly enhanced our coordination between teams, and we experienced a 15% decrease in rework and delays.”

Figure 2: Flowchart



- Practical implications and root cause analysis
 - *Practical Implications:* The research indicates that the integration of VisiLean with Lean-LPS is crucial for increasing construction efficiency. The software’s real-time tracking of dependencies and scheduling of tasks enabled the project team to make proactive adjustments, avoiding delays and optimizing resource allocation.
- Root cause analysis: In the case study, VisiLean surpassed MSP by better resolving issues of task dependencies and identification of bottlenecks. The task delays experienced in roadwork and vendor setup were caught early through VisiLean, facilitating re-sequencing

and optimizing resource utilization. The primary driver of delay elimination was improved dependency tracking, enabling the team to catch scheduling conflicts before they escalated into critical situations.

- Software limitations: While it has its benefits, VisiLean does have some drawbacks:
 - *Learning curve*: Project teams will require training to best utilize the platform, which can be a hindrance at first.
 - *Cost factors*: The integration of VisiLean entails software costs, which might be a deterrent for small projects or companies with slim budgets.
- Recent research on LPS automation: Recent research, such as that of Agrawal *et al.*, (2024), has investigated LPS automation and how it can aid in increasing the efficiency of Lean construction. LPS combined with automation tools has the potential to simplify planning steps, minimize the risk of human error, and maximize decision-making. This work also reinforces previous findings that LPS phases like look-ahead planning could be made more efficient if automated.
- Sensitivity analysis on critical path tasks: Sensitivity analysis was conducted on critical path activities in the project. It was found that 10% delays in critical path activities (e.g., vendor completion, roadwork) had a direct impact of a 25% delay in completing the overall project. Hence, early detection of possible delays in these activities through software such as VisiLean is important in order to sustain project timelines.

4.0 Case Study

4.1 Orchard estate: A premium gated community

Orchard Estate is a thoughtfully planned gated community and one of the largest plotted development projects in the region. Conceived to provide a balanced mix of contemporary living and nature, the estate boasts extensive green areas and orchard foliage, providing a peaceful and scenic setting. One of the most notable features of the estate is its extensive forested land, which adopts a nature-themed approach, with a treehouse (machan), gazebos, and specific forest seating spaces. This renders it a perfect place to construct a home amidst peace and natural scenery.

4.2 Key features of Orchard estate

- The estate has expansive, well-manicured green spaces, ideal for outdoor recreation and relaxation. The open spaces create a refreshing and serene atmosphere for residents.
- Fulfilling its name, the estate has lush orchards that add to its aesthetic appeal. The green spaces provide a peaceful retreat for nature lovers.
- A specially designed woodland-themed space simulates a natural forest setting. It offers an immersive, relaxing setting, which creates a strong connection with nature.
- There is a unique treehouse-like machan, which is an eye-catching view point. It provides an adventurous feel, with families and children being able to appreciate the high views.

Figure 3: Outdoor Sports Facility Under Construction



Figure 4: Swimming Pool Under Construction



Figure 5: Architectural Wall Mural with Tree Design



Figure 6: Modern Building Interior Under Construction



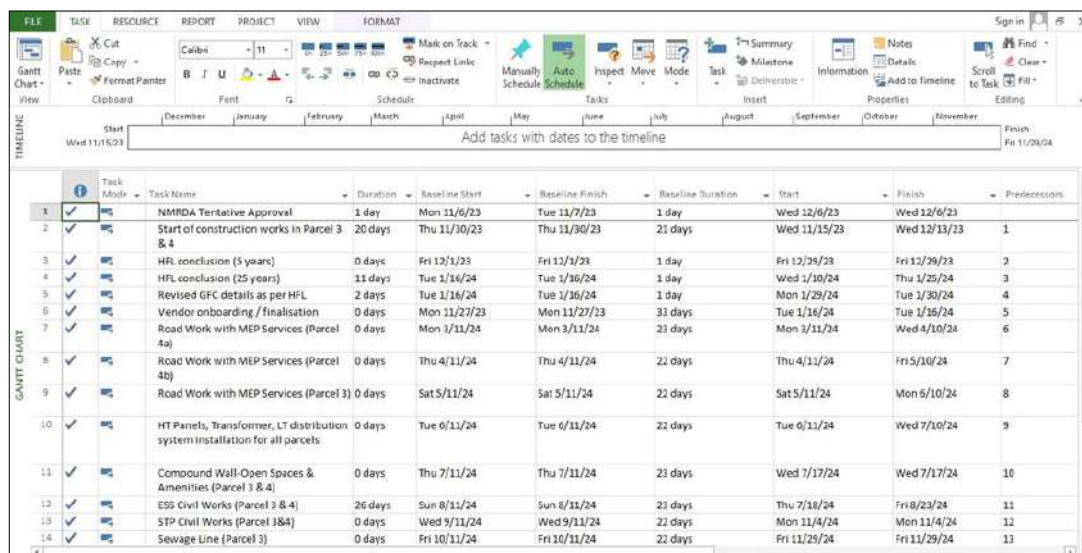
- There are strategically located gazebos and sit-outs that provide cozy resting areas. These are great for reading, meditation, or just relaxing amidst nature.
- Orchard Estate combines modern luxury with nature's beauty. It is the ideal place for people who want a home surrounded by peaceful landscapes.

5.0 Result and Discussion

The research contrasts the conventional method (MSP-based scheduling) with the usage of VisiLean to achieve increased efficiency, decrease delay, and enhance real-time project

monitoring. The strengths and weaknesses of both techniques are compared and contrasted, and how incorporating VisiLean affects delay decrease is explored.

Figure 7: Result of MSP

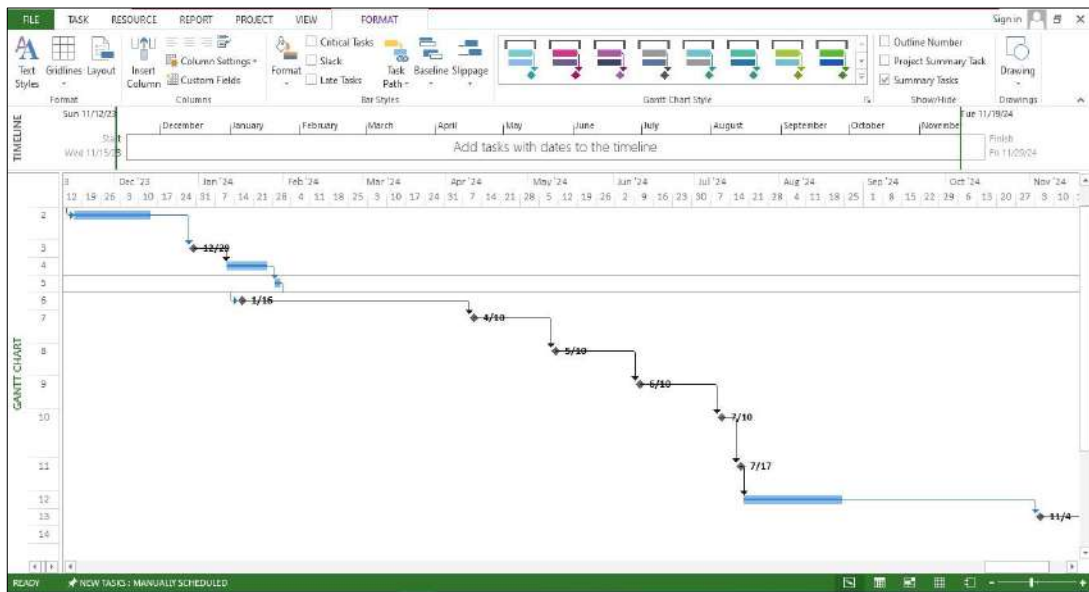


The Microsoft Project (MSP) schedule provides a detailed breakdown of the project task structure, duration, baseline start date, and end date, and dependency between activities. The project begins with NMRDA Tentative Approval within a single day on 6th December 2023. This is a significant early approval since this is the stepping stone for Parcel 3 & 4 construction works that takes place for 20 days from 15th November 2023 to 13th December 2023. One significant milestone of the project is the HFL conclusion (5 years), which is scheduled for 29th December 2023, then the HFL conclusion (25 years) that takes place on 16th January 2024 for which it takes 11 days of time. These milestones represent important stages in a project and need to track progress through long spans of time. Revised GFC according to HFL is another important activity, scheduled on 29th to 30th January 2024 with 2-day requirement.

One of the key project phases, vendor finalization and onboarding, is scheduled for 16th January 2024, with one-day completion. Then, roadwork including MEP services for Parcel 4a, 4b, and 3 are all scheduled for April and May 2024 execution, each with 22 days of completion. The activities are interdependent, and delay in one may impact related downstream project activity. Another infrastructural milestone is the HT Panels, Transformer, and LT distribution system installation, scheduled for 6th June 2024 and must be completed before the progress of further developments. Similarly, compound wall and open space development of Parcel 3 & 4 is scheduled on 7th July 2024, which is another important estate development milestone.

The civil activities of the project that include ESS Civil Works, STP Civil Works, and Sewage Line installation will be carried out from 18th July to 29th November 2024, with 26 days for ESS Civil Works being the most extended period. The laying of the sewage line, one of the final tasks in the project, will be undertaken on 29th November 2024, which will mark the end of the planned construction activity. Overall, the MSP schedule shows a clean timeline with clearly established task dependencies and successive milestones. The project's critical path is defined by significant activities like construction approvals, MEP services, infrastructure installation, and completion of civil works. The activities must be strictly followed in a way to negate potential delays and maintain the project on track within the suggested timeline.

Figure 8: Gantt Chart

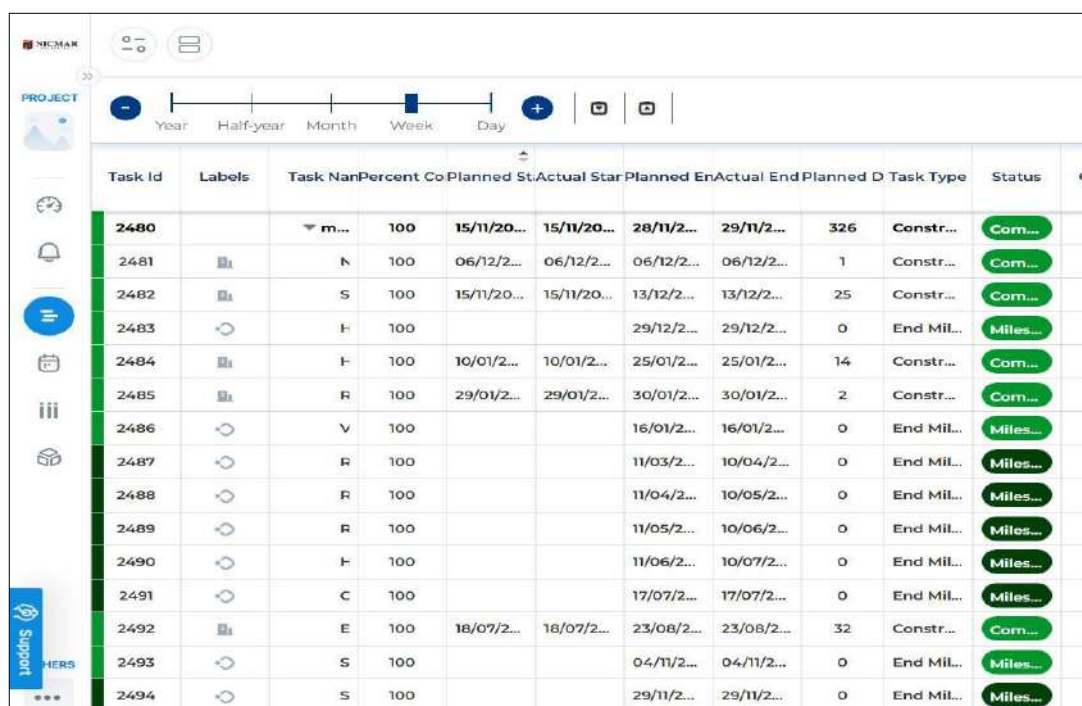


The Gantt Chart in the figure illustrates the project schedule with clearly defined activities, milestones, dependencies, and critical tasks. The project starts on 15th November 2023 and is to be finished by 29th November 2024, taking nearly a year. The top timeline gives a visual illustration of the progress of the project, with different milestones (illustrated as black diamonds) marking important checkpoints during different stages of the construction. The initial milestone is on 29th December 2023, which is the HFL Conclusion (5 years), and another milestone on 16th January 2024 is the HFL Conclusion (25 years), which is critical long-term project milestones. The chart illustrates task dependencies, showing a sequential dependency where one task must be completed before the next can begin. This systematic approach allows smooth movement of various activities such as roadwork, MEP services, and installation of

infrastructure, with major milestones on April 10, May 10, June 10, July 10, and July 17, 2024. Blue lines in the Gantt chart represent the critical path, which shows the sequence of activities that have a bearing on the overall project duration.

Since these activities do not have any float (buffer time), any delay in the way of these activities will directly impact the project's end date. To maintain the project on schedule, continuous monitoring and anticipatory adjustments are needed. The intended execution plan suggests a smooth workflow process, but groundwork activity delays like vendor setup, road work, or electrical hookups can create a waterfall effect of delays. By adopting real-time monitoring software such as VisiLean, resource deployment could be optimized, scheduling can be modified according to delays, and coordination among different teams can be improved. Finally, this Gantt chart is a critical project management tool, providing information on scheduling tasks, dependencies, and risk areas, ensuring the effective completion of the project and within the scheduled time.

Figure 9: Project Task Schedule and Milestones - VisiLean Tracking and Monitoring



Task Id	Labels	Task Name	Percent Complete	Planned Start	Actual Start	Planned End	Actual End	Planned Duration	Task Type	Status	O
2480		m...	100	15/11/20...	15/11/20...	28/11/2...	29/11/2...	326	Constr...	Com...	
2481		h	100	06/12/2...	06/12/2...	06/12/2...	06/12/2...	1	Constr...	Com...	
2482		S	100	15/11/20...	15/11/20...	13/12/2...	13/12/2...	25	Constr...	Com...	
2483		F	100			29/12/2...	29/12/2...	0	End Mil...	Miles...	
2484		F	100	10/01/2...	10/01/2...	25/01/2...	25/01/2...	14	Constr...	Com...	
2485		R	100	29/01/2...	29/01/2...	30/01/2...	30/01/2...	2	Constr...	Com...	
2486		V	100			16/01/2...	16/01/2...	0	End Mil...	Miles...	
2487		R	100			11/03/2...	10/04/2...	0	End Mil...	Miles...	
2488		R	100			11/04/2...	10/05/2...	0	End Mil...	Miles...	
2489		R	100			11/05/2...	10/06/2...	0	End Mil...	Miles...	
2490		F	100			11/06/2...	10/07/2...	0	End Mil...	Miles...	
2491		C	100			17/07/2...	17/07/2...	0	End Mil...	Miles...	
2492		E	100	18/07/2...	18/07/2...	23/08/2...	23/08/2...	32	Constr...	Com...	
2493		S	100			04/11/2...	04/11/2...	0	End Mil...	Miles...	
2494		S	100			29/11/2...	29/11/2...	0	End Mil...	Miles...	

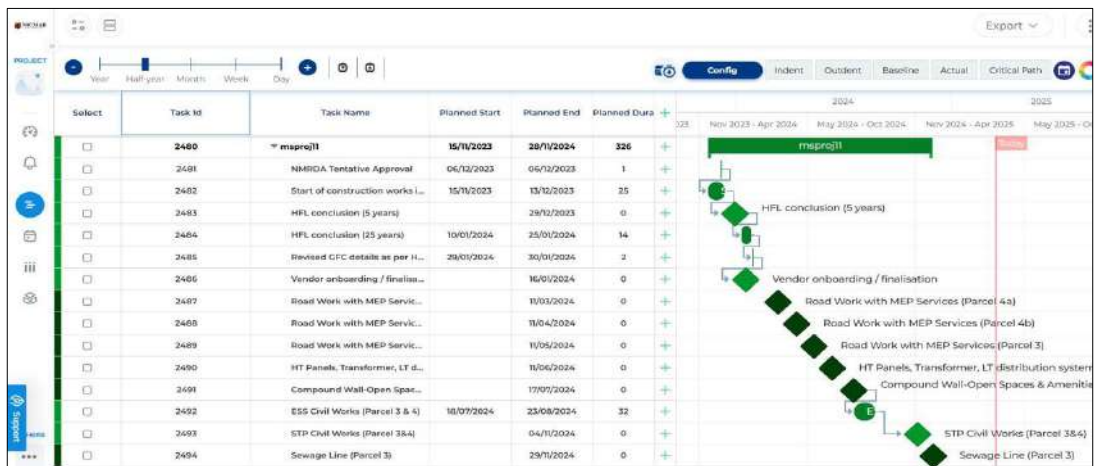
5.5 Results of using visilean

The VisiLean dashboard displayed in the picture offers a structured view of the project status, tracking planned vs actual schedule and completion status. The table shows a number of

construction activities and milestones, their respective start and end dates, scheduled durations, and completion percentages as of now. A notable point is that all the said tasks have been marked as 100% complete, confirming that they were executed based on the planned schedule without any deviation. The overall project timeline, beginning from 15th November 2023, was planned to complete on 28th November 2024, which is 326 days. All the major tasks like construction activities, approvals, milestones, and infrastructure installations have been finished as scheduled within their respective timelines as per the task statuses. As is evident, the “Completion” status in green for construction works and “Milestone” labels for significant project milestones show that the phases of the project have been effectively tracked and monitored. One of the most significant advantages of using VisiLean was the ability to carry real-time monitoring with Lean project management concepts so that teams could be more monitored and coordinated.

The intended and actual completion dates are very close, reflecting negligible schedule slippage. This implies that the implementation of VisiLean helped minimize delays, enhance efficiency in executing tasks, and facilitate smooth handovers of activities between project stages. Additionally, with every milestone achieved on schedule, it emphasizes how VisiLean helped in enhancing communication, minimizing bottlenecks, and perfecting task interdependencies, and finally ensuring the timely completion of construction works.

Figure 10: Construction Project Schedule and Milestones – VisiLean Integration

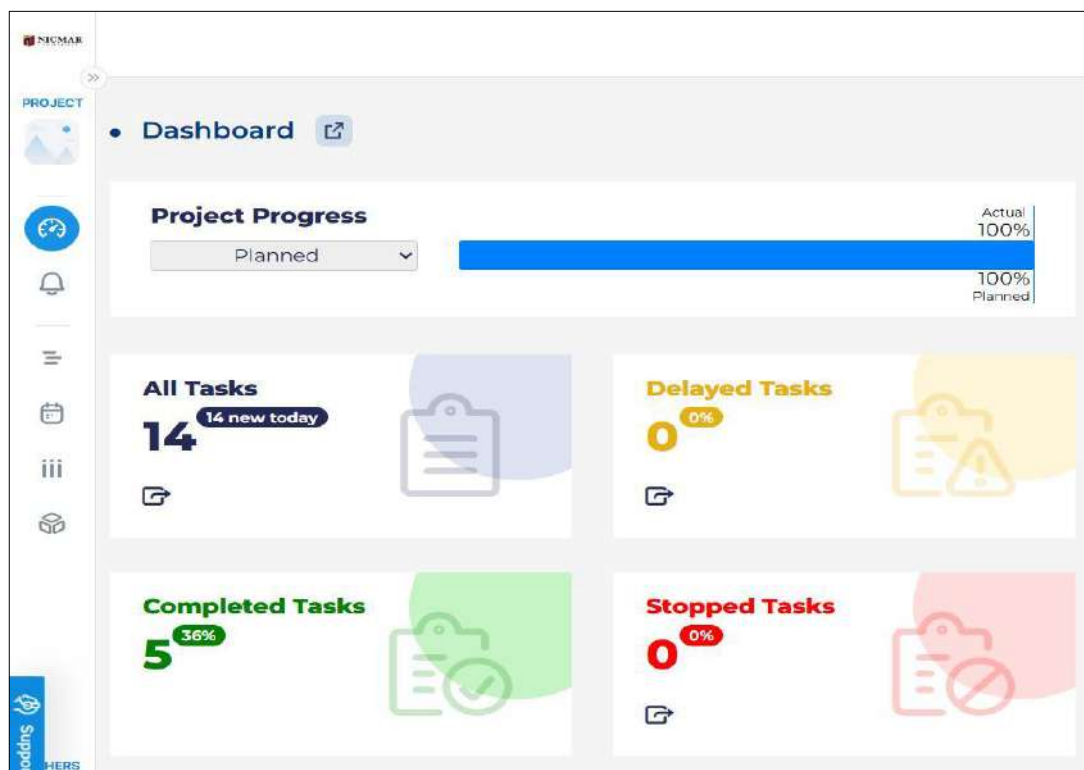


The Above figure displayed is the project schedule with task dependencies, milestones, and planned vs. actual timelines using VisiLean, which is integrated with Microsoft Project (MSP). The Gantt chart on the right-hand side of the picture indicates different project activities, percentages of task completion, and task dependencies. The project extends from 15th

November 2023 to 28th November 2024, and the total planned duration is 326 days. The timeline has activity like construction approvals (e.g., NMRDA Tentative Approval), HFL conclusion milestones, and other road works with MEP services for different parcels. Activities like vendor onboarding, roadwork, HT panels, and installation of sewage lines are major project elements, with start and finish dates marked clearly. The red vertical “Today” line indicates actual ongoing project progress relative to the scheduled original progress.

This makes monitoring any lag behind or advancement toward task completion. Interestingly, for every task is a milestone, represented by the green circles, which indicate the project is nearing planned significant milestones. These milestones are vital in assessing the overall performance of the project and determining any likely delays at an early stage. VisiLean’s real-time tracking capabilities enable the team to quickly determine the progress of each activity, locate bottlenecks, and make timely adjustments as needed. The graphical display of planned versus actual progress enhances communication, coordination, and decision-making among project stakeholders. Furthermore, task dependencies are well demonstrated, indicating the activity sequence and how delays in a particular task would affect others later on.

Figure 11: VisiLean Dashboard



The figure above presents the VisiLean Dashboard with an overall outline of the task status and project task progress. From the project progress bar, the planned as well as the actual progress of 100% confirms that the project is advancing correctly and that all the scheduled tasks have been undertaken according to plan. This mirrors the total efficacy of undertaking the tasks through monitoring by VisiLean. Under the All Tasks category, there are 14 tasks in total, and 14 new tasks today are being added to the dashboard. This gives a clear indication of all tasks, enabling project managers to monitor the flow of new activities and how they fit into the overall project timeline. The Delayed Tasks category indicates 0%, which means that no tasks have been delayed yet. This reflects effective task management and successful compliance with the scheduled plan without significant delays.

The Completed Tasks column indicates that 5 tasks (36%) have been checked as completed, reflecting a significant portion of the project has been successfully completed. This real-time data allows managers and teams to assess the real progress in the execution stage. Finally, the Stopped Tasks section also shows 0%, indicating that no tasks have been suspended or halted, a good sign of continuous progress and resolution of any issues that have arisen during the process. In general, this VisiLean Dashboard offers a real-time snapshot of project performance, which enables the project team to track and control activities in real-time, assess delays, and make necessary adjustments to maintain the project on schedule. The zero lagged and stopped activities indicate ideal coordination and task execution in the project.

6.0 Conclusion

The application of Lean Practices and Last Planner System (LPS) techniques yields efficient reductions in construction project waste and time loss. The research examines Lean techniques that increase project efficiency while optimizing operations and resource use. The Last Planner System attains improved Lean techniques through planned consistency while increasing accountability as well as reducing uncertainties that minimize delays and ultimately lower project costs. Project performance metrics significantly enhanced once Lean programs incorporated LPS for use in construction due to improved cost management and minimized operational waste and more efficient schedules. Project implementation is simplified through the studied approaches which not only eliminate waste but also bring projects in on time per the research detailed in this article. Lean construction methods produce other advantages through decision support as well as real-time project transparency by means of electronic platforms VisiLean and Building Information Modelling (BIM). For full industry-wide adoption of such advantages the solutions to change resistance and ignorance and training inadequacies must be addressed. Research must focus on formulating standardized integration frameworks as well as improved implementation methodology and Lean project management automation strategy. Additional productivity with enhanced sustainability and enhanced project management innovation result from incorporating Lean-LPS strategies within the construction sector.

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CHAPTER 88

Integrating Transit-Oriented Development and Land Pooling Mechanism: A Review of Urban Planning Strategies for Indian Cities

Priyanka Bendigiri¹ and Avi Gandhi²

ABSTRACT

Urbanization in India has triggered rapid and unplanned growth causing conflicts in land usages and transportation networks, leading to lack of integrated planning. This paper explores concepts of Transit-Oriented-Development (TOD) and land pooling and readjustment tools such as Town Planning Schemes (TPS) to address these issues. Through a review of literature and case studies, the study explores how they can help to improve existing urban planning practices in Indian Cities. While TOD is a concept how urban areas can grow around transit hubs, land pooling and readjustments gives a pragmatic approach of how can TOD be implemented and contextualized in different areas. However, fiscal constraints remain a concern, where Land Value Capture Mechanisms (LVC) help to capture incremental values in land to fund public infrastructure projects. This Paper highlights the need for integrated planning, the role of fiscal tools, and the challenges in current urban practices. It also points out gaps in implementation of TOD and TPS and suggests how integration of both can enhance revenue through LVC mechanism. Ultimately the study calls for more innovative planning approaches to address the challenges of rapid urbanization.

Keywords: Urbanization; Transit-oriented development; T. P. scheme; Land value capture; Fiscal tools; Integrated planning.

1.0 Introduction

Rapid Urbanization is a global trend, particularly in developing countries like India, where cities are sprawling at unprecedented rate (Padam & Singh, 2004; Kehinde, 2019). According to Census 2011, about 31.16% of India is urbanized and the number of million cities has increased from 35 in 2001 to 53 in 2011, underscoring how urban centers emerge as engines of economic growth (Hoselitz, 1953; Smith & Lobo, 2019; Parnreiter, 2022). However, this rapid expansion has strained infrastructure, resources and services, leading to unsustainable development (Cohen, 2006; Wang, 2020).

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Cities face challenges such as environmental degradation, rising greenhouse gas emissions, and social inequalities leading to unplanned and haphazard growth (Chancel, 2020; Sverdrup, 2019). Transportation sector is particularly one of the vulnerable sectors to growing urban pressure (Indian Institute of Human Settlements, 2015). Urban Sprawl, characterized by low density, unplanned development (Bhatia, 2024), has increased travel demand and trip lengths, with the national average trip length in India is currently 7.7 km (MoveInSync, 2023). Moreover, there are 246 vehicles per 1000 people in urban areas as of 2020, indicate growing dependency on private vehicles (Shangliao, 2020).

This trend is expected to increase, with daily trips projected to increase to 4816 lakhs by 2031 (Ministry of Urban Development, 2007). Public transport infrastructure, however, has limited contribution to modal split due to poor planning, limited capacity, utility degradation, overcrowding and funding constraints, resulting in overwhelming traffic volume on roads, potentially exceeding the road capacity leading to congestion and increased travel times (Pucher *et al.*, 2004; Wilkinson *et al.*, 2023). As a result of the above, overall livability of cities has been impacted. In response to these challenges, Transit-Oriented Development (TOD) has emerged as a key urban tool for integrated land use and transportation planning, aligning sustainable development goals sustainable cities and communities (SDG 11); industry, innovation and infrastructure (SDG 9); and climate action (SDG 13) (Ibraeva *et al.*, 2020). However, successful implementation of TOD requires suitable developmental and fiscal measures to address funding issues and equitable distribution of benefits, such as land value capture (Chan *et al.*, 2015; Wang & Xia, 2024). With improved infrastructure in any area, the influx of people increases, subsequently increases the demand and values of land. These increased values can be realized through land value capture mechanisms (Dittmar & Ohland, 2012; Tang, 2017; Alterman, 2017).

2.0 Objectives of the Review

The main aim of this review paper is to analyse Town Planning Schemes (TPS) as land based fiscal tool and demonstrate their growing adoption in India through Case Studies.

3.0 Thematic Analysis

3.1 Transit Oriented Development (TOD)

TOD is a methodology to combine land use planning and transportation planning to deliver urban spaces that are sustainable, compact and accessible (Suzuki *et al.*, 2013). Based on matrices of density, diversity and desing (Curtis *et al.*, 2009). TOD emphasizes hugher density using FSI near transit hubs for efficient land use, thereby reducing urban sprawl and increasing mode share of public transit networks. The general framework includes 1.) Identifying the main urban growth centers. 2.) Connection of the growth centers with a transit network. 3.) Identifying Action Plans to implement TOD and 4.) Encouraging Public-Private- Parntership for

easy implementation and financial assistance (Bertolini & Spit, 2005). Subsequently, following results in enhanced mobility, liveability, and sustainability in urban areas (Li *et al.*, 2009; Yen *et al.*, 2024).

3.2 Land, land use and spatial planning

The Land is a finite source, strategic land use planning ensures sustainability (Hailu *et al.*, 2019). Efficient planning focuses on dimensions of economic growth, employment, and equitable resource allocation, but also works to combat social dislocation (Harvey & Jowsey, 2019). Furthermore, spatial planning is essential to ensure disaster resilience through regulating growth patterns (Lourenco *et al.*, 2020). However urban expansion has caused land degradation, sprawl and gentrification (Assennato *et al.*, 2022)

3.3 Floor Space Index (FSI)

FSI controls the allowable building density on a land parcel and therefore whether a city develops horizontally or vertically depends on development and control regulations (Deshpande *et al.*, 2015). Higher Density enables vertical development and optimized land use (Suzuki *et al.*, 2015). Conversely, it will also increase real estate prices, leading to affordability challenges (Suzuki *et al.*, 2015).

3.4 Activities

Land Use guides urban activities, impacting accessibility and functionality and influencing travel patterns (Yildirim & Akin, 2023). Zoning rules prevent conflicts while promoting economic synergies (Appleya & Akin, 2023). Mapping activities where people spend their time can be useful in assessing if land use is productive while taking into account community demographics and public space designs to optimise social interactions, safety, and comfort (Francis *et al.*, 2012; Browning & Jackson, 2019).

3.5 Demography, social inequality and housing & property

Urbanization increases the competition for land, raising prices, and resulting in displacement and gentrification (Wang *et al.*, 2024). Increasing property values disproportionately impact low-income populations, resulting in social isolation (Chen *et al.*, 2023). Provisions for affordable housing and equitable zoning are needed (Turbay *et al.*, 2024).

3.6 Accessibility, transit ridership, mobility and transit

The Value of land is directly impacted by its proximity to transit hubs, as defined by the concept of accessibility (Ministry of Housing and Urban Affairs, GOI, 2017). A working mobility system in any city improves connectivity to the transit network and therefore, accessibility (Josephine *et al.*, 2021). However, the volume of transit ridership will be dependent on the diversity of uses within the vicinity of transit hubs, which guarantees the activity is

feasible (Sharma *et al.*, 2022). Hence, this gives rise to increased coordinated planning to meet future needs (UNEP, n.d.).

3.7 Environmental and sustainability issues

Urban Proliferation strains the existing infrastructure systems, exerting pressure on resources leading to pollution, climate change and deforestation (Uttara *et al.*, 2012). Sustainable practices, such as Transferable Development Rights (TDR), secure ecologically sensitive areas while allowing growth in different locations. Vertical development with energy efficient design systems is needed of the hour.

4.0 Land Value Capture

Land Value capture mechanisms are strategic developmental and fiscal tools used by the public sector to leverage the incremental value generated in land due to public investments in infrastructure projects or policy interventions (Lozano *et al.*, 2013; Suzuki *et al.*, 2015). In the context of urbanization, as cities sprawl and get densified, the demand of efficient and sustainable infrastructure increases, necessitating mechanisms to finance these infrastructure projects while reducing reliance on traditional taxation or borrowing systems (Peterson, 2009).

These mechanisms also ensure that benefits arising from development are equitably distributed among all the stakeholders (Suzuki *et al.*, 2015). Overall, land markets are also stabilized by reduced speculations due to externalities (Suzuki *et al.*, 2015). Land Value Capture mechanisms can be broadly classified into developmental tools and fiscal tools. Developmental Tools are predominately urban planning instruments that help to shape physical and spatial aspects through planned integration. It is a public participatory approach engaging multiple stakeholders such as land owners, developers, and planning authorities.

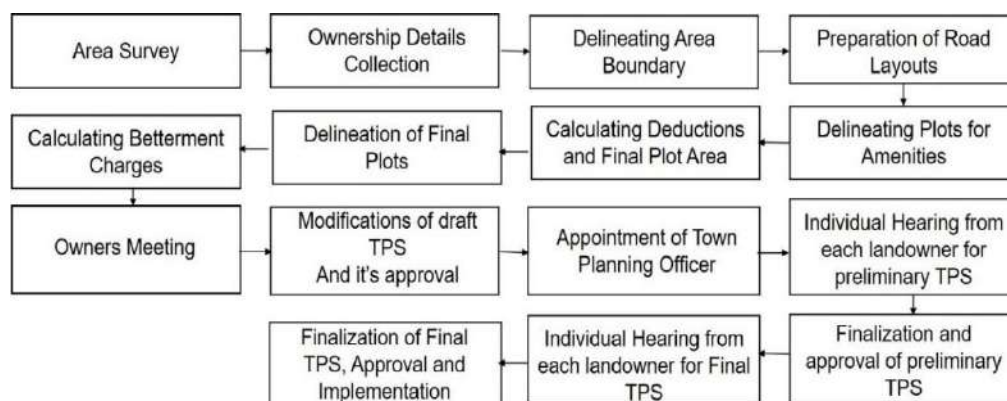
Key development tools include -1) Land Pooling and Readjustment: This mechanism involves pooling small and fragmented land parcels for well-planned development, enabling efficient delivery of public utilities. Landowners receive developed, higher-valued land, ensuring fair compensation, while a portion of land is retained for public use (Phatak, 2013; Suzuki *et al.*, 2015). 2) Transfer of Development Rights (TDR): TDR helps balance land use and support redevelopment by allowing development rights to be transferred from one parcel to another within designated area, ensuring controlled growth and better land management (Walters, 2013; Suzuki *et al.*, 2015). 3) Land Acquisition and Development: Government acquires land at the existing rates, develops it, and then sells or leases at an appreciated value, financing urban expansion (Lozano *et al.*, 2013; Peterson, 2009). 4) Land Use Changes: Modifying land use, such as converting agricultural land to residential or commercial use, increases the development potential and tax revenue (Phatak, 2013; Munshi, 2020). 5) Premium FSI: Developers can purchase additional Floor Space Index (FSI) beyond the base limit by paying a premium fee.

This increases revenue, densifies areas, reduces urban sprawl, and promotes sustainable development (Phatak, 2013; Suzuki *et al.*, 2015). Fiscal Tools are mechanisms that increase revenue streams of urban local bodies. Fiscal tools primarily involve betterment levies, development charges, increased stamp duty and property taxes or incentives to promote development. 1) Betterment Levies: Land Value appreciation from public investments, without private contribution, is monetised to ensure equitable distribution and align returns with public sector initiatives (Walters, 2013; Suzuki *et al.*, 2015). 2) Development Charges: Levied on developers to cover infrastructure upgrade costs based on market values (Medda, 2012; Phatak, 2013). 3) Land Value Tax/Incremental Contribution: A recurring tax on unimproved value of land, ensuring the public sector captures a share of land value appreciation over time (Peterson, 2009; Walters, 2013). 4) Vacant Land Tax: Encourages development on underutilized land, discouraging speculation and promoting public use (Phatak, 2013; Suzuki *et al.*, 2015). 5) Tax Incremental Financing: Increases property taxes, generating revenue that can be reinvested in infrastructure (Huston & Lahbush, 2018).

5.0 T.P. Schemes

TPS is an urban planning mechanism where land is pooled from landowners at market rates, and readjusted to provide public amenities, and then the reconstituted plots are returned back with appreciated land value (Larsson, 1997; Ballaney, 2008; CRDF & CUPP, 2012). During this process the government takes away approximately 40% of the land and gives back the remaining (Home, 2007; Banglawala & Pandey, 2012; CRDF & CUPP, 2012). Typically, the government retains about 40% of land for public use, while landowners receive the remaining 60% (Home, 2007; Mathur, 2013; CRDF & CUPP, 2012).

Figure 1: TPS Preparation Process in Gujarat



Source: Compiled by authors

Table 1: Historical Timeline of Town Planning Legislation and Practices

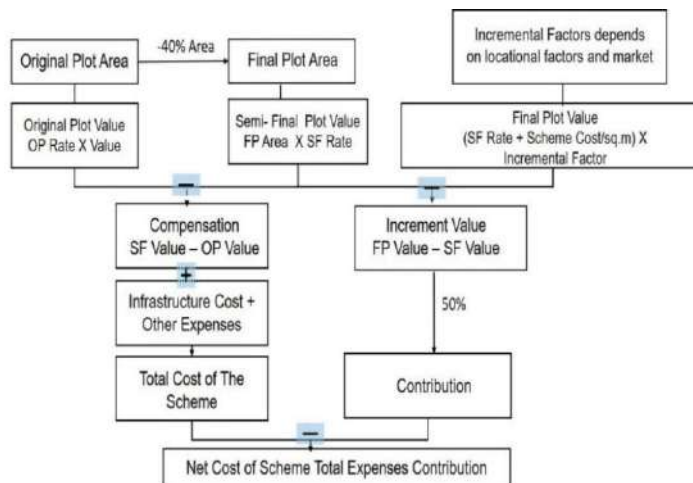
Year	Event
1896	Establishment of the Bombay Improvement Trust for land acquisition, slum clearance, and road widening in the Dadar-Matunga-Wadala-Sion area.
1915	Bombay Town Planning Act established by Arthur Edward Miram, introducing a public participatory approach, land pooling, and fair benefit distribution.
1949	Formation of the Bombay Provincial Municipal Corporation, leading to the establishment of the Bombay Municipal Corporation for urban development.
1954	Revision of the Bombay Town Planning Act, introducing a two-stage planning process (Development Plan and T.P. Scheme).
1960	Bombay split into Maharashtra and Gujarat, and both states passed their respective Town Planning Acts (Maharashtra Regional and Town Planning Act in 1966 and Gujarat Town Planning and Urban Development Act in 1976).
1980	T.P. Schemes fell out of use in Maharashtra due to time constraints, complex governance issues, and lack of public support.
1976	Gujarat Town Planning and Urban Development Act introduced, dividing the town planning process into three stages (Draft, Preliminary, Final).
1990	Urban Development Authority of Ahmedabad (AUDA) revived T.P. Schemes after failure to acquire land for the ring road project. Key changes included faster land possession and readjustment of land for market sale, making T.P. schemes more financially viable.

Source: Compiled By authors

5.1 Town planning valuation

As stated by Deuskar (2011), CRDF and CUPP (2012), and Mittal (2014), land valuation in TPS is made using three matrices: Original Plot Value (OPV), Semi-Final Plot Value (SPV), and Final Plot Value (FPV). OPV is evaluated using ready reckoner rates or the most recent sale deed amount, adjusted by inflation. SPV indicates the developing time frame represented and is usually equal to OPV unless the land is relocated. The FPV indicates the value of land that is fully developed using Ready Reckoner rates, or close to the same cost of the most recent sale deed with inflation applied. The difference between OPV and SPV is the compensation paid to landowners. Difference between FPV and SPV is the incremental contribution, and the government collects 50% of it as betterment charges.

Figure 2: Valuation, Cost and Finance for TPS Implementation



Source: Compiled by authors

5.2 CASES

5.2.1 Amravati

The land pooling scheme, in Nelapadu village, was a significant urban planning initiative. A total of 1300.92 acres belonging to 981 landowners were pooled, and a TOD based planning is being implemented. Higher density plots were allocated near the transit corridors, while 267.75 acres of the area were residential, and 65.03 acres commercial. The Layout, therefore, consisted of plan layout and zoning in a clustered community style with institutional zones along the edges of the settlement. Landowners' preferences, vastu compliance, and access and connectivity were all taken into consideration. The final plots were allocated by an online lottery that was publically available to ensure transparency. It is one of the best urban planning practices for the development of greenfield cities in India.

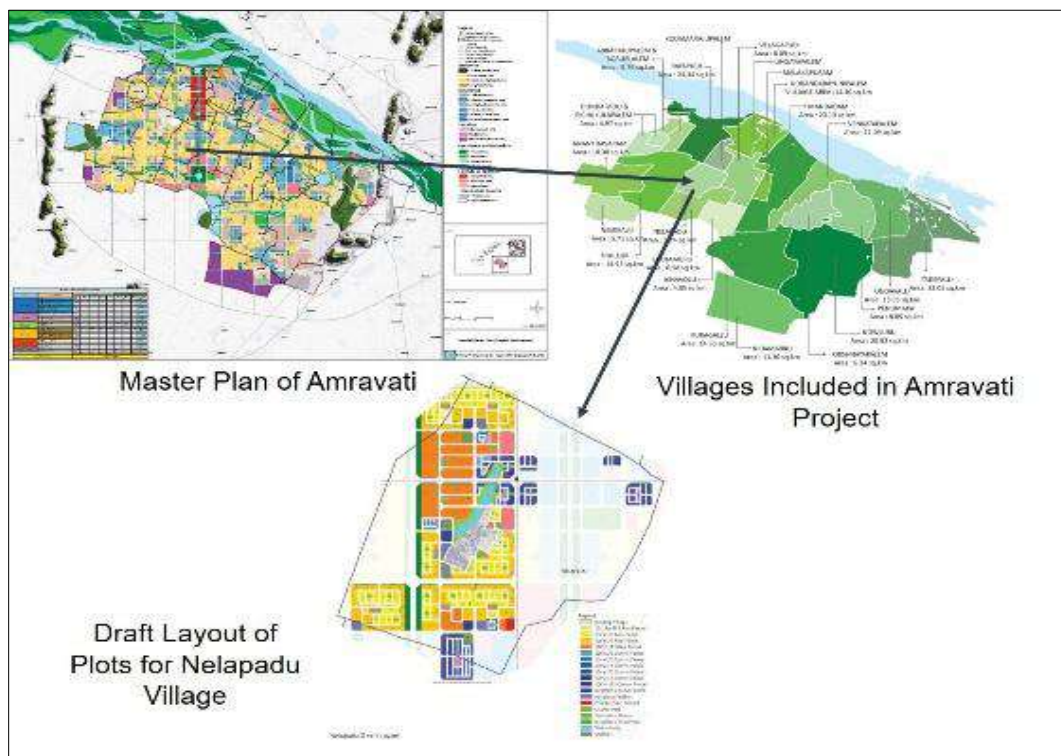
5.2.2 Pune – Holkarwadi

Pune, a culturally vibrant and educational city in the state of Maharashtra, is developing prominently as an IT hub resulting in unplanned development, traffic congestion, and over utilization and stress on existing infrastructure system. In response, six TPS are proposed of around 1000 hectares of land by Pune Metropolitan Region Development Authority. Out of the 6 Holkarwadi has been chosen for the case study, which was reclassified from agricultural zone to urban area under MRTP act along with all urban utility services. The base FSI is set to 2.5, with a maximum of 4.0 for Authority Plots to incentivise development. This case study highlights how effective implementation of T.P. Scheme can address urban sprawl (PMRDA, n.d.).

Table 2: Redistribution and Valuation Statement also Called F-Form in Gujarat

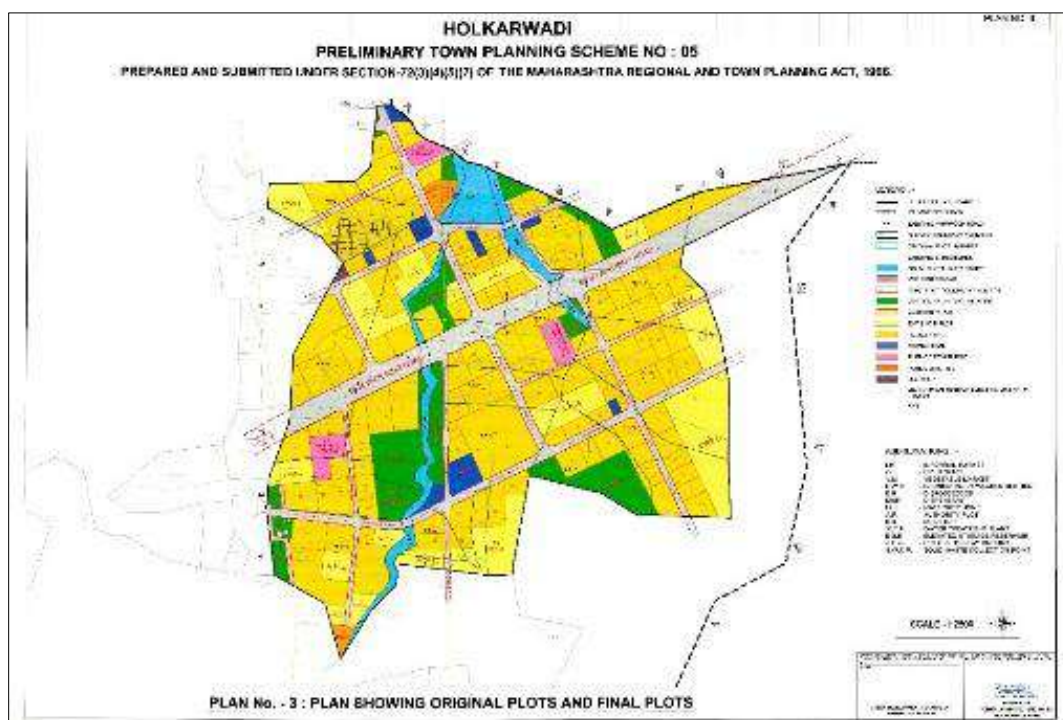
		A	B	C	D	E	F	G	H	I	J
	Different Scenario for Land Deductions	Original Plot Value (Rs./sq.m.)	Original Plot Size (sq.m.)	Total Original Plot Value (Rs.)	Final Land Value (Rs./sq.m.)	Final Plot Size (sq.m.)	Total Original Plot Value (Rs.)	Increase in The Value of Property (Rs.)	Betterment Charges to be paid (Rs.)	Benefit To the owner (Rs.)	Betterment Charges (Rs./sq.m.)
		Original Plot			Final Plot			Betterment Charges Calculation			
	i	A	B	A X B	D	B – (i X B)	E X D	F - C	(F - C)/2	G - H	I/E
Scenario 1	50%	4500	10000	45000000	10000	5000	50000000	5000000	2500000	2500000	500
Scenario 2	40%	4500	10000	45000000	10000	6000	60000000	15000000	7500000	7500000	1250
Scenario 3	20%	4500	10000	45000000	10000	8000	80000000	35000000	17500000	17500000	2187.5

Figure 3: Master Plan of Amravati and TPS Draft Layout of Nellapadu Village



Source: Compiled by authors

Figure 4: TPS Layout of Hokalarwadi (TPS - 05)



Source: PMRDA Website

5.2.3 BHUJ

The earthquake in 2001 had a devastating impact on Bhuj city of Gujarat, particularly in Walled City. According to Balachandran (2017) and Byahut & Mittal (2017), the major reason for large scale destruction was because of poor urban planning, and a lack of disaster-resilient infrastructure. A disaster management agency was later set up along with urban authorities which initiated redevelopment and proper governance framework using Development Plan and TPS, which focussed on land pooling and readjustment along with changes in development and control regulations, seismic safety, infrastructure upgrades across all surveyed land plots. The financial assistance was given by Asian Development Bank and technical assistance was given by Environment Planning Committee.

6.0 Conclusion

Rapid Urbanization of Indian cities have significantly increased the demand of land which is eventually leading to unplanned haphazard urban growth leading to traffic congestion, land use conflicts, inadequate infrastructure, resource depletion and subsequently causing social

inequality and segregation. This declines the economic productivity and quality of life for residents. In order to achieve sustainable growth, it is essential to ensure land use planning and transportation planning systems are in place and well-integrated with each other. While TOD has emerged as an urban planning tool to contextualize local area plans with prime focus on transit stations, TP schemes have emerged as land pooling and readjustment strategy aimed to regulate development and use of land, particularly to develop new greenfield cities and peri-urban areas of existing cities. Integrating both TOD and TP scheme helps to ensure urban growth is sustainable with optimized land use, improved connectivity and accessibility, increased property valuation, equitable development and fostering holistic urban planning.

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CHAPTER 89

Interpretation of Current Urban Redevelopment and Neighbourhood Liveability

Mayuri Raju Dangle¹ and Pankaja Bagul²

ABSTRACT

Globally more people are living in urban areas than in rural areas. In 2018, 55% of the world's population was urban, a big increase from 30% in 1950. By 2050, it's expected that 68% of the global population will live in cities. This means there is a fast transition from rural to urban, indicating that the urban is growing more, its uses are changing along with people's needs. The density increase is both urban density and population density, implying more population and buildings per square area of land in the city. The core city, which used to have certain characteristics to it, is now altering its identity and evolving its form, changing its scale and functions to the developing needs and undergoing a transformation in the form of redevelopment. The existing neighbourhoods in the core city are now undergoing change in the form of urban regeneration in both commercial and residential usage, leading to urban decay or over utilization, which if curtailed in a planned manner, can be collared to our benefit. Many researches have studied and indicated relationship between two factors of urban redevelopment, also interchangeably known as revitalization, renewal or regeneration and urban density, or between density and liveability. This study tries to understand relationship between these rising challenges in urban areas by analysing the effects of redevelopment on liveability, and other sub-topics, through comparative literature review by global and national researchers.

Keywords: Urban redevelopment; Neighbourhood; liveability; Pune.

1.0 Introduction

Liveability refers to the extent to which a place supports long-term well-being, encompassing physical, social, and psychological dimensions (Marans & Stimson, 2011). As urbanization intensifies, planning has shifted from infrastructure provision to addressing holistic quality of life. However, liveability lacks a unified scientific measurement model and is assessed through objective, subjective, and behavioural indicators (Marans & Stimson, 2011). Neighbourhoods play a crucial role in liveability, evolving historically from social and survival needs into structured urban spaces (Hoppenfeld, 1967). Mumford (1938) emphasized socio-spatial organization over economic functions, influencing planning theories focused on community cohesion, walkability, and sustainability.

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Urban redevelopment significantly impacts neighbourhood liveability by revitalizing infrastructure, housing, and amenities while also disrupting social ties and cultural identities. The challenge lies in balancing modernization with inclusivity, equity, and sustainability. Pune, historically known as the “Oxford of the East,” is undergoing rapid redevelopment, raising concerns over overcrowding, affordability, and heritage conservation (Redevelopment – The Need of the Hour, 2022). In Pune, government policies such as reduced GST, flexible FSI, and RERA safeguards have accelerated redevelopment, benefiting developers and residents. However, achieving a balance between economic interests and community well-being is critical. This study examines the intersection of redevelopment and liveability to provide insights for fostering sustainable, inclusive, and vibrant urban neighbourhoods.

Aim of the study: To interpret and analyze urban redevelopment and the parameters of neighbourhood liveability.

1.1 Objectives of the study

- To understand the perception of urban liveability through literature review of different journals, articles and papers.
- To find out the qualitative and quantitative parameters that contribute to the liveability of a neighbourhood from literature review. Understanding the chosen factors.
- To study effects and measure liveability of residents of chosen neighbourhood that have undergone redevelopment.
- To analyze the relationship between urban redevelopment and neighbourhood liveability for informed decision-making in urban planning.

1.2 Research methodology

The research is starting with the initial approach of trying to analyse the relationship between the two variables of the study: Urban redevelopment and Neighbourhood liveability, which is used to carry out the literature review. The study is open to any new ideas, additions or changes in the approaches.

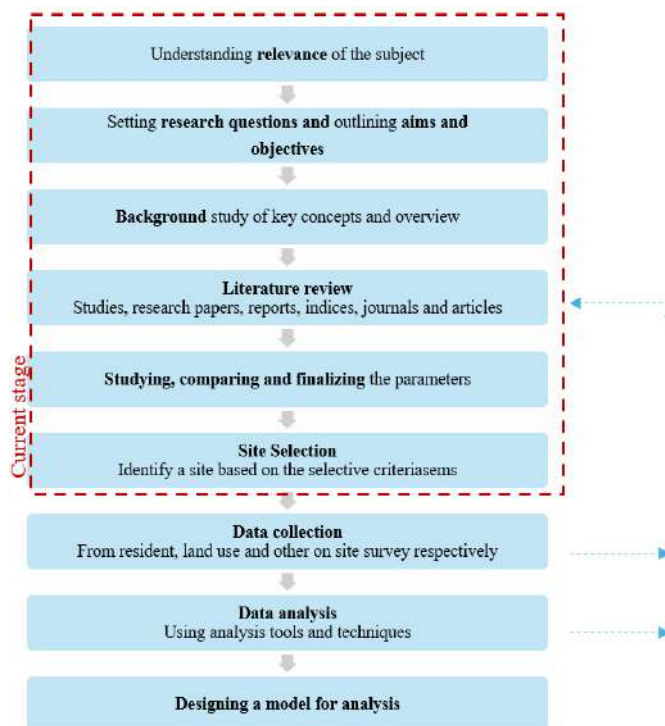
1.3 Research questions

- What methodologies are most commonly used to assess liveability in urban redevelopment contexts?
- What are the measurable parameters of liveability most affected by redevelopment efforts?
- How do residents perceive the changes brought about by urban redevelopment projects in terms of liveability, inclusivity, and community well-being?

2.0 Literature Review

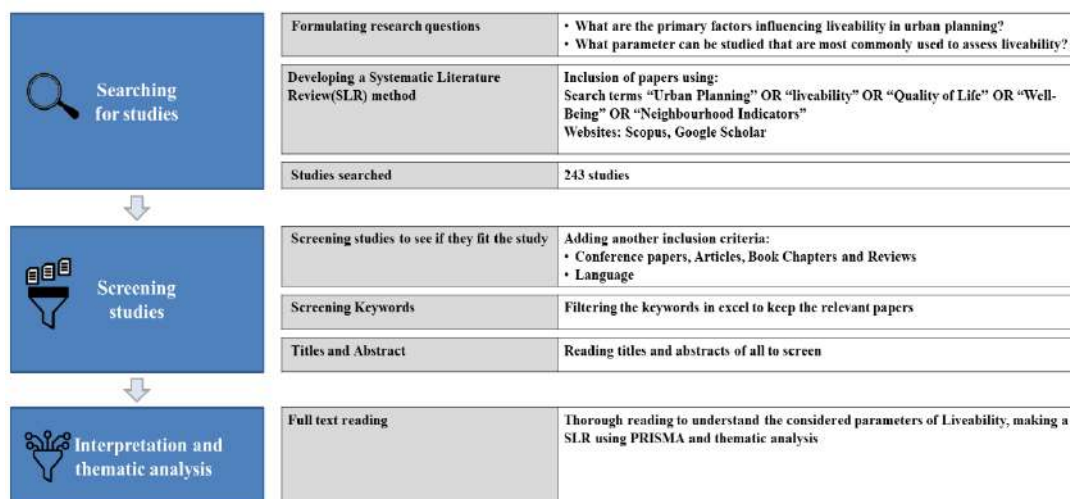
The literature review aims to establish a strong theoretical foundation for understanding urban redevelopment and neighbourhood liveability by examining existing studies, frameworks, and models.

Figure 1: Research Design Flow



2.1 Literature review methodology

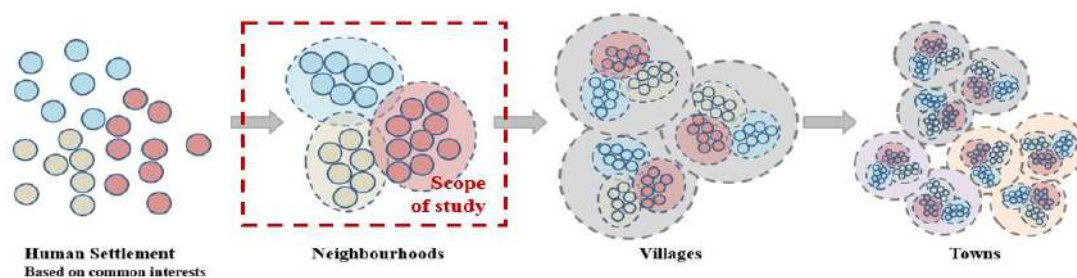
Figure 2: Methodology of Literature Review



2.2 Neighbourhood

A neighbourhood is a sub-division of a city, that is populated by a group of people, whenever they want to share a place. The inception of the concept starts from man himself, when the settlements were formed and people started living, hunting and growing food together. It is an evolution of social and physical reasons that defined the proximity of settlement and community development (Mumford, 1938). These neighbourhoods have grouped together to form villages, towns and cities. In both urban and rural settings, the neighbourhood as a whole is a common occurrence. This concept reflects the broader vision of urban planning, where human relationships and local identities are prioritized over purely functional or economic considerations (Mumford, 1938).

Figure 3: Hierarchy of Settlement Formation (Hoppenfeld, 1967)



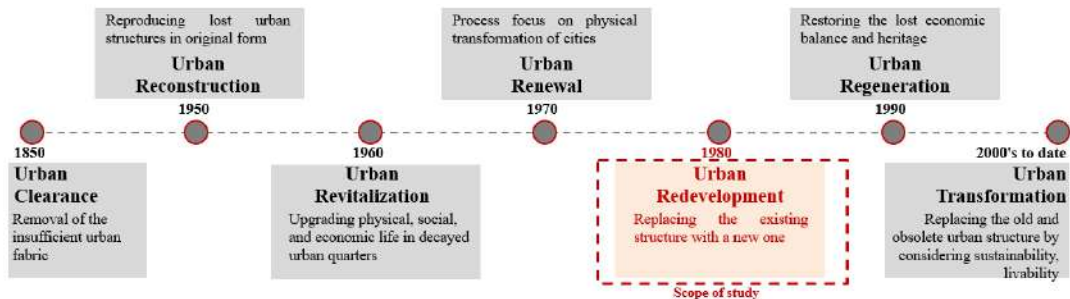
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2.3 Redevelopment

Redevelopment is defined as the act or process of changing an area of a town by replacing old buildings, roads, etc. with new ones (Cambridge University Press & Assessment, 2025). Redevelopment is an urban phenomenon, which has emerged in recent years. The existing developed cities are undergoing a phase of transformation, which is driven by redevelopment. It is essentially referring to the process of improving, revitalizing, or reconstructing an existing area, neighbourhood, or structure, often to address the changing needs of the residents. It typically involves significant physical, social, and economic changes aimed at enhancing the area's functionality, aesthetics, and liveability. In various literatures, "Urban Renewal" is interchangeably termed as "Urban Regeneration" in the United Kingdom and "Urban Development" in the United States.

This synonym gives few timelines to the concept. Regeneration can be referred to as a reaction to the evolving nature of an area, as an integrated vision, which develops while seeking the economic, physical, social and environmental changes for improvement (Sykes & Roberts, 2000). While some literature state that it began during the 1930's (Urban Renewal) with the idea of clearing slums (Carmon, 1999), others state in 1990's (Urban Regeneration) for reproducing lost urban structures in original form (Jariwala Pooja Bipinchandra, 2020). The type, pace and flow of regeneration decided the urban liveability and vice versa.

Figure 4: Timeline of Terminologies Related to Urban Revitalization in Historical Order (Sykes & Roberts, 2000)



Source: Compiled by author

2.3.1 Evolution of urban revitalization and it's changing priorities (Sykes & Roberts, 2000)

Urban redevelopment evolved from slum clearance to a holistic approach emphasizing sustainability and liveability.

2.4 Liveability

Liveability refers to the degree to which a place is good for living. Liveability refers to the concerns that are related to the long-term wellbeing of individuals and communities (Oxford). In the last few years, liveability has been studied in various cities around the world. It's a comparatively new subject of urban planning, which has evolved from various past judgements and planning and design implementations. While the initial years of planning was mostly focused on physical infrastructure and facility provision, now, a need of social and psychological forethought has started, because with rising population and urbanization, individual needs are overseen. Although there is no single scientific model of measuring liveability, it can be largely categorized into three categories: Objective, Subjective and Behavioral (Marans & Stimson, 2011).

While objective has specific/scientific proven or measurable data (rates, statistics, distance), subjective has data which can change from user to user (desire, perception, feelings, satisfaction level) and behavioural gives statistical data from subjective indicator (e.g. Visit to park is the willingness for a person to go in the park, but it can be measured with the number of visits per month of week). The Quality of Life in rural areas is different than that of urban, considering the factors of density, income, family size, social behaviour etc. The concept is further discussed in the literature review by various researchers around the world.

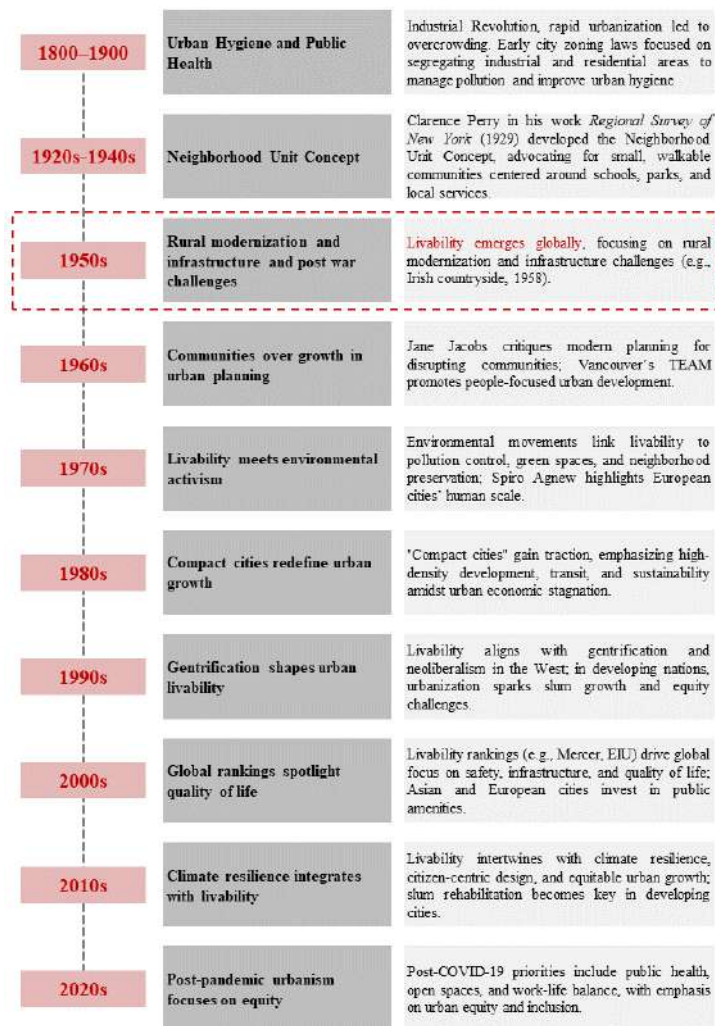
2.4.1 History of liveability (Kaal, 2011)

Liveability has evolved through societal and urban shifts. This explains that as years went by, with rising and developing globalization, the standard of living also grew with changing priorities, and so did the parameters that defined them.

2.4.2 How is liveability measured?

Measuring liveability involves a structured process to assess the quality of life in urban environments. The first step is defining a framework that outlines the core dimensions of liveability, such as housing, environmental quality, health, safety, infrastructure, and social well-being. Within these dimensions, measurable indicators are identified—for instance, access to public transport, air quality levels, green space availability, or income equality. Data is then collected through surveys, field observations, or official records to provide quantitative and qualitative insights.

Figure 5: Timeline of Concept of Liveability (Kaal, 2011)



Source: Compiled by author

Figure 6: Steps of Liveability Assessment



Source: Compiled by author

Next, the indicators are weighted based on their relative importance to the target population or policy goals. A composite score is calculated to reflect the overall liveability of an area. Finally, the findings are used to inform urban planning, policy-making, and stakeholder engagement to address deficiencies and enhance quality of life. This iterative process drives continuous improvements in urban environments and policies. Many indices, frameworks and benchmarks have been set across the world and India to assess liveability. In two of indices, Vienna, Austria holds the first rank of most liveable city, followed by other European and American cities. It is evident that most cities in the top 10 have had an early start in development compared to their global south counterparts. Although each index has their own variation of marking and categorization, the umbrella parameters to access liveability remain the same. Some indices focus on economic factors have economically developed cities on top, others who focus on human index of satisfaction are on top. A framework is a structured tool or conceptual model used to organize and analyze a system. A ranking index is a comparative tool that assigns scores to entities, such as cities or countries, based on predefined criteria and indicators.

Table 1: List of Indices, Frameworks and Assessments Studied

Report	Name
1. International	The Global Liveability Index 2023
2 International	Mercer Quality of Living Index 2023
3 National	Ease of Living Index 2020
4 International	Global Power City Index 2023
5 National	Liveability Index 2010
6 National	AARP Livability Index
7 International	City Prosperity Initiative
8 International	Liveable And Sustainability Cities- A Framework
9 National	Liveability Standards in Cities
10 International	Numbeo

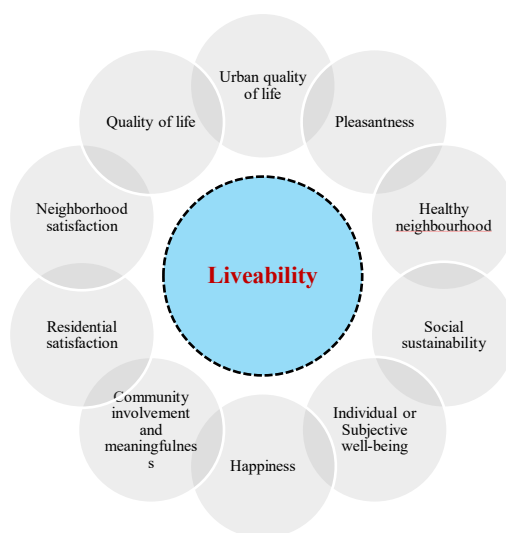
Source: Compiled by author

The Global Liveability Index 2023 evaluates cities based on stability (25%), healthcare (20%), culture & environment (25%), education (10%), and infrastructure (20%) (Intelligence, 2023). This suggests a balanced focus on safety, healthcare access, and urban quality. The Mercer Quality of Living Index 2023 emphasizes political and social stability (23.5%), medical standards (19%), and public services (13%), indicating that governance and healthcare play a

significant role in quality of life (Mercer, 2023). The Ease of Living Index 2020 highlights quality of life (35%) and citizen perception (30%), showing a strong emphasis on subjective well-being and economic ability (15%) (Smart City, 2020). The Global Power City Index 2023 ranks cities on economic strength (600 points), liveability (500), and accessibility (400), signifying the importance of economic performance in urban rankings (Foundation, 2023).

The Liveability Index 2010 integrates economic and socio-cultural aspects with education and health, indicating a comprehensive approach (Competitiveness, 2010). The AARP Liveability Index assesses housing affordability, neighbourhood proximity, and transportation, emphasizing accessibility (Index). The City Prosperity Initiative links urban productivity with governance and equity, stressing inclusive growth (Habitat). The Liveable and Sustainable Cities Framework prioritizes quality of life, sustainability, and economic competitiveness (Network). Liveability Standards in Cities highlight social (25%) and infrastructure (25%) aspects, showing their critical role (Ministry of Urban Development). Numbeo's rankings cover economic and environmental indices, reinforcing affordability and urban comfort as key parameters (Numbeo, n.d.).

Figure 7: Liveability Synonyms Derived from Literature Review



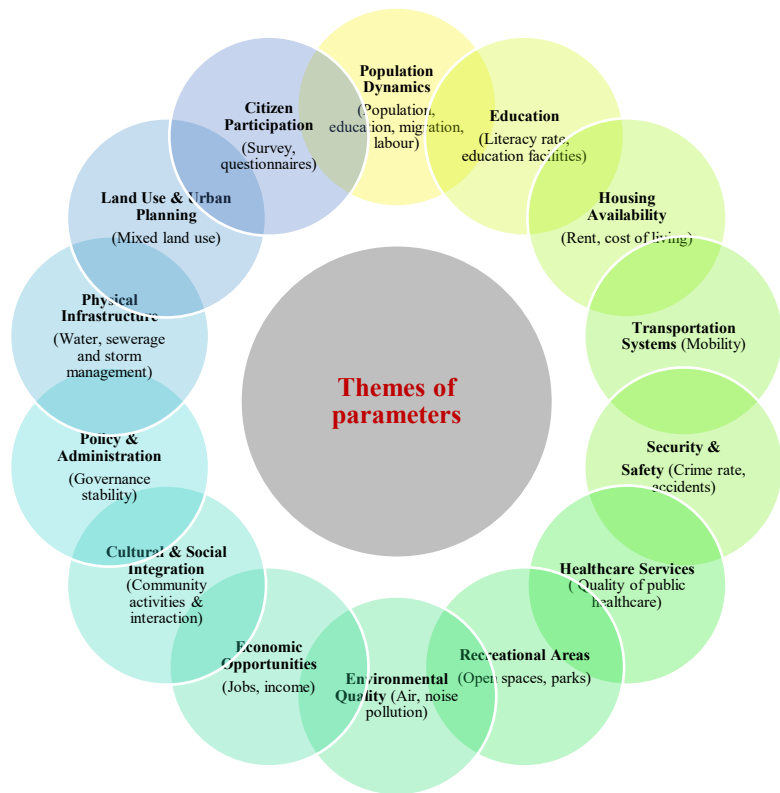
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2.4.3 Parameters of liveability based on literature review

Urban liveability encompasses a range of parameters that collectively define the quality of life experienced by residents within a neighbourhood. Based on the review of various scholarly articles, key aspects influencing liveability include physical infrastructure, social dynamics, environmental quality, and economic opportunities (Hamam Serag *et al.*, 2013).

Physical infrastructure pertains to the availability and accessibility of amenities such as housing, transportation, public spaces, and utility services. Social parameters focus on inclusivity, community cohesion, and cultural vibrancy, ensuring a sense of belonging for diverse populations. Environmental quality considers factors like air and water cleanliness, green spaces, and climate resilience, which are critical for sustainable living.

Figure 8: Themes of Parameters Based on Literature Review



Source: Compiled by author

Economic aspects emphasize employment opportunities, affordability, and access to essential services. These parameters collectively serve as a framework to evaluate and enhance urban redevelopment projects, ensuring they align with the principles of liveability and holistic development. Various literatures have defined liveability through different aspects and parameters. While some literatures have thematically differentiated “Quality of life” into subjective, objective and perspective (Marans & Stimson, 2011), some have defined them as subjective well-being (Mouratidis, 2019). Several aspects of subjective well-being have been related to density of an area, land use, greenness, transportation and nuisances (Hajrasouliha *et al.*, 2018).

3.0 Way Forward: Study Parameters Development and Scope of Work

3.1 Liveability assessment

The 14 themes derived from various literature reviews are now being divided into qualitative and quantitative parameters. Where quantitative parameters will act as External Parameters to study the Rate of change, number of events and distance and qualitative will act as Introspective Parameters which will understand the resident's opinions, perceived changes and levels of satisfaction

Table 1: Study Parameters Development

	Theme	Quantitative Parameters	Qualitative Parameters
1	Population Dynamics	Population density (people per square km)	Perception of demographic changes (e.g. generational shifts, etc.)
		Population growth rate (percentage)	Community sentiment on population increase
		Age distribution of residents	
2	Education	Number of schools within a defined radius	Resident satisfaction with quality of local education
		Student-teacher ratio	Accessibility perceptions of local educational institutions
		Literacy rate	
3	Housing Availability	Number of housing units available per 1,000 people	Perception of housing affordability
		Housing vacancy rate	Resident satisfaction with housing diversity (e.g., rental vs. ownership options)
		Average size of housing units	
4	Transportation Systems	Public transit frequency (buses/trains per hour)	Resident opinions on ease of mobility
		Average commute time	Perceived reliability of public transport services
		Kilometers of pedestrian and cycling infrastructure	
5	Security & Safety	Number of reported crimes per 1,000 residents	Residents' sense of safety during day and night
		Police presence (officers or patrol frequency)	Perceived effectiveness of security measures
		Availability of surveillance (CCTV cameras)	
6	Healthcare Services	Number of healthcare facilities per 1,000 people	Perception of healthcare accessibility and affordability
		Average emergency response time	Resident satisfaction with quality of medical care
		Doctor-to-patient ratio	
7	Recreational Areas	Area of recreational spaces per capita	Resident satisfaction with recreational facilities
		Number of parks/community centers in the vicinity	Opinions on the adequacy of recreational options for different age groups
8	Environmental Quality	Noise levels in decibels	Opinions on environmental changes due to redevelopment
		Percentage of green cover	

9	Economic Opportunities	Employment rate	Perceived access to job opportunities
		Number of new businesses or start-ups established post-redevelopment	Opinions on economic upliftment due to redevelopment
10	Cultural & Social Integration	Number of community events held annually	Perception of inclusivity and cultural harmony
		Diversity index (ethnic/cultural heterogeneity)	Resident opinions on preservation of local traditions
11	Policy & Administration (Governance stability)	Current government policies and regulations that contribute to the liveability standards	Perception towards the local government of the residents (reliability and trust)
12	Physical Infrastructure	Length of roads and utility networks (e.g., water, electricity)	Resident satisfaction with infrastructure maintenance
		Percentage of area covered by basic infrastructure services	Perceived ease of access to essential services
13	Land Use & Urban Planning	Area wise percentage division of each land use	Perception towards change in landuse and adaptation of different age groups
14	Citizen Participation	Percentage of residents involved in planning	Perceived influence of residents in redevelopment decisions
		Number of citizen consultations held	Satisfaction with opportunities to voice concerns or ideas

Source: Compiled by author

3.2 Redevelopment assessment

3.2.1 Types of redevelopments based on usage

Table 2: Types of Redevelopments Based on Usage

Sr. No.	Types	Examples
1	Residential Redevelopment	Redevelopment of Mumbai's chawls into high-rise residential complexes
2	Mixed-Use Redevelopment	BDD Chawl Redevelopment in Mumbai, integrating residential, commercial, and public amenities.
3	Commercial Redevelopment	Phoenix Mills in Mumbai, converted from a textile mill to a shopping and entertainment complex.
4	Recreational and Tourism Redevelopment	Sabarmati Riverfront in Ahmedabad transformed into parks and recreational spaces.
5	IT/Industrial Redevelopment	Whitefield in Bengaluru, converted from industrial zones to IT hubs.
6	Port and Waterfront Redevelopment	Eastern Waterfront Project in Mumbai converting old port areas into commercial and residential zones.

Source: Compiled by author

Since the study is based on liveability, it will only include residential and mixed-use redevelopment.

3.2.2 Redevelopment scenarios

Figure 9: Before and After Scenario of Redevelopment

Before Redevelopment	After Redevelopment.
A mid-density residential neighborhood with 3-4 story apartment buildings, characterized by a mix of owner-occupied and rental housing, insufficient parking, wide setbacks and established community ties	The area transitions to high-density living, with 10-15 story apartment complexes featuring modern amenities, underground parking, common open spaces, and a larger population.
	Scope of this study

Source: Compiled by author

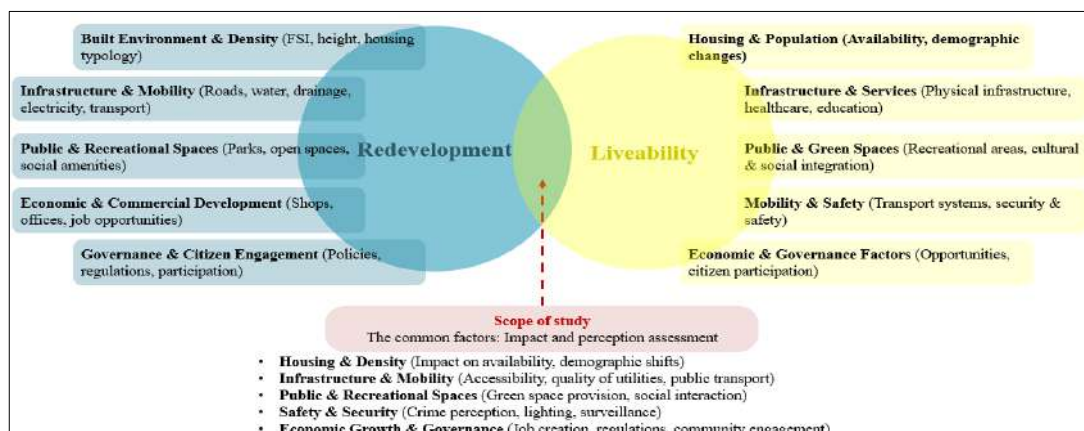
4.0 Study Framework

The scope of the study is defined as an overlap of the two major factors: Redevelopment and liveability. Where, the 14 parameters will try to infer to the common aspects and the effect of redevelopment on neighbourhood liveability.

4.1 The current scope and data collection methods

The study currently focuses on some of the physical redevelopment factors in the area, which in future scope can be analysed by comparison with the qualitative and quantitative parameters of liveability, while others can be assessed in the future scope.

Figure 10: Study Framework development



Source: Compiled by author

4.2 Indian context of liveability

India's urbanization has brought significant challenges and opportunities, prompting the government to implement various schemes and policies to improve liveability in cities. Recognizing the need for sustainable and inclusive urban development, flagship initiatives like

the Smart Cities Mission (2015) and AMRUT (Atal Mission for Rejuvenation and Urban Transformation, 2015) were launched to enhance infrastructure, public services, and overall quality of life. The Smart Cities Mission focuses on leveraging technology for citizen-centric solutions, creating sustainable urban ecosystems, and improving public spaces through area-based development. Complementing this, AMRUT targets the provision of essential infrastructure such as water supply, sewerage, and urban transport in smaller cities.

Table 3: Data Collection Methodology for Redevelopment Study

Primary Data	Secondary Data
Observations, GIS Mapping	Census, Government Reports
• Current Building use • Redeveloped/Not • Year built • Building typology • No. of storeys • No. of commercial floors • Parking • Building condition	• Population dynamics • Development plans

Source: Compiled by author

Figure 11: Smart Cities Mission



Together, these policies and schemes are paving the way for cities that are more liveable, inclusive, and sustainable. India is home to several cities that excel in urban liveability, balancing rapid development with cultural and environmental preservation. Cities like Bengaluru, Pune, Chennai, Hyderabad, and Ahmedabad have made significant strides in sustainable practices, urban mobility, and citizen-centric initiatives. Despite their high rankings in national and global indices for quality of life, they face challenges such as traffic congestion, pollution, and unplanned urban sprawl.

Figure 12: Swachh Bharat Mission – Urban (2014)



5.0 Gaps Identified in Existing Studies

While, urban densification has its own merits and demerits, there are substantial gaps in understanding its impacts on liveability in different areas of the same city. There is a need to integrate qualitative user experiences with quantitative urban development data (Hannah Badland, 2014). This research will address this gap by combining user experience surveys with spatial analysis (quantitative data) to have better urban planning solutions.

Figure 13: Maharashtra in India

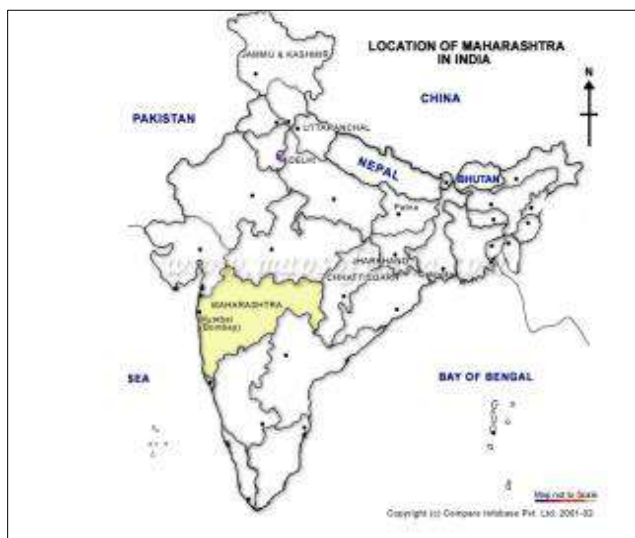


Figure 14: Pune District in Maharashtra



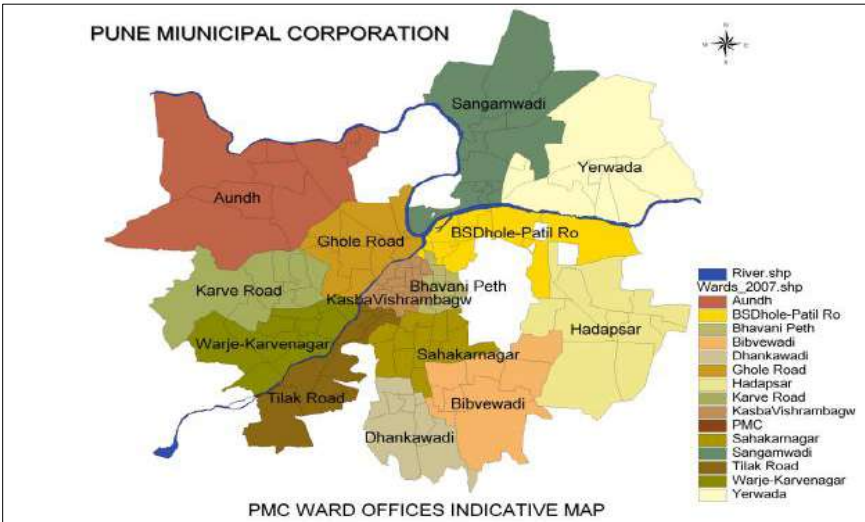
Figure 15: Pune District



5.1 Positioning Pune

Pune, often referred to as the “Oxford of the East,” is a dynamic city in western India, known for its educational institutions, cultural heritage, and robust economic base. Historically, Pune played a pivotal role during the Maratha Empire under *Chhatrapati Shivaji Maharaj* and later as a center for the Indian independence movement. The city’s rich cultural past is reflected in landmarks like the *Shaniwar Wada* and *Aga Khan Palace*.

Figure 16: Pune Municipal Corporation (PMC)

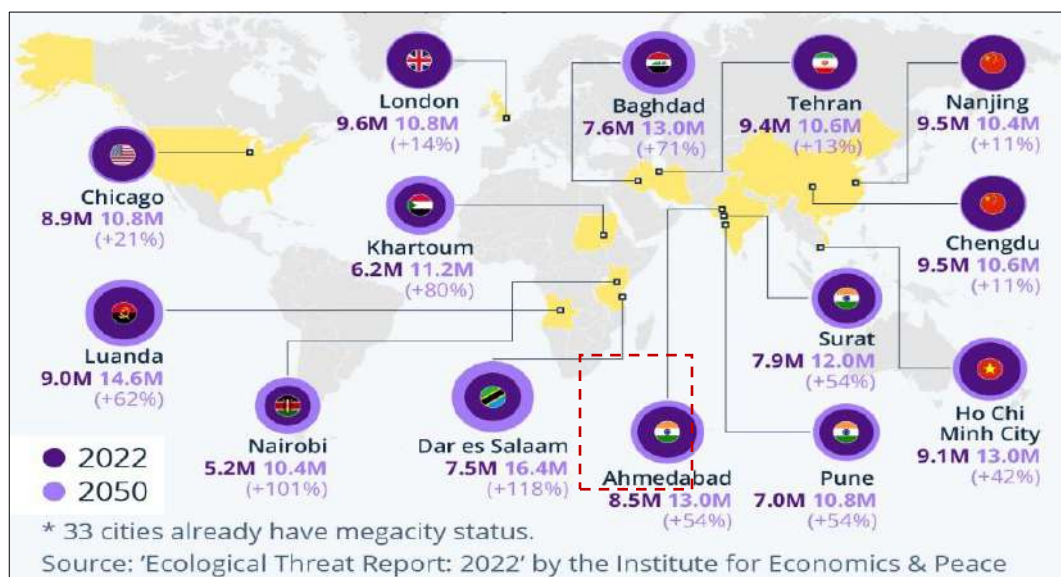


Population (2011)	33,71,626 (temporary)
Area	340.45 sq. km

(Pune Municipal Corporation, 2024)

Economically, Pune is a thriving hub for the automotive and manufacturing industries, hosting global giants like Tata Motors, Bajaj Auto, and Mercedes-Benz. It has also emerged as a significant IT and software services hub, with major technology parks and start-ups contributing to its modern identity. The city's agrarian roots remain visible in the surrounding districts, supporting a mix of urban and rural livelihoods. The influx of students and professionals has diversified its demographic profile, making it one of the fastest-growing cities in India.

Figure 17: Megacities of World (Ecological Threat Report , 2022)



Source: Statista

Pune is celebrated for its liveability, ranking highly in national indices for its efficient public transport, smart city initiatives, and waste management practices. However, challenges like traffic congestion and air quality issues persist. Blending its historical significance with modern innovation, Pune stands as a vibrant example of India's urban transition. This population density and growth of urban redevelopment needs to be scrutinized with the lens of liveability.

5.2 Pune's redevelopment

Redevelopment is the latest change that will be essential to Pune's progress. Pune had its first major urban change in the 1980's and 1990's, when historic *Wadas* were converted into three or four-story structures. Three to four-story buildings will now become eight to eleven-story structures as a result of redevelopment.

**Figure 18: History of Redevelopment Pune
(Redevelopment – The Need of the Hour, 2022)**



Source: Compiled by author

Redevelopment offers societies a number of advantages, and both societies and flats view it as an opportunity.

- Reduced GST percentage
- Bank guarantee
- TDF and FSI usage rights
- Reduced rates for additional area
- Completely transformed new property
- Modern amenities at no extra cost
- Legal protection through RERA Act

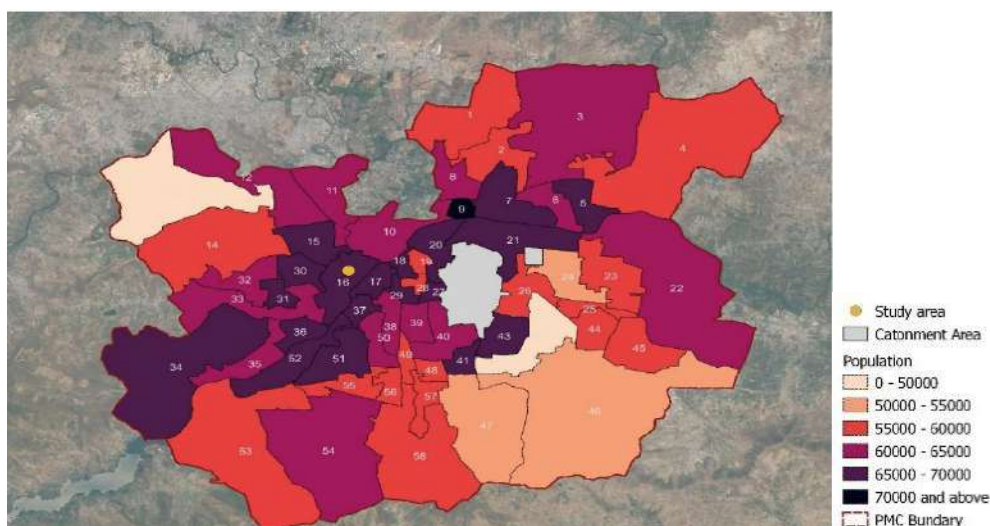
To mention a few, Kothrud, Bibewadi, and Sahakar Nagar were the main areas that underwent the initial makeover. Naturally, the second wave of change brought about by redevelopment has begun to take shape in these neighbourhoods, which are once again prime places. 5% of all Pune-registered societies are expected to undergo renovation. There are currently about 20,000 registered societies. This suggests that in the upcoming years, about a thousand societies will undergo reconstruction (Redevelopment – The Need of the Hour, 2022). In recent years, the real estate sector has suffered considerably. The pandemic, global downturn, and demonetization have induced builders to reconsider their investments in large-scale projects in the outlying regions. For builders, the main issue with such initiatives was the return on

investment. Redevelopment initiatives offer the ideal foundation for recovery. Builders may now engage in these projects at a reduced cost and be sure that they will turn a profit within three years because there is no land cost.

5.3 Need: Why Pune?

Urban redevelopment and neighborhood liveability are intricately linked, as redevelopment directly impacts the physical, social, and economic fabric of neighborhoods. Below are the key factors that underscore the need for this study:

Figure 19: PMC Ward wise Population (Census, 2011)



Source: Compiled by author

Transforming Urban Landscape and growing density: Pune's urban transformation has been evident since the 1980s, with the redevelopment of historic *Wadas* into mid-rise buildings (Redevelopment – The Need of the Hour, 2022). The current phase of redevelopment, involving the construction of eight to eleven-story structures, represents a significant shift in the city's urban landscape. While redevelopment improves housing stock and infrastructure, it raises critical questions about its impact on liveability, such as:

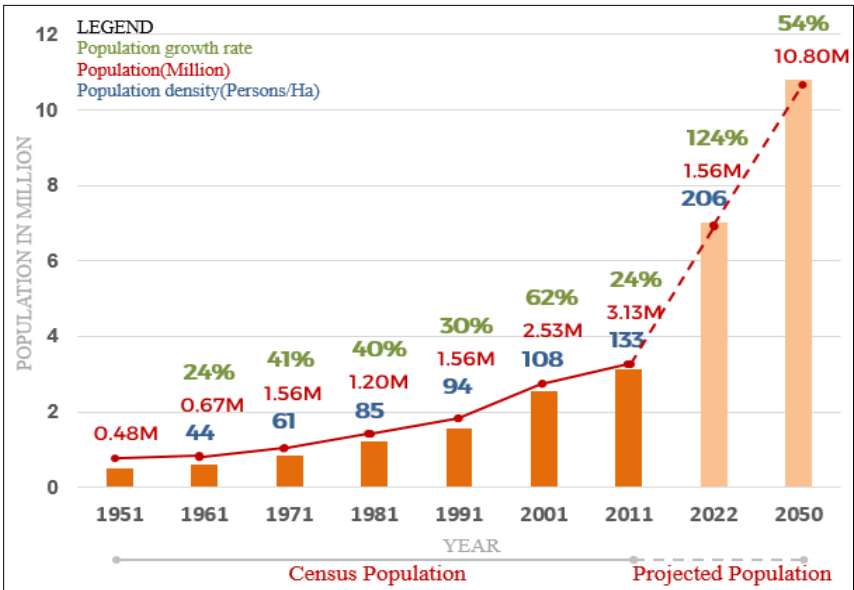
- Does redevelopment lead to overcrowding, or does it improve urban density management?
- How does the redesign of spaces affect community interaction, accessibility, and amenities?

Studying these changes will help evaluate whether redevelopment enhances the quality of life for residents or introduces new challenges.

Balancing modernization and cultural identity: Pune's identity is deeply intertwined with its rich cultural heritage and historic architecture. The city's *Wadas*, traditional courtyard-style homes, symbolized its historical charm and community-centric living. However,

redevelopment has led to the gradual transformation of these heritage structures into contemporary high-rise buildings. This transformation raises critical questions about the trade-off between modernization and cultural preservation:

**Figure 20: Trend Growth of Projection and its Density (Census, 2011)
(Ecological Threat Report, 2022)**



Source: Compiled by author

- How does the shift from traditional architectural styles to modern high-rises impact residents’ sense of belonging and identity?
- What role does cultural heritage play in shaping residents’ perceptions of liveability in redeveloped neighborhoods?
- How does redevelopment affect the quality of social interactions and community bonding in transitioning neighborhoods?

Furthermore, redevelopment has altered community dynamics by replacing smaller, close-knit neighbourhoods with larger, more impersonal housing complexes. Traditional spaces for communal interaction, are often replaced by private amenities like gyms or clubs, which may limit community engagement.

6.0 Site Profile and Context

6.1 Pilot study: Deccan Gymkhana

Deccan Gymkhana, originally a residential neighbourhood, is undergoing significant redevelopment with increasing density and changes in built form. The area is now witnessing a

shift towards mixed-use development, with commercial offices and retail spaces integrating into the urban fabric. This transition impacts housing satisfaction and transportation accessibility (Marans & Stimson, 2011) while also influencing pedestrian mobility and urban aesthetics (Chiara & Valentina, 2017). Additionally, rising concerns about security and environmental sustainability (Denis *et al.*, 2021) highlight the need to assess liveability changes. As Deccan Gymkhana evolves, understanding its redevelopment's effects on residents' quality of life is essential for informed urban planning.

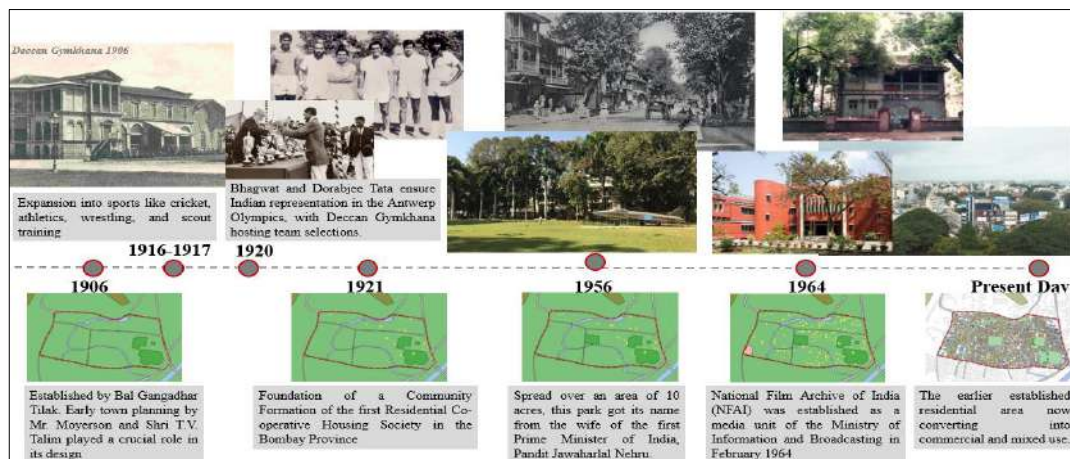
6.2 Historical evolution & growth pattern

Deccan Gymkhana, originally planned in 1906, reflects Pune's early structured urban development. Initially a residential neighbourhood, it evolved into a hub for sports and cultural activities, contributing to India's Olympic representation in 1920. The establishment of a cooperative housing society in 1921 set a precedent for organized residential planning. Today, the area is undergoing significant transformation, with increasing commercial and mixed-use developments, raising questions about its changing density, built form, and liveability.

6.3 Building use and study area delineation

The Deccan Gymkhana area exhibits a diverse mix of uses, characterized by a dense network of residential, commercial, and mixed-use buildings. Residential areas constitute the predominant land use, covering approximately 67% of the total area, followed by commercial and mixed-use developments at 19.74%, which are primarily concentrated along major roads. The site delineation for this study is justified by its strategic location, surrounded by major roads such as SB Road, BMCC Road, Canal Road, Bhandarkar Road, FC Road, Prabhat Road, and Law College Road, ensuring seamless connectivity and accessibility. This makes it an ideal case for analyzing urban redevelopment and its impact on neighbourhood liveability.

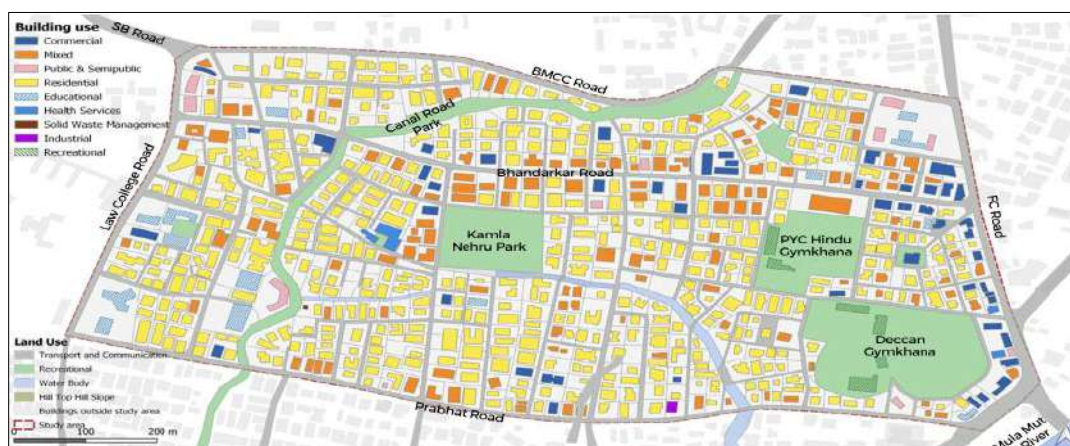
Figure 21: History of Deccan (Gymkhana, 2025)



Source: Compiled by author

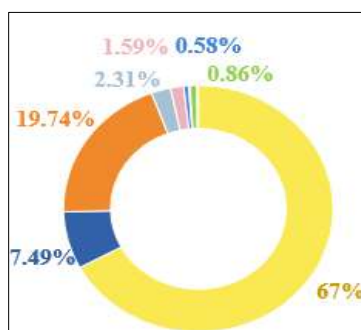
The area exhibits a balanced land use distribution, comprising residential, commercial, institutional, and recreational spaces, including Kamla Nehru Park and Deccan Gymkhana, which contribute to the overall liveability of the neighbourhood. Additionally, the site has witnessed significant redevelopment, with older low-rise buildings being replaced by higher-density developments, providing an opportunity to assess changes in liveability parameters such as population density, infrastructure adequacy, and social cohesion. The well-defined boundaries ensure a controlled geographic extent for analysis, minimizing external influences.

Figure 22: Building Use - Deccan Gymkhana



Source: Compiled by author

Figure 23: Building Use distribution - Deccan Gymkhana



Source: Compiled by author

Total buildings = 704

Total Land area = 0.814 Sq. km.

Several studies emphasize the importance of a substantial residential component when assessing urban liveability in redeveloped areas. (Marans & Stimson, 2011) highlight housing

satisfaction as a key determinant of liveability, underscoring the need for a significant residential presence. (Chiara & Valentina , 2017) discuss the role of residential density in pedestrian accessibility and sustainable mobility, while (Tsuyoshi *et al.*, 2023) link safety perceptions more strongly to residential environments than commercial zones.

Additionally, research on mixed-use development (Denis *et al.*, 2021) suggests that maintaining a balance between residential and commercial land use is crucial for sustainable urban living. Given that more than 50% of the study area remains residential despite redevelopment, it remains a valid case for liveability assessment. This aligns with existing research, which identifies residential environments as essential for evaluating key liveability parameters such as housing satisfaction, accessibility, safety, and environmental quality.

6.4 Demographic profile

The population density calculation is derived by dividing the total population of 7 million (Ecological Threat Report , 2022) by the total area of 340.45 sq. km (Pune Municipal Corporation, 2024), resulting in approximately 20,561 persons/Sq. km. Converting this into hectares, the density is about 206 persons per hectare. Using this density, the estimated population for a specific area of 0.814 sq. km is calculated by multiplying the population density by the area, yielding an approximate population of 16,737 people. This estimation helps in understanding the distribution of residents within the study area and provides a basis for analyzing the impact of urban redevelopment on population concentration. Higher density can indicate increased demand for infrastructure, housing, and amenities, influencing neighborhood livability. This data is crucial for evaluating whether redevelopment has led to overcrowding or if urban planning measures have adequately accommodated the growing population.

$$\begin{aligned}\text{Population Density} &= \text{Total Population} \div \text{Total Area} \\ &= 7,000,000 \div 340.45 \\ &\approx 20,561 \text{ persons per sq. km.} \\ &= 206 \text{ persons/Ha}\end{aligned}$$

$$\begin{aligned}\text{Population of 0.814 sq. km} &= \text{Population Density} \times \text{Area} \\ &= 20,561 \times 0.814 \\ &\approx 16,737 \text{ people} = 205 \text{ persons/Ha}\end{aligned}$$

Equation 1 Population calculations

6.5 Redevelopment scenario

24% of redevelopments are single buildings with most of them being residential and mixed. The redevelopment pattern in Deccan Gymkhana illustrates a significant transformation in the built environment, with 34% of the buildings undergoing redevelopment between 2001 and 2025. The process involves demolishing old structures and constructing new buildings on the same plots, utilizing an increased Floor Space Index (FSI) to accommodate a higher population. The remaining 66% of buildings have not been redeveloped since before 2001,

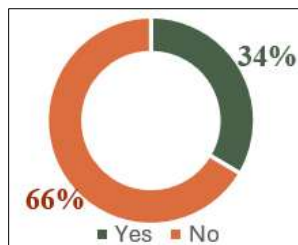
maintaining their original built form. The site exhibits a mix of land uses, including residential, commercial, institutional, and recreational spaces, with major parks such as Kamla Nehru Park and PYC Hindu Gymkhana playing a crucial role in maintaining liveability. The redevelopment trend indicates a shift towards higher density, impacting infrastructure demand, urban mobility, and social dynamics. While redevelopment facilitates modernization and improved amenities, it also raises concerns about increased congestion, loss of neighbourhood character, and potential strain on utilities and open spaces. The surrounding arterial roads ensure good connectivity, making this area a prime location for urban transformation.

Figure 24: Redevelopment Scenario



Source: Compiled by author

Figure 25: Redevelopment Scenario Percentage



Source: Compiled by author

Figure 26: Green Areas, Walkability and Pedestrian Access in the Area



Source: Compiled by author

7.0 Limitations

The study is constrained by the reliance on post-redevelopment assessments due to the absence of pre-redevelopment data, which limits the ability to compare past and present conditions comprehensively. Future research should focus on assessing the longitudinal impacts of redevelopment over time and integrating multi-city comparative analyses to provide a broader understanding of urban liveability outcomes, but the area should be similar to redevelopment characteristics and area (similar to 0.841 sq. km.).

8.0 Conclusion

The study comprehensively analyzes urban redevelopment and neighbourhood liveability by integrating literature review insights, empirical findings, and quantitative assessments. The literature review highlights key parameters influencing liveability, such as population dynamics, housing availability, transportation systems, and environmental quality, emphasizing the complex relationship between redevelopment and urban well-being. The findings reveal that 66% of the study area has undergone redevelopment, primarily driven by increased Floor Space Index (FSI) consumption to accommodate higher population densities. The redevelopment trend has reshaped land use, with residential and mixed-use developments dominating the landscape. While redevelopment has enhanced infrastructure and economic opportunities, concerns related to environmental quality, open spaces, and cultural integration persist. The study contributes to the ongoing discourse on liveability by providing empirical evidence on post-redevelopment scenarios and identifying gaps in the planning process.

9.0 Scope

Future research should focus on developing a liveability index/assessment tailored specifically for redeveloped neighbourhoods. Such an index would integrate both quantitative and qualitative parameters derived from the literature review, where the residents will be surveyed and both external parameters will provide a standardized service, while introspective parameters will give an insight into the aspects, offering a comprehensive tool for evaluating the impacts of redevelopment. By including metrics like air quality indices, housing affordability, and resident perceptions of safety and community engagement, the index could provide valuable insights for urban planners and policymakers. It would also facilitate comparative analyses of different redevelopment projects, enabling the identification of best practices and areas for improvement. In conclusion, the study calls for a paradigm shift in urban redevelopment strategies, advocating for approaches that prioritize inclusivity, sustainability, and cultural preservation. By addressing the gaps identified in this review, future redevelopment initiatives can transform urban neighbourhoods into resilient, vibrant, and equitable spaces. The proposed liveability index represents a significant step toward achieving this vision, offering a framework for aligning redevelopment with the holistic well-being of urban communities.

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CHAPTER 90

Investigations on Applications of BIM for Managing MEP Projects

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ABSTRACT

Managing Mechanical, Electrical, and Plumbing (MEP) systems is becoming more challenging for the construction industry because of its complexity and the demand for increased sustainability, precision, and economy. To overcome these obstacles, this study investigates Building Information Modeling (BIM) as a possible solution for coordinating MEP projects. The study examines the difficulties in integrating MEP systems within the building ecosystem, such as complex design, adhering to changing regulations, and the recurring problems of delays and conflicts. It draws attention to the advantages and drawbacks of using BIM in MEP coordination through thorough literature research and examination of actual situations. The study uses semi structured interviews from BIM professionals and attempts to capture insights on application of BIM for coordinating MEP projects. It includes a thorough examination of key BIM capabilities such 3D modeling, conflict detection, accurate resource estimate, and real-time collaboration. The report also identifies obstacles to BIM adoption, such as high upfront costs, interoperability problems, and the requirement for qualified specialists, and suggests possible ways to overcome these challenges. In conclusion, the research highlights the critical role that BIM can offer for project management of MEP systems.

Keywords: BIM; MEP; Project management; Construction management.

1.0 Introduction

Building Information Modeling (BIM) is a game-changing technique in the architecture, engineering, and construction (AEC) sectors that improves accuracy, efficiency, and collaboration. BIM gives stakeholders the ability to realistically see projects before construction starts by providing 3D models that retain comprehensive information about dimensions, materials, costs, and maintenance schedules, in contrast to traditional 2D drawings. Errors are reduced, and resource allocation is optimized. BIM integrates artificial intelligence (AI) and machine learning for automated functions including energy analysis, clash detection, and quantity take-offs, which is in line with trends in digital transformation. These developments powered by AI decrease errors and rework while increasing efficiency and accuracy.

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Virtual reality (VR) and augmented reality (AR), which provide immersive design review experiences, stakeholder interaction, and construction simulations, are also supported by BIM. In addition to improving user experience, this change in the AEC sector encourages digitization, sustainability, and cost-effectiveness. MEP (Mechanical, Electrical, and Plumbing) coordination is a crucial part of BIM, guaranteeing the smooth integration of fire safety, piping, HVAC systems, and electrical wiring in a virtual 3D model. Construction teams can maximize system placements for effective installation and maintenance, visualize spatial layouts, and identify conflicts early with BIM. This procedure improves teamwork, lowers mistakes, and boosts project execution. Notwithstanding its advantages, using BIM in MEP coordination has drawbacks. Complex designs, changing laws, and the requirement for exact coordination can cause delays and conflicts. Conflict resolution at coordination meetings takes a lot of time and results in rework and inefficiency.

Differences between BIM models and installations on-site emphasize how important it is to communicate well to avoid disputes. Effective BIM coordinators are essential to the success of a project since untrained workers may fail to consider important design factors, which can lead to problems with compliance and setbacks. Furthermore, the high expense of BIM software and qualified staff puts a strain on finances, especially for smaller businesses. Costs can be decreased by outsourcing drafting work, but project timeframes and quality may suffer and control over design processes may be restricted. Including cutting-edge technology in BIM, including automated design verification, can simplify procedures and lessen cost difficulties. Through a number of technological developments, MEP coordination within BIM has improved. Rule-based routing for MEP components and automated analysis of ceiling spaces are made possible by programs like Revit and its Application Programming Interface (API). Autoroute and other add-ins help identify design deviations, minimize conflicts, and cut down on coordination meetings. By automatically creating BIM MEP models from laser scanning data, Dynamo, a Revit plug-in, increases the efficiency of revisions. By combining all service drawings into a single 3D model that stakeholders can view, cloud computing improves MEP coordination and promotes real-time cooperation. Advanced algorithms are used by conflict detection solutions, like Navisworks, to effectively identify and resolve problems, cutting down on coordination time and improving project results. Key advantages of BIM for MEP coordination include better teamwork, precise planning and estimation, greater safety and risk management, increased productivity, and improved quality control. For stakeholders looking to remain competitive in the changing construction market, embracing BIM and its technological innovations is crucial.

2.0 Research Objectives

The prime research objective will be focused on below mentioned areas:

- What are the Challenges in managing MEP projects?

- What are the Benefits and limitations of using BIM for coordinating MEP projects?
- What is the Potential of BIM in industry 5.0?

3.0 Literature Review

This literature review highlights the approaches and various findings in the area of energy-compliant building design and cost analysis. Building Information Modeling (BIM) has played a key role in transparent valuation processes, supporting AI models for life cycle cost analysis in green buildings and encouraging multidisciplinary collaboration. BIM enhances efficiency in Mechanical, Electrical, and Plumbing (MEP) facility design by facilitating three-dimensional representation, early detection of conflicts, and overall cost savings (Rodríguez, 2023). Research suggests that despite the higher initial investment in green buildings, they prove to be economically viable due to reduced operational costs. Studies indicate that adopting sustainable materials and practices can lead to overall construction cost reductions of up to 15.2% and 30% (Prajwal *et al.*, 2021; Manjunath *et al.*, 2021). Further, integrating BIM with robotic marking systems (Iqbal *et al.*, 2023) and the Internet of Things (IoT) allows for automated layout printing, improving accuracy and reducing manual labor.

Other techniques such as Case-Based Reasoning (CBR), Work Breakdown Structure (WBS), and regression models play a crucial role in identifying various cost components and predicting maintainability performance (Mohanta *et al.*, 2022). Research highlights that an initial cost prediction model is essential for the project's economic viability. Sustainable Building Assessment Tools (SBAT) are necessary to account for India's unique climate conditions, with key standards set by LEED, GRIHA, and BEE (Reddy *et al.*, 2018).

The study by Plebankiewicz *et al.* (2019) emphasizes the need for integrated assessment systems to analyze costs and benefits of green certification in office buildings. The transition from Industry 4.0 to Construction 5.0 introduces automation, human-robot collaboration, and enhanced digital modeling for more sustainable construction (Marinelli, 2023). BIM plays a significant role in integrating Industry 5.0 principles, emphasizing societal and environmental benefits beyond economic productivity (Hadi *et al.*, 2023). Furthermore, integrated project delivery methods optimize technology, processes, and contractual arrangements for improved efficiency in energy-compliant buildings (Ikudayisi *et al.*, 2023).

Tools such as Life Cycle Cost (LCC) analysis, payback period analysis, Net Present Value (NPV), and sensitivity analysis are critical for cost evaluation (Blomberg *et al.*). In addition, integrating BIM with lean construction techniques enhances workflow efficiency, reducing reworks and promoting sustainability (Teo *et al.*, 2022). Studies by Wu *et al.* (2022) reveal that productivity in MEP installations can be significantly improved through BIM-led collaboration and quality control mechanisms. Emerging trends include the integration of Digital Twins with BIM to optimize energy efficiency and sustainable practices. The fusion of these technologies with IoT, big data analytics, and blockchain presents new opportunities for real-time data processing, automation, and efficient resource utilization (Chen *et al.*, 2022).

However, challenges such as high initial costs, interoperability issues, and lack of training hinder the widespread adoption of BIM (Ullah *et al.*, 2019). A key concern remains the alignment of cost estimation models with real-world scenarios, necessitating more accurate first-cost estimation models for green buildings (Gashaw *et al.*, 2023). Studies also highlight that property values are influenced by collective green building variables rather than individual factors, necessitating a work package-based approach to project evaluation. BIM integration improves MEP coordination and constructability (Wang *et al.*, 2016). Studies on MEP system optimization through BIM reveal substantial cost reductions and enhanced project outcomes (Partl *et al.*, 2019). Additionally, smart material management within BIM-based MEP designs has shown improvements in resource control and construction accuracy (Feng & Lin, 2017). Research on the Shanghai Disaster Control Centre demonstrates how BIM can detect and resolve MEP clashes, reducing costs and improving construction efficiency (Shou *et al.*, 2013).

4.0 Research Methodology

The research methodology comprises of 10 semi-structured interviews which were conducted with industry experts from various professional backgrounds in this domain, with experience ranging from 2 to 25 years. The method was used to collect the data through a qualitative approach. Therefore, the questionnaire was designed after careful consideration of existing literature in the domain of managing BIM in MEP projects. These interviews provided valuable insights into our research questions, capturing a range of perspectives from different domains. After analysing the responses, the findings were synthesized from ten interview reports, integrating key insights to form a comprehensive summary of the data collected.

Table 1: List of Respondents

Sr. No.	Designation	Experience in MEP Projects
1	MEP Costing Manager	8 years
2	Senior Engineer	3 years
3	Director	25 years+
4	Assistant Professor	5 years+
5	Founder	19 years
6	BIM Process Engineer	9 years
7	Senior Design Engineer	10 years
8	BIM Engineer	2 years
9	BIM Engineer	12 years+
10	Founder	21 years+

The questionnaire's layout and response analysis are the main topics of this section. A thorough summary was produced by synthesizing the most important findings from 10 interview reports after the data was reviewed. A summary of the semi-structured interviews is provided below.

5.0 Data Analysis and Findings

The questionnaire's layout and response analysis are the main topics of this section. A thorough summary was produced by synthesizing the most important findings from 10 interview reports after the data was reviewed. A summary of the semi-structured interviews is provided below.

5.1 Common challenges in managing MEP projects

- Regular Design Modifications: Rework, delays, and cost overruns result from ongoing changes.
- Co-ordination and Spatial Conflicts: Inefficiencies arise when plumbing, electrical, and mechanical services are not aligned.
- Time and Cost Management: Project viability is impacted by financial limitations and execution hold-ups. Problems with Clash Detection: For a project to be completed smoothly, conflicts must be found and resolved. Lack of Skilled Staff: There is a dearth of qualified experts in MEP services.
- Inadequate Awareness and Training: MEP engineers do not have access to organized training programs.
- Complete MEP Management: It can be difficult to oversee every facet (design, costing, implementation, and quality). Ensuring smooth integration across various MEP systems is known as inter-service coordination.

5.2 Impact on project timeline and cost

- Delays: Coordination issues, design revisions, and execution inefficiencies extend project timelines.
- Cost Overruns: Rework, scope changes, and mismanagement result in increased costs.
- Quality Compromises: Lack of focus on quality may lead to functional failures.
- Local Resistance and Regulatory Coordination: Delays due to compliance requirements and resistance from local authorities.

5.3 Strategies to mitigate these challenge

- Early Design Finalization: By completing designs early on, uncertainties can be reduced.
- Advanced Planning: Planning MEP tasks ahead of time to provide a more seamless execution.
- Frequent Stakeholder Coordination: Better team-to-team communication.
- Risk identification and mitigation: Preventing serious problems by addressing possible hazards early.
- Training and Upskilling: Giving MEP experts practical instruction.

- Employing Professional Consultants: Bringing in experts from the field to assist with design and implementation.
- Using BIM for Clash Detection: Making use of BIM tools for mistake reduction and spatial planning.
- Systematic handling of design modifications to reduce interruptions is known as a change management system.

5.4 BIM software used in MEP projects

- Preliminary design layouts and 2D drafting are done with AutoCAD.
- Revit MEP: cooperation between BIM, MEP design, and 3D modeling.
- Visualization, project review, and clash detection in Navisworks.
- Real-time data sharing, project tracking, and cloud-based collaboration are all features of BIM 360.

5.5 Benefits of using BIM in MEP projects

- Decreased Errors and Rework: Costly site updates are avoided with early clash detection.
- Better Cooperation: Better collaboration between various stakeholders and teams.
- Time and Cost Efficiency: Better budget control and less waste are achieved through optimized planning.
- Improved Visualization: MEP plans may be clearly understood thanks to 3D representations.
- Better Safety and Quality: By increasing design correctness, BIM guarantees better project quality.

5.6 Challenges in using BIM for MEP projects

- High Initial Cost: Implementing BIM calls for a large financial outlay.
- There is a shortage of qualified individuals with experience in BIM applications.
- Interoperability problems include trouble integrating BIM with older systems and other tools.
- Opposition to Change: A number of stakeholders are reluctant to abandon conventional approaches.
- Complexities of Data Management: It can be difficult to handle big files and guarantee data accuracy.

5.7 Addressing BIM limitations

- Frequent Training Programs: enhancing teams' proficiency to enhance the adoption of BIM.
- Phased Implementation: To facilitate the transition, BIM is gradually integrated.

- Enhancing Interoperability: Creating a more seamless connection between BIM and other building instruments.
- Standardizing BIM Protocols: Creating consistent industry-wide BIM execution strategies.

5.8 Compliance and guidelines in BIM usage

- ISO 19650 (International BIM Standards)
- National Building Code (NBC) for India
- ASHRAE, NEC, UPC, NFPA (Mechanical, Electrical, Plumbing, Fire Protection Standards)
- British Standards, European Norms (EN), IEC Guidelines

5.9 Future potential of BIM in industry 5.0

- Human-Centric Approach: BIM will enable better collaboration between humans and machines.
- Sustainability: Pertains to the optimization of energy consumption and the minimization of material waste.
- Resilience: BIM-based simulations enhance disaster preparedness and safety.
- Skill Development: Using BIM for worker training and automation

5.10 Desired advancements in BIM for MEP projects

- AI and Automation: AI-based clash detection and design optimization.
- Augmented and Virtual Reality: Improving design visualization and on-site coordination.
- Cloud and IoT integration: Enables real-time project tracking and better decision-making.
- 3D printing: Facilitates rapid prototyping and prefabrication utilizing BIM models.
- Improved User Interfaces: Making BIM tools more intuitive and user-friendly.

5.11 Additional insights on BIM adoption

- BIM should be used in all MEP projects. Experts underline the benefits of efficiency and cost reductions.
- Leadership and Training Are Important: Providing structured training to stakeholders to encourage their use of BIM.
- BIM represents the future of MEP project management: Continuous improvements will further transform project execution.

6.0 Conclusions, Limitations and Directives for Future Research

6.1 Conclusions

In Mechanical, Electrical, and Plumbing (MEP) projects, the application of Building Information Modeling (BIM) has improved resource management, reduced errors, and

transformed coordination. The growing complexity of MEP systems and the need for digital solutions are highlighted in this study. Better visualization, early clash detection, and smooth collaboration through real-time data sharing are all made possible by BIM.

Ten experts in MEP (mechanical, electrical, and plumbing) project management were interviewed; the interviews provide light on typical problems, solutions, and the function of BIM (building information modelling) in the construction industry. Coordination problems amongst various MEP services and stakeholders, a shortage of qualified staff, frequent design modifications, cost overruns, and implementation delays are the main obstacles encountered. These difficulties frequently result in delays, higher expenses, and inefficiency. Experts stress the significance of early design finalisation, stakeholder cooperation, risk management, and effective communication in order to address these problems. Using BIM tools, such as Revit, Navisworks, and BIM 360, is a standard procedure to increase project productivity. BIM has been shown to improve resource allocation, minimise errors, detect conflicts early, and increase design accuracy. High upfront expenditures, reluctance to adapt, interoperability problems, and the requirement for specialised training are some of the drawbacks.

6.2 Limitations

- The study is predicated on qualitative information obtained through semi-structured interviews with just ten individuals in the domain.
- Without using statistical data for analysis, the study depends on the qualitative insights obtained from ten respondents through interviews.
- According to the opinions of experts, we got varying responses about Industry 5.0's potential in BIM for MEP projects. While some experts highlighted its advantages—such as better decision-making, sustainability, and collaboration—others offered little to no commentary on the subject. This discrepancy in answers points to a knowledge gap, implying that Industry 5.0 and its effects on BIM in MEP projects could not be well known or thoroughly investigated in the sector.

6.3 Directives for future research

- *Cost optimization strategies:* Future research should look into ways to lower the high upfront costs associated with implementing BIM, such as modular licensing models catered to various project sizes, cloud-based BIM services, and affordable software solutions.
- *AI automation and BIM:* Examining how AI-powered design optimization, automated clash detection, and predictive maintenance function in BIM software might result in more intelligent and effective project management.
- *Integration with IoT and smart sensors:* Future studies should look into how combining BIM with IoT and smart sensors might help with predictive maintenance, energy-efficient building operations, and real-time MEP system monitoring.
- *Sustainability and BIM:* Greener and more robust infrastructure can result from examining

how BIM might support sustainable construction methods including lifespan assessment, carbon footprint reduction, and energy-efficient design.

- *Training and workforce development:* To solve the skills gap in the industry, research should look into ways to upskill construction professionals and include BIM instruction into university and vocational training programs.

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CHAPTER 91

Investigations on the Role of BIM in Facility Management

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ABSTRACT

This study addresses the increasing complexity of controlling subsystems like Heating, Ventilation & Air Conditioning (HVAC) systems and electrical systems in existing facilities, where traditional approaches often fail to ensure optimal performance, predictive maintenance, and energy economy. Building Information Modeling (BIM) is revolutionizing Facilities Management (FM) by enhancing decision-making and operational efficiency throughout the asset's lifecycle. The study examines the implementation of BIM in FM, focusing on HVAC and Electrical systems. The study comprises of literature review and semi-structured interviews, resulting in analysing BIM's cutting-edge power in asset management. According to preliminary studies, interoperability issues among platforms and restricted scalability for smaller facilities exists. To address these barriers, the paper makes practical solutions for improving BIM's influence on FM procedures through success stories and case study learnings. This study demonstrates and contributes BIM's potential to transform FM processes, by providing actionable insights and concrete advantages to broaden adoption of BIM in FM.

Keywords: BIM; Facilities management; Predictive maintenance; Operational efficiency; Asset life cycle.

1.0 Introduction

The necessity for creative methods to handle facility management (FM) has been highlighted by the quick expansion of infrastructure construction in India as well as the growing complexity of contemporary structures. Reactive maintenance techniques, fragmented data, and inefficient resource allocation are common problems with the traditional facility management approaches. A revolutionary answer is offered by Building Information Modeling (BIM), a digital technology that combines operational, structural, and architectural data. By connecting the design/construction stages with the building's operating lifecycle, BIM gives facility managers access to up-to-date, precise data for preventive decision-making.

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From Bengaluru's IT parks to Mumbai's skyscrapers, India's dynamic urban geography makes this integration especially crucial for maximizing occupant comfort, sustainability, and operational efficiency. Addressing issues like energy inefficiencies, growing repair expenses, and the need for more intelligent future-ready infrastructure is made possible by the combination of BIM and FM. The study looks at how BIM is included into FM processes to pinpoint the concrete advantages of this collaboration, such as improved operational efficiency, energy management, and predictive maintenance. The study will also suggest ways to get around obstacles to BIM-FM incorporation in the Indian setting. The study looks at how BIM-driven data centralized management, presentation, and predictive analytics enhance FM outcomes. The objectives include:

- Evaluate how BIM is currently being used in FM.
- Determine and assess the possible advantages of incorporating BIM into FM procedures, particularly with a focus on HVAC and Electrical systems.

Although the study emphasizes the promise of BIM in FM, it is important to recognize several limitations. There is currently little data available on for a long time BIM-FM implementations in India. By using secondary data in the form of research papers, case studies and semi-structured interviews, the previously mentioned objectives are examined.

2.0 Literature Review

A revolutionary paradigm that presents previously unheard-of chances to maximize building lifecycle management is the incorporation of BIM in FM. In order to identify gaps that guide the study's focus, this section summarizes previous research on several important topics, such as the advantages of BIM-FM integration, technical uses, sustainability, technological advancements, and sector-specific difficulties.

2.1 The basics of integrating BIM with FM

Because of its capacity to centralize data, optimize workflows, and improve decision-making, BIM has the potential to completely transform FM. Early research by Su *et al.* (2011) and Kelly *et al.* (2013) highlights the advantages of BIM over conventional 2D CAD systems, especially in terms of enhancing data accuracy, expediting work orders, and facilitating real-time asset tracking. However, obstacles including fragmented data handovers, industry reluctance to technological adoption, and problems with BIM and FM tool compatibility still exist (Patacas *et al.*, 2015; Pärn *et al.*, 2017).

2.2 Technical uses for electrical and HVAC systems

The function of BIM in managing intricate systems like electrical infrastructure and HVAC (heating, ventilation, and air conditioning) is the subject of an expanding corpus of research. Yang *et al.* (2017) proposed a BIM-based architecture that cut troubleshooting time by

68% and identified 47 vital data requirements for HVAC maintenance. While Dahanayake *et al.* (2022) investigated IoT-BIM synergies to improve energy management and fault detection, Karimi *et al.* (2021) showed how effective BIM is at combining MEP systems into underground train stations.

2.3 Sustainability and lifecycle management

It is commonly known that BIM may help with sustainable FM practices. Potkany *et al.* (2015) support the use of BIM in lifecycle planning by relating efficient FM to lower energy use and CO2 emissions. Nical *et al.* (2016) go on to emphasize the value of BIM in energy analysis and retrofit planning, which is in line with international sustainability objectives. Studies like Liu *et al.* (2016), however, show a lack of early FM involvement throughout the design stages, which results in preventable maintenance expenditures.

2.4 Innovations in technology and digital instruments

BIM-FM integration is changing as a result of emerging technologies like digital twins, augmented reality (AR), and the Internet of Things. While Gheisari *et al.* (2016) show how mobile AR can enhance field accessibility to BIM data, Karimi *et al.* (2021) show how digital twins allow for real-time performance monitoring. The Edge building in Amsterdam is cited by Araszkievicz *et al.* (2017) as a model for smart FM; nonetheless, they emphasize the necessity of compatibility between BIM platforms and older systems.

2.5 Sector-specific difficulties and knowledge administration

According to Pinti *et al.* (2022), the public sector's adoption of BIM-FM is still in its infancy. They point out that nations such as the UK and Italy lack standardized methods and pilot-based deployments. Similar to this, Adetayo *et al.* (2023) highlight how technical and financial limitations cause differences in the use of BIM across regions, especially in Africa.

2.6 Future directions and human factors

Inadequate training and resistance to change continue to be major obstacles. While Lavy *et al.* (2015) support earlier BIM-COBie integration to reduce manual data entry mistakes, Aziz *et al.* (2016) attribute the underutilization of BIM with FM to organizational inertia.

2.7 Research shortcomings and inputs

Although previous research highlights the transformative potential of BIM, there are still shortages in overtime BIM-FM case studies, especially in developing nations like India. Regional issues including dispersed infrastructure expansion and the merging of HVAC and electrical systems in densely populated urban areas are not well covered in studies. To close these gaps, this study assesses how well BIM can optimize HVAC as well as electrical FM procedures in India's changing construction environment and suggests solutions for overcoming adoption hurdles.

3.0 Semi structured Interviews

3.1 Methodology

Semi structured interviews provide comprehensive understanding on a particular topic under investigation. Professionals in the commercial, industrial, as well as educational sectors of facility management took part in semi-structured interviews about BIM in FM. The topics of discussion included ROI measurement, implementation difficulties, BIM integration, its function in HVAC as well as electrical works, and upcoming advancements.

3.2 Responses

Table 1: Respondent Details

Respondent no	Designation	Total work experience (in years)
1	Design Manager	6
2	Facility Manager	25
3	Assistant Professor	4
4	Virtual Builder	5
5	Facility Operations specialist	11
6	Assistant FM manager	9

3.3 Summary of responses

- The respondent connects assets and models using Vueops Sitrine, allowing 3D representation for HVAC/electrical maintenance, even though they have no direct FM experience. Dependency on designs and the absence of trade models are obstacles. AI-driven problem identification is a trend for the future, and BIM centralization lowers staffing expenses.
- The response compares worldwide procedures with Siemens, JLL, as well as Honeywell while integrating BIM and Cam Plus One with BMS for asset monitoring. By optimizing HVAC scheduling, BIM reduces energy consumption by 30%. The incompatibility of outdated equipment is one of the challenges. Failure prediction powered by AI is a development for the future.
- The respondent oversees lab and institutional facilities and contrasts conventional FM in India with 3D BIM in the United States. BIM improves vendor data access, workstation layout, and procurement. There are obstacles to adoption of older structures. Future developments will include electrical monitoring based on sensors.
- The respondent uses Autodesk Cloud to integrate BIM in real-time for projects in Dubai. Among the advantages are 3D clash detection and lower rework expenses. Technical learning curves and stakeholder unfamiliarity are obstacles. In large, multidisciplinary projects, BIM produces a 50% return on investment.

- In accordance with Singapore's BIM Level 2, the respondent, who managed a tech hub as well as medical facility, improved drainage systems and cut HVAC energy consumption by 18% using BIM. BIM reduced AC breakdowns by 25% and avoided 14 days of electrical rework. IoT-BIM will be used in future to monitor humidity in real time.
- The respondent, who oversaw resorts as well as commercial buildings, reduced peak energy use by 15% by optimizing electrical load distribution. BIM increased mall renovation productivity by 20% and reduced fire-alarm testing duration by 40%. Tenant resistance is one of the difficulties.

4.0 Case Studies

4.1 User-Centric BIM-Based Framework for HVAC Root-Cause Detection

A user-centric BIM-based paradigm for identifying the underlying causes of HVAC issues was presented by Alavi & Forcada (2022). Parameters such as timeliness, flexibility for integrating data from several sources, decision support capabilities, and visualization efficacy were used to evaluate the framework. The TR5 structure located at Universitat Politècnica de Catalunya was the subject of the case study. The following were the main conclusions drawn from this case study:

- The framework used Dynamo along with code written in Python to represent and depict HVAC faults by integrating information from CMMS as well as BMS systems into BIM.
- It made it possible to determine, semi-automatically, if HVAC problems were caused by insulation concerns, breakdowns in equipment (indoor and outdoor units), or an undersized system design.
- Without the need for physical equipment inspection, the facilities management team was able to diagnose issues more quickly and accurately thanks to the BIM model's user-friendly color-coded display.

4.2 Bim-energy simulation approach for detecting building spaces with faults and problematic behaviour

A BIM-based methodology for identifying spaces in buildings with HVAC system issues and troublesome behavior was given by Shalabi & Turkan (2020). The assessment was predicated on factors including impact on maintenance planning, detection accuracy, visualization efficiency, and integration capability. To illustrate the use of the framework, a case study of the King Pavilion, an educational facility was carried out. The following were the case study's main conclusions:

- Within the BIM context, the framework combined information from building energy management systems (BEMS), computerized maintenance management systems (CMMS) and energy simulations.
- Facility managers were able to identify areas with unusual patterns (inactive, exaggerated, or inadequate HVAC activity) by comparing simulated and real heating/cooling loads.

- The framework pointed out that while BEMS can identify alarms, it frequently overlooks concealed HVAC inefficiencies. This technique revealed these inefficiencies, allowing for predictive maintenance and less energy waste.

4.3 Using a retro BIM workflow: Case studies on energy driven retrofit projects

A 25,000 square foot mixed-use building located at 1204 Mason St. in San Francisco was the subject of a case study on energy retrofitting with BIM assistance by Skripac & Bergman (2012).

- The study's main objectives were data collecting effectiveness, simulation tool interaction, retrofit accuracy, and decision-making support. Time was saved by streamlining data collecting with a 3D laser scan. When energy simulations were calibrated using actual electricity bills, they showed that inefficient mechanical systems, uninsulated walls, and single-pane windows caused significant losses.
- Energy-Efficiency Measures (EEMs) like DHW improvements, more efficient insulation, steam-to-hydronic boiler utilization, as well as enhanced lighting/ refrigeration were prioritized with the aid of BIM visualization.
- For occupant comfort, daylight simulation insights were obtained through combining Revit and DesignBuilder along with Ecotect. Suggestions for incentive funding were communicated to PG&E's Saving by Design program.

5.0 Conclusion

BIM has shown revolutionary potential when included into FM especially when it comes to HVAC and electrical system optimization. The following are the findings of the study:

5.1 Important takeaways from semi structured interviews

- Practical viewpoints on the current application of BIM in FM across a range of industries, especially commercial, institutional, as well as industrial projects, were offered by Real-World Insights.
- Outlined important obstacles such exorbitant installation costs, challenges integrating with previous systems, and a shortage of qualified staff.
- Highlighted benefits prove how BIM can increase energy efficiency, lower operating costs, and facilitate predictive maintenance by using asset monitoring and 3D visualization.
- Shared perspectives on return on investment (ROI) indicate that while smaller projects necessitate a longer-term cost-benefit analysis, larger ventures yield a quicker ROI.
- New trends were identified, including the usage of digital twins for sophisticated facility management, IoT-BIM interface for real-time monitoring, and AI-driven predictive Maintenance.

5.2 Usage of BIM in FM from case studies

In FM, BIM is actively used to improve sustainability and operational efficiency. Important uses consist of:

- **As-Built Modeling:** Accurate digital copies of existing facilities are made possible by scanning with lasers and 3D point cloud information, which is essential for retrofits (Case study 3).
- **Energy Simulation:** In order to discover inefficiencies, BIM is combined with tools such as EnergyPlus and DesignBuilder to model HVAC effectiveness, daylighting, and electrical consumption (Case Studies 1–3).
- **Interoperability:** BIM and FM technologies (CMMS, BEMS) work together to centralize data, facilitating quicker maintenance workflows and root-cause identification of HVAC issues (Case Studies 1-2).
- **Retrofit Planning:** In accordance with energy efficiency objectives, BIM-driven analytics direct HVAC modernization and envelope improvements (such as window replacements and insulation) (Case Study 3).

5.3 Advantages of BIM for FM for electrical and HVAC systems

The case studies demonstrate quantifiable benefits of using BIM:

- **Cost and energy savings**
 - By improving insulation, HVAC retrofits were able to lower heating loads by as much as 18.58% (Case Study 3).
 - Opportunities to reduce lighting consumption by 35–50% were found through daylighting simulations (Case Study 3).
 - Utility costs were decreased and operational disruptions were minimized by proactive maintenance (Case Studies 1-2).
- **Preventive maintenance**
 - Rapid fault identification (such as refrigerant leaks and valve malfunctions) was made possible by the combination of BIM with CMMS, which reduced downtime (Case Studies 1-2).
 - HVAC response times were improved by using color-coded BIM visuals to prioritize repairs (Case Study 1).
- **Improved ability to make decisions**
 - Hidden inefficiencies like old boilers and inadequate ventilation were discovered through data-driven comparisons between simulated and real energy use (Case Studies 2–3).
 - BIM-assisted electrical system audits identified expensive equipment (such as café refrigeration units), which led to focused improvements (Case Study 3).
- **Comfort of occupants**

- By resolving underheated/overheated zones, thermal and airflow assessments increased satisfaction among tenants (Case Studies 2–3).

5.4 Conclusion in Indian context

- BIM increases energy efficiency lowers expenses for upkeep, and improves problem detection when used alongside BMS, CMMS, and BEMS. By detecting HVAC problems early and refining retrofitting techniques, it makes proactive maintenance possible. Sustainability is further improved by data analytics and digital twins. High expenses and complicated retrofitting are obstacles, though.
- Adoption of BIM is required in India because to the country's aging infrastructure and excessive energy consumption. BIM assists in optimizing energy use, addressing HVAC inefficiencies, and complying with energy laws. Maintenance and retrofitting are improved when BIM is used with CMMS and BEMS. Government incentives should be used to assist the development of affordable BIM solutions that are adapted to the regional resources, climate, and legislation. Programs for BIM-based energy optimization training are essential. AI-driven failure identification for real-time HVAC efficiency improvements should be the main focus of future research.

5.5 Final takeaway connecting semi structured interviews and case studies

5.5.1 ROI and preventive maintenance

- The ROI for large-scale projects (such the commercial complexes in Dubai) was 3–4 years, which is consistent with Case Study 3's breakeven point after HVAC upgrading. Large upfront expenses, on the other hand, presented difficulties for smaller Indian facilities, supporting the demand for scalable approaches like BIMx (freeware), which was brought up in interviews.
- The potential of BIM to anticipate HVAC issues was shown in every case study (e.g., refrigerant leakage in TR5 and valve problems in King Pavilion). This was supported by interviews, where experts reported that BIM-driven preventive alarms resulted in 25% fewer AC problems.

5.5.2 Increased efficiency in operations

- Validated interview responses from Case Studies 1 (UPC's TR5 Building) and 2 (King Pavilion) demonstrated how BIM can cut down on time spent on maintenance (35%) and energy expenses (15–20%). In a similar vein, experts from the UAE and India reported 25–30% fewer HVAC breakdowns as a result of predictive maintenance processes made possible by automated alarms and BIM visualization.

- As in the third case study (San Francisco retrofitting), interviewees highlighted BIM's 3D collision identification for electrical systems, which prevented two weeks of rework by identifying inefficient wiring layouts.

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CHAPTER 92

Legal Compliance in Construction of Tunnel: Issues and Challenges

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ABSTRACT

Tunnel projects are crucial for infrastructure development and economic growth in India, where over 1000 such projects are currently underway, it is essential to understand and be aware of the legal as well as technical challenges faced during tunnel construction, since delays of these projects can have cascading impact on Indian economy. This study underscores the technical and technical challenges encountered, drawing lessons from the Mumbai-Ahmedabad High-Speed Rail (MAHSR), Pillur III Water Tunnel Project in Coimbatore. It highlights issues such as delays in completion and cost overruns due to complex regulatory clearances, land acquisition, and geological uncertainties that can disrupt progress. To mitigate these challenges, the study recommends for streamlined approval processes through Single Window Systems, comprehensive geological surveys prior to construction, the adoption of the Construction Manager at Risk (CMAR) model, better pre-construction surveys and improved dispute prevention mechanisms.

Keywords: Regulatory clearances; Land acquisition; Geological uncertainties; Single window systems; Legal challenges.

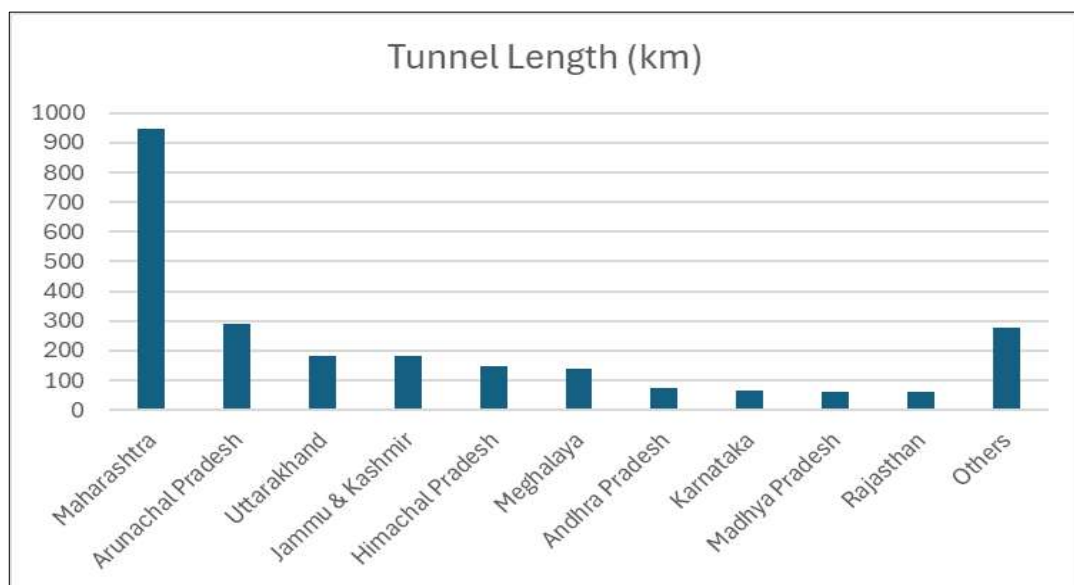
1.0 Introduction

With the Union Budget 2023-2024 allocating ₹7.5 lakh crore for capital expenditure, these investments are critical to boosting economic productivity. Currently, 1,726 tunnels spanning 3,600 km are in various stages of development. Approximately 75% (by number) and 62% (by length) of these have been completed, while 22% (number) and 36% (length) are under construction. The remaining 3% (number) and 2% (length) have been recently awarded. However, delays due to technical and legal challenges threaten to disrupt this progress, potentially causing cascading economic impacts. Addressing these issues is imperative to sustain the sector's growth and align it with India's infrastructure ambitions (New building materials & construction world, 2024).

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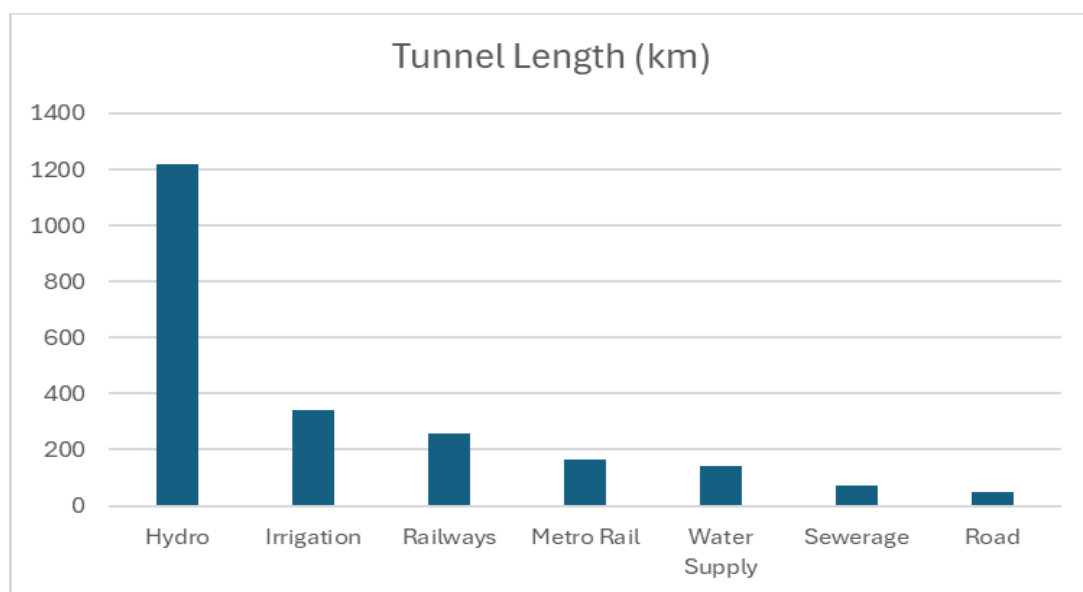
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Figure 1: State-wise Upcoming Tunneling Projects in the Pipeline - In Terms of Tunnel Length (km)



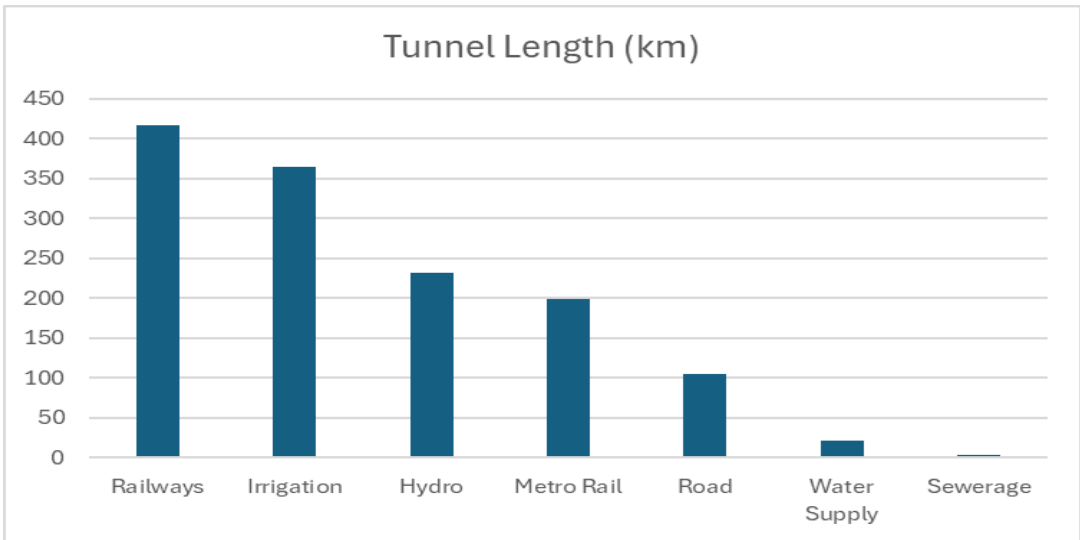
Source: What's driving growth of India's tunnelling industry: New building materials & construction world, 2024

Figure 2: In Terms of Completed Tunnel Length- Sector-wise



Source: What's driving growth of India's tunnelling industry: New building materials & construction world, 2024

Figure 3: Under Construction Tunnel Length- Sector-wise



Source: What’s driving growth of India’s tunnelling industry: New building materials & construction world, 2024

2.0 Methodology

This study adopts a dual-method approach combining doctrinal and non-doctrinal methodologies. The doctrinal method involves analyzing legal documents such as statutes, case laws, academic articles, and government reports to evaluate the legal framework for tunnel construction. This analysis identifies gaps in current regulations and compares them with global practices to propose improvements. The non-doctrinal method is based on practical insights gained from an internship at the Pillur III Water Tunnel Project in Coimbatore, Tamil Nadu. Data collection included daily site observations of construction activities such as drilling, blasting, and rock support installation. Contract documents and DPRs were reviewed to validate field observations. Additionally, a phone interview with the project manager of KSR Infracon provided insights into challenges like labor mobilization due to Covid, delays from Client side in providing Water-pipeline design. Validation processes involved cross-checking field observations with DPR data and interview responses to ensure accuracy and reliability. This integrated methodology provides a balanced perspective on the technical and legal aspects of tunnel construction.

3.0 Literature Review

Various studies highlight the multifaceted challenges in tunnel construction. Bommakanti, (2024) detailed the Kolkata Metro’s underwater tunnelling through difficult soil,

solved by specialized TBMs and watertight construction involving pre-cast segments and difficult grouting procedures. Gleason (2024) addressed workforce shortages impacting project execution, advocating for specialized education. Diwakar *et al.* (2022) emphasized geological risks in Himalayan tunnels like rock bursts and squeezing due to the region's low tolerance of geology, movements of tectonic plates, and the complexity of geological structure and composition, requiring enhanced surveys. Ayat *et al.* (2021) analyze 47 Pakistani tunnel projects, finding that geological uncertainties caused 63% of cost overruns, while procurement irregularities added 15-20% to timelines.

Vazquez *et al.* (2021) showcased Bois d'Arc Lake tunnel's wetland access solutions through CMAR which facilitated collaboration between the design team and the contractor, allowing for constructability reviews and identification of cost-saving opportunities. Wang *et al.* (2016) used modelling to address fault fracture zones' impact on tunnel stability, validating that the presence of a fault fracture zone significantly reduces the stability of the surrounding rock, making the tunnel more prone to collapse. Sharma *et al.* (2013) explored metro rail project selection balancing technical, financial, and social factors. Zhang *et al.* (2020) systematize 49 delay factors in Chinese subway tunnels, ranking 'unforeseen geological conditions' and 'TBM breakdowns' as the most severe (4.82/5 severity index), followed by financing delays (4.67) and design changes (4.53). The study by Ekasorn *et al.* (2024) evaluates structural risks to buildings near tunneling projects, focusing on soil movement-induced impacts. Using Bangkok's MRT Blue Line Project as a case study, it assesses pile settlements, differential settlements, and building angular distortion. The study highlights the role of accurate simulations in mitigating structural damage and ensuring building safety in dense urban areas.

4.0 Issues and Challenges

Tunnel construction faces several challenges. Land Acquisition Issues lead to delays due to resistance from landowners over the compensation valuation and resettlement measures, with the RFCTLARR Act, 2013 often faltering due to poor coordination and deficient framework. Regulatory Delays occur because projects require multiple approvals from authorities like the Fire Department, the Central Ground Water Authority (CGWA requiring NOCs for groundwater extraction), the Airport Authority of India (AAI mandated by the Aircraft (Amendment) Act, 2020), Coastal Zone Management Authority (CRZ governed by the Coastal Regulation Zone Notification, 2019), Archaeological Department (under the Ancient Monuments and Archaeological Sites and Remains Act, 1958), Forest Department (under the Forest Conservation Act, 1980), and National Board for Wildlife (governed by the Wildlife Protection Act, 1972), necessitating a single-window clearance mechanism to streamline the process. Disputes over Contractual Ambiguity related to risk allocation and geological uncertainties clauses, emphasizing the need for clear contract provisions. Technical Challenges arise from complex geology, skill gaps among TBM operators, and inadequate geological surveys, leading to unforeseen obstacles and costly delays.

4.1 Critical analysis of LARR Act, 2013

India's Land Acquisition, Rehabilitation and Resettlement (LARR) Act, 2013, while aiming to ensure fair compensation and transparency, faces critical challenges in implementation. The ambiguous definition of 'public purpose' under Clause 2 allows land acquisition for private ventures under public benefit claims, sparking disputes (Ashwin Mahalingam, Aditi Vyas, 2011). Compensation calculations rely on outdated land values (Indian Stamp Act, average sale prices) and lack clear criteria for 'similar land,' fostering litigation (Clause 26). States like Gujarat and Maharashtra exempt projects (defence, industrial corridors) from Social Impact Assessments (SIAs), prioritizing mutual consent and higher compensation, while 14 states (e.g., Assam, Rajasthan) have modified rules under Section 109, delegating land valuation and project execution to state committees (Amit Gupta, 2019). Rehabilitation provisions remain vague, with unresolved job guarantees for displaced families (Dhanmanjiri Sathe, 2015). Overlapping state-central laws and corruption further complicate implementation, leading to delays, inadequate resettlement, and hindered infrastructure projects like tunnels, as outdated compensation frameworks and procedural ambiguities fail to address direct/indirect costs or ensure timely resolutions.

4.2 Regulatory clearance

India ranks 63rd in the World Bank's Ease of Doing Business Index, reflecting significant challenges in fast-tracking regulatory clearances for large infrastructure projects. While financing, technology, and foreign investment approvals have improved, land and environmental clearances remain major bottlenecks. Environmental approvals, mandated by the Ministry of Environment, Forest, and Climate Change, are often delayed due to public interest litigations and NGO activism. Projects require multiple approvals from Central, State, and local authorities, including permits for utility relocation, tree cutting, and NOCs from various ministries, leading to poor coordination and conflicting requirements. Land acquisition and Resettlement & Rehabilitation (R&R) processes vary across states, further complicating implementation. For instance, delays in the Udampur-Ramban and Ramban-Banihal sections of NH-44 were caused by pending land acquisition, relocation of HT towers, clearance for tree felling, and shifting of a mosque (Civil Society vs State of Jk & Ors, 2021). Many approvals lack defined timelines, making project scheduling unpredictable and increasing costs while delaying completion.

4.3 Case laws

M/S The Exchange Agencies vs. Delhi Metro Rail Corporation Ltd., 2010, dealt with structural damage to an adjacent building during metro construction, with the Delhi High Court awarding ₹3,37,900 and 12% annual interest to the plaintiff, emphasizing mitigative strategies during tunneling. In Jamshed Noshir Sukhadwalla And 4 Ors vs. Union of India and 11 Ors, 2018, the Bombay High Court rejected a stay order sought to protect Zoroastrian fire temples from metro tunnel construction, prioritizing infrastructure development. Sivakumar vs. Chennai

Metro Rail Limited, 2019, involved residents opposing metro construction at Thiruvika Park; the Madras High Court dismissed their plea but directed park restoration and tree planting.

R.C. Joshua vs State Of Tamil Nadu, 2024, challenged land acquisition for a metro project under the Tamil Nadu Acquisition of Land for Industrial Purposes Act; the Madras High Court upheld the acquisition, interpreting 'industrial purpose' broadly. Civil Society vs State of JK & Ors, 2021, addressed delays in NH-44 sections due to land acquisition and forest clearances; the Jammu and Kashmir High Court directed coordination by the Chief Secretary and appointed a Nodal Officer for compliance. Afcons Infrastructure Ltd vs Nagpur Metro Rail Corporation Ltd., 2016, involved disqualification from bidding on a viaduct tender; the Supreme Court upheld NMRCL's decision, emphasizing deference to tender document interpretation. Lastly, Delhi Airport Metro Express Pvt. Ltd. vs Delhi Metro Rail Corporation Ltd., 2021, revolved around termination notice validity due to structural defects; the Arbitral Tribunal sided with DAMEPL, awarding substantial termination payment later restored by the Supreme Court.

4.3.1 PILLUR III Project, Coimbatore, Tamil Nadu, 2022

Pillur III Project in Coimbatore aimed to improve water supply by constructing a 900-meter tunnel through Kattan Hills. The methodology included a reinforced concrete portal, laser surveys, geological investigations via probe holes (assessing water and gases), and rock classification (Classes I-VI) determining the needed support systems. Trial blasts were conducted, and controlled blasting was performed using non-electric detonators with wet drilling for dust control. After blasting, rock surfaces were immediately cleaned using water or compressed air, and steel supports, rock bolts, and wire mesh were installed. Adverse Geological Occurrences were addressed with chemical grouting or ground freezing. Excavated materials were managed responsibly, drainage systems were implemented, and adequate site illumination was maintained. The Environmental Monitoring Plan controlled vegetation removal, managed earthworks and blasting activities, prevented soil erosion, and safely stored pollutants. Used newer, well-maintained vehicles, and fitted equipment to reduce air and noise pollution. Monitoring compliance with environmental requirements. Concluding, this study helped the researchers understand the technical challenges arising from a tunnel project.

4.3.2 Mumbai-Ahmedabad High-Speed Rail (MAHSR) project

The Mumbai-Ahmedabad High-Speed Rail (MAHSR) case study effectively addresses the objectives of analyzing technical and legal challenges in tunnel construction and evaluating regulatory compliance frameworks in India. Technically, the project highlights complexities like constructing India's first 21 km undersea tunnel using Tunnel Boring Machines (TBMs) to navigate geologically unstable zones and protect marine ecosystems. These engineering feats were overshadowed by legal hurdles, including protracted land acquisition under the RFCTLARR Act, 2013, which mandated Social Impact Assessments (SIAs) and prolonged negotiations with affected communities, particularly in Maharashtra and securing approvals

from 14+ agencies (e.g., MoEF&CC, NBWL) and litigation over mangrove destruction in CRZ-I zones, exemplify India's fragmented clearance processes. Delays in forest clearances (e.g., 21,997 mangroves destroyed, pending compensatory afforestation) and legal disputes over buffer zones around protected areas escalated costs by ₹50,000–70,000 crore and delayed completion by 5 years. The MAHSR case highlights the need for streamlined processes, such as single-window clearances, specialized tribunals for land disputes, to mitigate such delays in future infrastructure projects. For a developing nation like India, such inefficiencies in regulatory frameworks refrains foreign investment and halts any new infrastructure. Delays and cost overruns in such type of Capital heavy infrastructure can have cascading impact on our economy.

5.0 Conclusion

This study emphasizes the importance of addressing challenges in tunnel construction to avoid delays and cost overruns that can cause cascading impact on Indian economy. By analyzing real-world cases like the Kolkata Metro's underwater tunnelling challenges, Delhi Metro's structural defects, and Himalayan geological risks, key risks such as land disputes, contract ambiguities, geological uncertainties, and environmental concerns were identified. Proactive planning is essential, and best practices to mitigate these risks include implementing a Single Window System (SWS) for streamlined regulatory approvals (as seen in India's PM GatiShakti initiative). Managing Geological risks by deploying pre-construction surveys using Ground Penetrating Radar (GPR) and 3D seismic mapping, as employed in Kolkata's East-West Metro, alongside site-specific solutions like microseismic monitoring in the Himalayas and pre-excavation grouting for fault zones. The Construction Manager at Risk (CMAR) delivery model can be advantageous for tunnel projects because it involves the contractor early in the design phase, allowing for constructability reviews and identification of cost-saving opportunities without compromising design integrity. As followed in the Bois d'Arc Lake project, this collaborative approach between the owner, contractor, and design team enables proactive and collaborative problem-solving, efficient risk management, and timely delivery, making it well-suited to address the unique challenges and uncertainties in a typical tunnel construction. Urban design optimization through multi-criteria analysis to compare underground vs. elevated corridors using cost, security, and social impact metrics and standardized designs i.e., reusing designs for stations/tunnels wherever possible to cut costs and delays. Reduce costs, while big data-driven demand forecasting and phased construction prevent overinvestment.

Dispute prevention relies on precise contract terms (avoiding issues like Delhi Metro vs. DAMEPL) and joint inspections/third-party audits. Environmental safeguards like binding restoration plans and pre-committing to restoration of green space (Sivakumar vs. Chennai Metro Rail Limited, 2019) and structural protection measures to mitigate settlement issues caused by underground excavation preventing damage to adjacent buildings and infrastructure by maintaining soil stability and minimizing settlement helps mitigate litigation risks. Together,

these practices—spanning technical innovation, legal clarity, and community engagement—ensure tunnel projects align with India’s ambitious infrastructure vision, transforming delays into opportunities for sustainable growth and reinforcing infrastructure’s role as a catalyst for national development.

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CHAPTER 93

Leveraging BIM for Sustainable Construction Practices and Integrated Project Delivery

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Syeda Sara Fatima Quadri S.¹, Gaurav Pradeep Dubey¹ and Hindavi Tikate²*

ABSTRACT

The research proposal aims to promote and implement eco-friendly housing and construction practices, to address the growing concerns regarding sustainable design associated with the construction industry. By adopting sustainable building materials and environmentally friendly design approaches, we can differentiate as well as mitigate the negative impacts of construction on ecosystem. The application of Building Information Modeling (BIM) emerges as a powerful tool in project to address the challenges by enabling sustainable design and construction practices. This project investigates the potential of BIM to optimize building design for reduced environmental impact, improved resource efficiency, enhanced economic performance and promotes framework for energy efficiency. Evaluation of economic feasibility of BIM enabled sustainable construction, comparing upfront investments against long-term cost savings through operational efficiency and resource savings. The project outlines the primary objectives which consists of the barriers for the Sustainable Development in construction industry in questionnaire survey along with the activities undertaken to achieve project barriers in terms of research and Experimental methods, to anticipate the Expected outcomes by implementing the Sustainable Design and BIM tool that transform the Construction Industry by integrating Sustainability principles into every phase of building's lifecycle. Also improve construction site efficiency and reduce waste generation, leading to cost savings and environmental benefits.

Keywords: BIM; Economy; Energy efficiency; Sustainability; Systematic literature Review.

1.0 Introduction

1.1 Background and context

Architecture, engineering, and construction (AEC) is changing dramatically in favour of sustainable methods. Traditional design techniques have challenges in meeting the needs for decreased ecological footprint and resource efficiency as the environmental impact of buildings becomes more apparent.

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In this context, Building Information Modelling (BIM) emerges as a transformative technology with the potential to revolutionize sustainable design and construction (Ning GU, 2010). The importance of BIM in accomplishing sustainable construction objectives will be covered in detail in this chapter. We'll start by discussing the growing significance of sustainability in the AEC sector and the environmental problems caused by traditional building methods. We will then review the fundamental features and capabilities of building information modelling. To prepare for a more thorough analysis of the factors that encourage and hinder its use, we will conclude by giving a summary of how BIM might support sustainable design and construction. There is growing concern about the necessity of acknowledging the significance of sustainable construction. The goal of sustainable construction can be greatly aided by the cutting-edge technologies used in the sector. There are many different sustainability rating systems in use worldwide, but they all strive to enhance a building's overall performance to meet the objectives of establishing a healthy built environment. Green construction initiatives present obstacles and problems for Building Information modelling (BIM). The requirement for standards and rules, a lack of BIM knowledge and experience, the high expense, and a lack of research and BIM implementation are some of the difficulties. Non-uniform data formats, a lack of interaction, unclear ownership, inadequate BIM training, and reluctance to adopt BIM are some of the obstacles to using BIM in the construction of green buildings. The perception of extra effort during implementation and a lack of client demand are two possible drawbacks of BIM in green construction projects. These obstacles and difficulties make it difficult to apply BIM effectively in green construction projects, which affects the overall sustainability objectives, cooperation effectiveness, and project quality. Policymakers and construction personnel should address these challenges and barriers to promote the utilization and optimization of BIM capabilities in the construction of green buildings (Kineber *et al.* 2023).

1.2 Research objectives

There is a great chance to address the environmental issues facing the AEC sector by combining sustainable design principles with Building Information Modelling (BIM). The objective is to find research papers and journals that address the integration of sustainable construction practices with integrated project delivery (IPD) using PRISMA:

- To assess the research methodology, hypotheses, traits, and contextual background.
- To determine effective tactics and barriers to their implementation.
- To make recommendations for future research directions on how to improve the construction industry's integration of sustainable construction methods and integrated project delivery (IPD).

1.3 Research problems

There is a great chance to address the environmental issues facing the AEC sector by combining sustainable design principles with Building Information Modelling (BIM).

Nonetheless, several important research issues necessitate additional study:

- *Quantification of sustainability benefits:* In order to support sustainable decision-making throughout the design stage, this study will investigate how BIM can be integrated with performance simulations and life-cycle assessment tools.
- *Interoperability and data exchange:* It's possible that sustainability assessment tools and current BIM software programs can't interchange data easily. The technical issues surrounding interoperability will be examined in this study, along with potential solutions for effective data sharing and teamwork over the project lifecycle.
- *Skill and knowledge gaps:* This study will pinpoint the knowledge gaps and suggest ways to modify training curricula to close them and promote a sustainable design culture in the AEC sector that incorporates BIM.

This study aims to explore the potential benefits of Building Information Modelling (BIM) for environmentally friendly construction practices. By analysing and incorporating research paper findings, the study will look into how BIM encourages resource efficiency, energy optimization, and waste reduction throughout the project lifespan. Important subjects, including BIM's capacity to improve energy efficiency modeling, integrate with green building materials, and support sustainable design, will be the focus of the examination. To provide users with a comprehensive grasp of how BIM impacts sustainability in the building industry, a wide range of case studies, technical advancements, and frameworks are covered in the selected literature.

The growing global awareness for sustainable construction techniques has led to substantial advancements in Building Information Modelling (BIM) technology. The interdisciplinary platform that BIM provides for cooperation ensures better project outcomes and supports sustainable development initiatives. The potential of BIM to enhance structural design, increase energy efficiency, and speed up the building process has been extensively studied. To solve the issues of carbon emissions, resource management, and lifecycle cost optimization in construction projects, the integration of sustainability ideas with BIM has shown to be crucial (Motawa and Carter 2013).

2.0 Literature Review

2.1 Introduction to literature review

The reviewed papers explore various aspects of Building Information Modeling (BIM) and its possible interaction with technology to enhance the sustainability and efficiency of buildings. One research shows how BIM and IoT can be applied to logistics and facility control, highlighting the need for more case studies and practical uses (Tang, Sheldon *et al.* 2019). Another addresses challenges to BIM adoption in developing nations, like limited government support, and promotes a larger range of case studies beyond those from China, India, and Malaysia (Bui *et al.* 2016).

The benefits and drawbacks of BIM are looked at in further detail in a number of contexts, particularly difficulties with interoperability and the need for greater industry and academic interaction (Costin *et al.* 2018). The paper highlights the benefits of BIM and IPD and proposes more case studies for enhancing understanding of sustainable practices (Oraee *et al.* 2019). The investigations focus on the benefits and challenges associated with implementing Building Information Modeling (BIM) in the construction industry.

One study finds 28 connections among BIM abilities and legal structures to enhance understanding of contractual challenges (Abd Jamil & Fathi 2018). Another addresses the insufficient use of BIM in Malaysia, bringing out advantages like better scheduling and cost control, but also difficulties with interoperability and a skills gap. Additional study suggests that in order to enhance design partnership and project management, technical and legal barriers have to be addressed (Azhar *et al.* 2008). In order to promote adoption, an analysis carried out in Hong Kong identifies barriers like the lack of industry standards and recommends setting up specialist BIM departments and training efforts (Chan *et al.* 2019). Another study highlights companies a refusal to create new BIM models due to contractual constraints, yet praising advances in internal protocol (Farnsworth *et al.* 2015). Ultimately, study on Sustainable Construction Management Practices shows the value for ongoing training, involvement of stakeholders, and rules regarding procurement that emphasize sustainability for effective implementation (Goel *et al.* 2019).

Every study shows that effectively applying BIM may lead to major benefits in project delivery and makes suggestions for future government support. (Liao & Teo 2017). The research explores the advantages and uses of Building Information Modeling (BIM) to increase efficiency and sustainability in the building industry. Another study gives information on a real-world example and suggests frameworks for post-occupancy evaluations and energy simulations (Motawa & Almarshad 2013) and use of Case-Based Reasoning in conjunction with BIM to improve maintenance methods (Motawa & Almarshad 2013). Also, research gives more recent case studies by highlighting the potential of BIM in the AFC sector and looks at historical trends (Latiffi *et al.* 2014). This paper generally highlights the value of BIM in project management, reduction in wastage, and increasing efficiency in the building industry.

Research has been conducted on collaboration and sustainability techniques used in the building industry. They relate the BIM to Integrated Project Delivery (IPD) and emphasize how it enhances collaboration, low errors, and maximizes the resources used while suggesting further research be done on implementation difficulties (Zou *et al.* 2017). There are obstacles to using BIM like financial constraints, complexity, and lack of knowledge (Manzoor *et al.* 2021). Further research visualizes how programs (like Autodesk) will improve energy and resource efficiency (Khan & Ghadg 2019). They find the connection between the usage of BIM and environmentally friendly building practices, using structural equation modeling to fix the key variables in nations like China and Nigeria (Manzoor *et al.* 2021). Lastly, analyses highlight how BIM can evaluate sustainability standards, automate assessments, and improve project

design decision-making (Carvalho *et al.* 2019), also it tackles the non- technical and technical obstacles to prevent the AEC sector from using BIM (Gu & London 2010).

Table 1: Barriers to Implementing BIM for Sustainable Construction with Decarbonisation & Circularity

Sr. No.	Parameters	Codes	Authors and Year
1	Lack of understanding hampers sustainability adoption	BBIM1	Häkkinen, 2011.
2	High initial cost deters sustainable practices.	BBIM2	Liu, 2015
3	Costly errors for circular construction.	BBIM3	Azhar, 2008
4	Insufficient market demand for BIM-based sustainable practices.	BBIM4	Walasek, 2017
5	Difficulty in justifying the long-term ROI for decarbonization.	BBIM5	Liu, 2015
6	Economic downturn reduces BIM investment for sustainability.	BBIM6	Abdalla, 2021
7	Lack of Standards and Guidelines for Sustainable Practices.	BBIM7	Memon, 2014
8	Inequities in workforce development limit the participation of marginalized groups.	BBIM8	Azman, 2014
9	Lack of equity policies hinders the progress of sustainable construction.	BBIM9	Häkkinen, 2011
10	Complex and unclear environmental regulations.	BBIM10	Rahman, 2014
11	Insufficient human resources with expertise	BBIM11	Carvalho, 2019
12	Difficulty in integrating sustainability with financial tracking systems.	BBIM12	Walasek, 2017
13	Requires a longer project timeline, leading to higher costs.	BBIM13	Khan, 2019.

Table 2: Risk Factors for Implementing BIM for Sustainable Construction with Decarbonization & Circularity

Sr. No.	Parameters	Codes	Authors and Year
1	Fluctuating Market Conditions	RBIM1	Khan, 2019.
2	Increased complexity of projects	RBIM2	Mok, 2008
3	Insufficient management support for sustainability	RBIM3	Liao, 2017
4	Project complexity may cause errors	RBIM4	Leung, 2008
5	Neglecting comprehensive life-cycle assessments.	RBIM5	Wong, 2015
6	Focus on short-term costs over sustainability.	RBIM6	Barszcz, 2017
7	Risk of data breaches and loss.	RBIM7	Jones, 2017
8	Managing diverse sustainable construction regulations.	RBIM18	T. & Belloni, 2011.
9	Integrating BIM with existing systems is difficult.	RBIM9	Migilinskas, 2013
10	Challenges in tracking sustainability metrics.	RBIM10	Motawa, 2013

Table 3: Success Factor to Implement BIM for Sustainable Practices with Decarbonization & Circularity

Sr. No.	Parameters	Codes	Authors and Year
1	Evaluates embodied carbon of materials	SBIM1	Khan, 2019
2	BIM aids in reducing lifecycle emissions	SBIM2	Singh, 2011
3	Optimizes energy via simulations.	SBIM3	Wu, 2017
4	Encourages reuse, lowers environmental impact.	SBIM4	Almarshad, 2013
5	Facilitates disassembly and material recovery.	SBIM5	Bragança, 2019
6	Supports circular economy building design	SBIM6	Azhar, 2009
7	BIM tracks sustainability performance metrics.	SBIM7	Barszcz, 2017
8	Enables decisions via environmental assessments.	SBIM8	Carvalho, 2019
9	Enhances transparency of construction's environmental impact.	SBIM9	Zanni, 2017.
10	BIM adoption driven by policies.	SBIM10	Othman, 2021.
11	Clear KPIs foster accountability, improvement	SBIM11	RRA Issa, 2009
12	Clear data protocols improve interoperability	SBIM12	Chen, 2018
13	IPD enhances collaboration and decisions.	SBIM13	Latiffi, 2014

3.0 Methodology

3.1 Research methodology

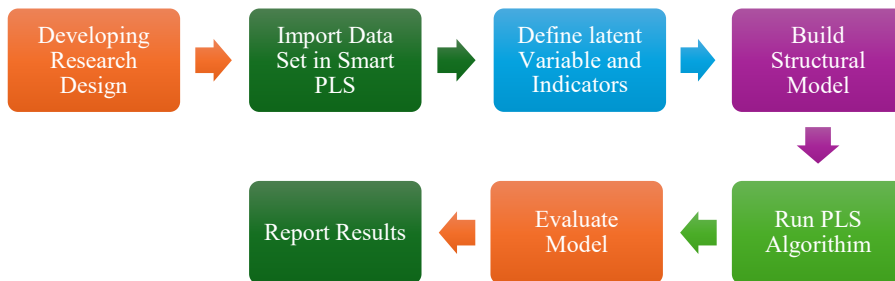
A detailed research design was created following the conclusion of the literature review to act as a guide for the investigation, detailing the goals, methodology, sample strategies, and data gathering methodologies. Then, using the knowledge gleaned from the literature research, a thorough questionnaire was meticulously created to guarantee that pertinent data could be efficiently collected. To guarantee the precision and dependability of the information gathered, data collection was then conducted methodically with a well-defined sample in mind. This study follows a quantitative research approach using Structural Equation Modeling (SEM) via Smart PLS to analyze the relationships between variables.

The research investigates how Building Information Modeling (BIM) Contributes to sustainable Construction Practices and Integrated project delivery. The Conceptual model consists of BIM Implementation as the independent variable, Sustainability practices and integrated project delivery as mediating variable and project performance as the dependent variable. The following hypothesis are proposed to analyze the data.

Once the research design is finalized, the data set is imported into Smart PLS, a specialized software for PLS-SEM analysis. Next latent variables and indicators are defined ensuring that the constructs used in the model are appropriately specified and measured. Subsequently, a structural model is built, establishing the relationship between the latent variables.

To assess the model, the PLS algorithm is executed, which computes path coefficients and evaluated the strength of relationships within the model. Following this, the model is evaluated using reliability, validity and Cronbach's alpha value to ensure its robustness and accuracy. Finally, the results are reported, interpreting key findings and drawings conclusions based on the analysis. This methodology ensures a systematic and rigorous approach to examining the research hypothesis.

Figure 1: Proposed Hypothesis



3.2 Hypothesis

Based on the findings of the literature review, the following hypothesis was formulated. The creation of the questionnaire as well as the techniques of data collecting and analysis, were all influenced by this hypothesis.

- *Hypothesis 1:* Barriers to BIM Implementation (BBIM) negatively influence Leveraging BIM for Sustainable Construction & Integrated Project Delivery (LBIM).
- *Hypothesis 2:* Leveraging BIM for Sustainable Construction & Integrated Project Delivery (LBIM) is adversely affected by Risk Factors in BIM Implementation (RBIM).
- *Hypothesis 3:* Leveraging BIM for Sustainable Construction & Integrated Project Delivery (LBIM) is positively impacted by Success Factors for BIM Implementation (SBIM).
- *Hypothesis 4:* Barriers to BIM (BBIM) and Risk Factors in BIM (RBIM) have an indirect negative influence on leveraging BIM for Sustainability (LBIM) through Success Factors for BIM (SBIM) as a mediating variable.

3.3 Data collection

3.3.1 Sampling strategy

The sample approach used for this study focused on well-known construction industry specialists to streamline the data collection process. Data were gathered regardless of the respondents' geographic location, other demographic characteristics, or their particular area of competence within the construction industry. Based on professionals' knowledge and

comprehension of the industry overall, this technique was chosen to collect a wide range of perspectives. The approach made sure that the responses represented knowledgeable viewpoints on the research topic by concentrating on seasoned people. 110 samples in all were collected for analysis, offering a thorough foundation for evaluating the results.

3.3.2 Questionnaire design

The questionnaire was designed to assess respondents' qualification, experience and knowledge of BIM in sustainable construction, focusing on three main areas; barriers, risk factors and success factors related to decarbonisation and circularity. Responses were collected using a 5-point Likert scale ranging from "Strongly Agree to Strongly Disagree". The survey was created using Microsoft Forms for ease of use and visualization, with data exportable to MS excel for further analysis.

3.3.3 Data collection strategy

A standardized questionnaire was used to collect primary data, and it was sent by email, WhatsApp, and LinkedIn to prominent construction industry individuals. To gather both quantitative and qualitative data, the survey had a combination of closed-ended and open-ended questions. To promote truthful answers, confidentiality was guaranteed, and an attempt was made to keep the questionnaire simple and short. This method made sure that the information gathered was trustworthy and pertinent for additional study.

4.0 Data Analysis

4.1 Descriptive analysis

The section aims to systematically examine and interpret the data collected to address the research objectives outlined earlier. In this study, the focus is on evaluating the integration of Building Information Modeling (BIM) with sustainable design practices within the construction industry. The parameters for the analysis were meticulously identified through an extensive review of existing literature, encompassing insights from numerous research papers. These parameters serve as a foundation to assess the effectiveness, challenges, and opportunities associated with BIM implementation for achieving sustainability goals. Through an analysis of survey responses from seasoned professionals, this part aims to identify trends, connections, and important variables affecting the adoption of BIM and how it affects sustainable building practices. The results' interpretation will aid in comprehending the useful applications of BIM and offer practical advice for improving project outcomes and promoting ecologically friendly building practices.

4.2 Smart PLS analysis

Smart PLS was used to analyse the data that was gathered. Because of its efficiency in managing intricate models with several variables and its capacity to yield trustworthy outcomes

even with comparatively small sample sizes, this approach was chosen. Four different models were created based on the data gathered, using a range of independent factors to investigate how they affected the results. To provide a thorough grasp of the underlying linkages, each model was created to capture distinct facets of the study subject. These models' specifics and justifications are shown below.

4.2.1 Structure equation model

SEM model on BIM implementation for sustainable construction:

Independent Variables (Exogenous Constructs)

- Barriers to BIM Implementation (BBIM)
- Risk Factors in BIM Implementation (RBIM)

Mediating Variable: This variable acts as a bridge, influencing the dependent variable:

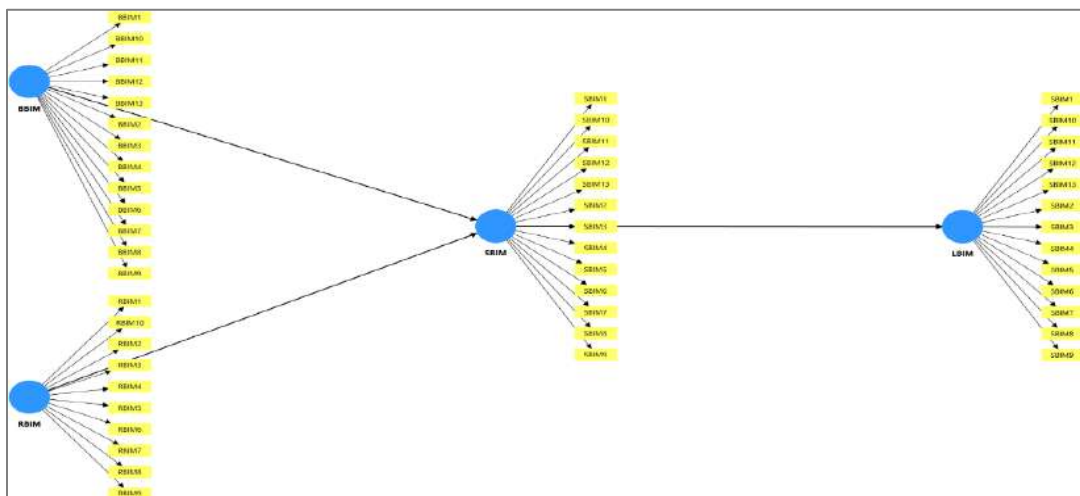
- Success Factors for BIM Implementation (SBIM)

Dependent Variable (Endogenous Construct): This is the outcome influenced by other variables:

- Leveraging BIM for Sustainable Construction & Integrated Project Delivery (LBIM)

4.3 Hypothesis testing

Figure 2: PLS Model

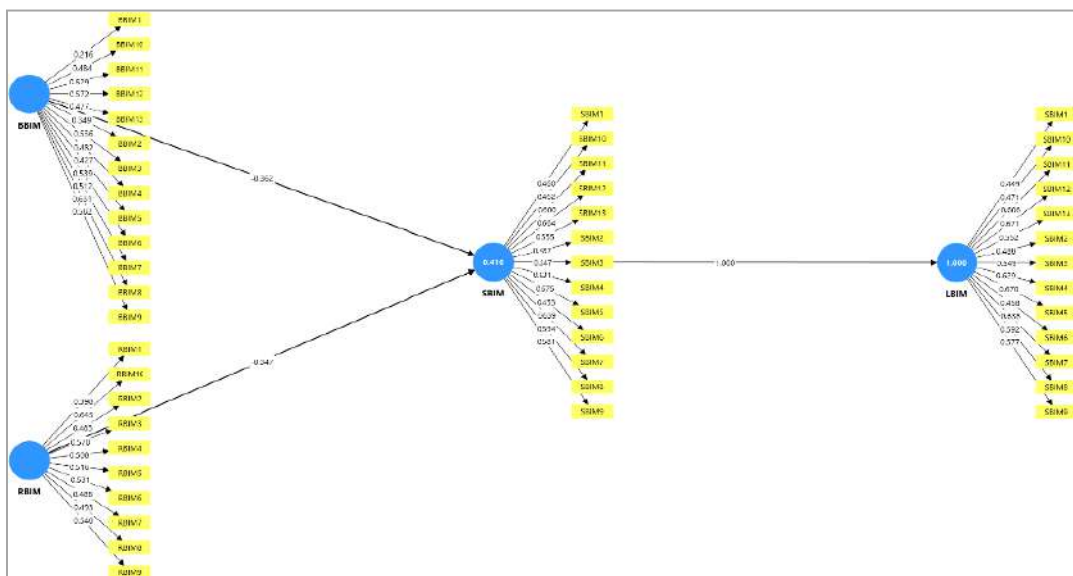


4.3.1 Measurement model assessment

To guarantee the accuracy of the findings, the validity and reliability of the constructs employed in the structural model were assessed under this model. By looking at the outer loadings of each observable variable connected to the latent constructs, indicator reliability was

evaluated; values greater than 0.7 were considered acceptable. Cronbach's alpha and composite reliability were also used to assess internal consistency reliability; both of these metrics were above the suggested cutoff point of 0.7, indicating that the items were consistent. Figure 3 shows that the Leveraging BIM for Sustainable Construction & Integrated project delivery is not significantly impacted by the Barriers to BIM implementation (BBIM), but the path coefficient (β) is negative for BBIM $\rightarrow$ SBIM due to the reversal of the likert scale (Strongly disagree, disagree, neutral, agree, strongly agree) for the BIM success factors (SBIM). This implies that obstacles by themselves do not significantly affect the adoption of BIM for sustainability. Rather, SBIM (Success factors for BIM) mediates their influence.

Figure 3: PLS-SEM Algorithm Graphical Output



4.3.2 Model evaluation

Reliability & Validity Checks Requirement:

- Cronbach's Alpha (>0.7), Composite Reliability (>0.7).
- AVE (Average Variance Extracted) > 0.5.
- Fornell-Larcker Criterion for discriminant validity.

Overview: Convergent dependability issues are indicated when AVE values are less than 0.5. Poor validity is shown by BBIM's (0.248) and RBIM's (0.271) excessively low AVEs, as seen in Figure 4.

4.3.3 Cronbach’s alpha – Bar chart

The result for each construct meets the acceptable threshold (>0.7), according to the Cronbach’s Alpha Bar chart in Figure 5. However, if RBIM is closer to the lower limit, the reliability of the indicator may need to be reconsidered.

Figure 4: Construct Reliability and Validity Overview

Construct reliability and validity - Overview					Copy to Excel/Word	Copy to R
	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (A...		
BBIM	0.748	0.755	0.804	0.248		
LBIM	0.823	0.832	0.860	0.325		
RBIM	0.704	0.699	0.786	0.271		
SBIM	0.823	0.832	0.860	0.325		

Figure 5: Cronbach’s Alpha- Bar Chart

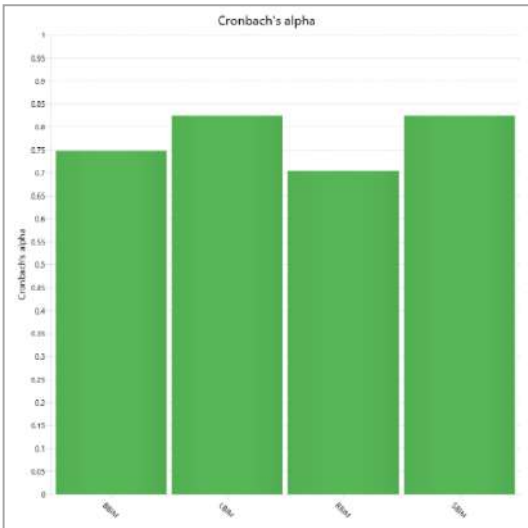
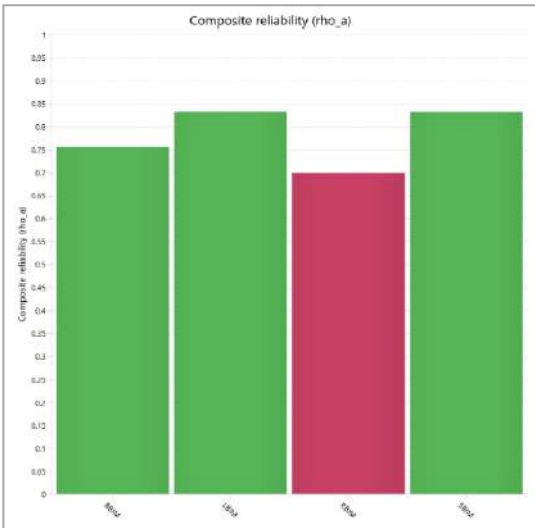


Figure 6: Composite Reliability (rho_a) - Bar Chart



4.3.4 Composite Reliability (rho_a) – Bar chart

RBIM has a composite reliability of 0.699, which is below 0.7, this means RBIM does not exhibit strong internal consistency while other constructs are above 0.7, indicating good reliability (Figure 11).

4.3.5 Composite Reliability (rho_c) – Bar chart

Figure 7 confirms the internal consistency of constructs where all the values are above 0.7 which is good.

4.3.6 Average Variance extracted (AVE) – Bar chart

The AVE indicated that the values for constructs are below the acceptable threshold of 0.5 as shown in Figure 8. This suggests that the constructs may not adequately explain the variance in the respective indicators, raising concerns about the poor convergent validity of the measurement model.

Figure 7: Composite Reliability (rho_c) - Bar Chart

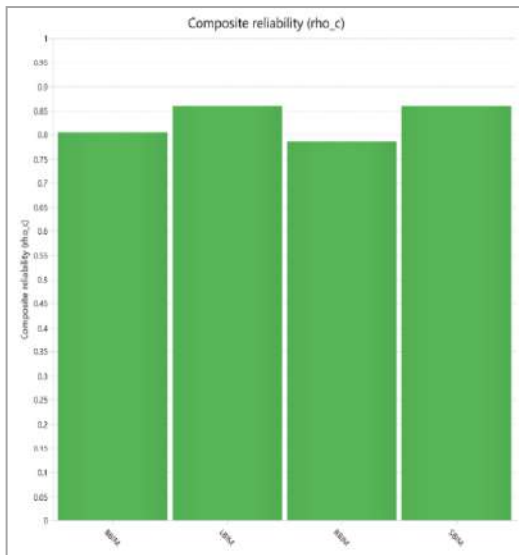
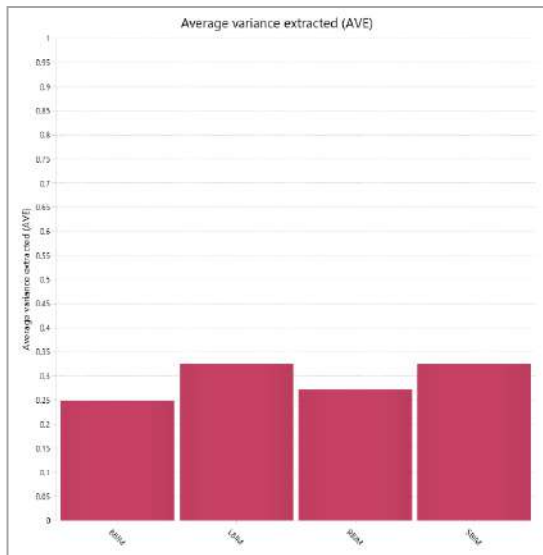


Figure 8: Average Variance Extracted (AVE)- Bar Chart



4.3.7 Fornell – Larcker Criterion for discriminate validity

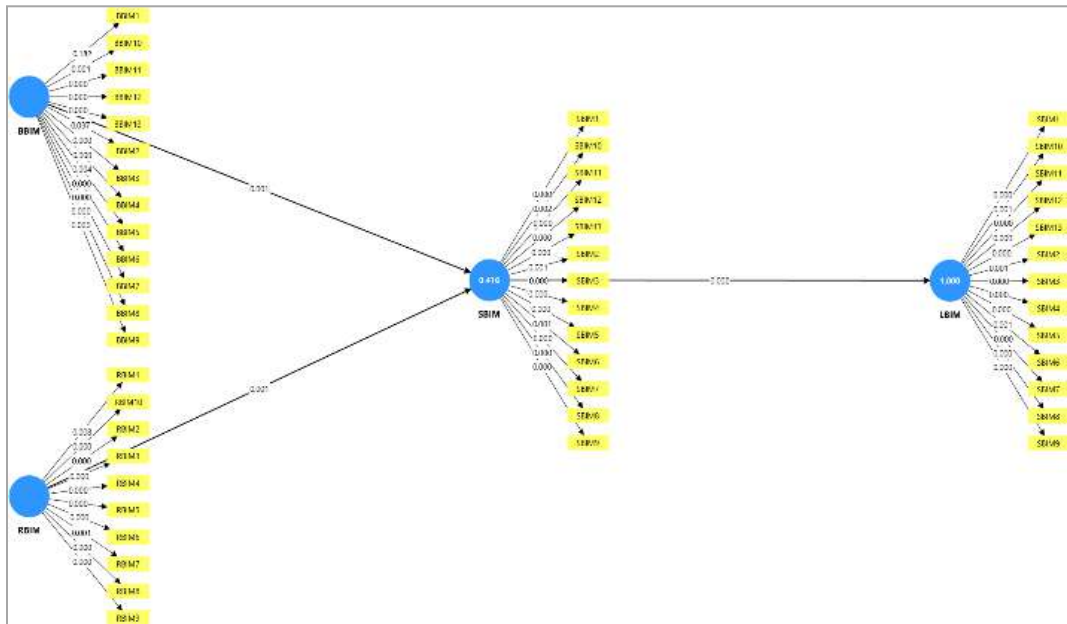
In contrast, BBIM's score, 0.498 (see Figure 9), is lower than its correlations with other constructs, indicating poor discriminant validity, and the diagonal values are bigger than the off-diagonal values.

Figure 9: Fornell-Larcker Criterion for Discriminant Validity

Discriminant validity - Fornell-Larcker criterion				
	BBIM	LBIM	RBIM	SBIM
BBIM	0.498			
LBIM	-0.585	0.570		
RBIM	0.656	-0.581	0.521	
SBIM	-0.589	1.000	-0.584	0.570

4.3.8 Parth coefficients and significance

Figure 10: Bootstrapping Graphical Output



4.3.9 Path coefficients (β) and p-values

- Go to “Bootstrapping” (5000 samples, 0.05 significance level).
- $p < 0.05$ means the hypothesis is significant.

The path coefficients (β) and p-values indicate statistical significance. The p-values for BBIM $\rightarrow$ SBIM (-0.362, $p=0.001$), RBIM $\rightarrow$ SBIM (-0.347, $p=0.001$), and SBIM $\rightarrow$ LBIM (1.000, $P=0.001$) confirm that these relationships are statistically significant. Consequently, the hypothesis is validated as substantial.

4.3.10 Mediation Analysis (H4)

- Check indirect effects (BBIM $\rightarrow$ SBIM $\rightarrow$ LBIM and RBIM $\rightarrow$ SBIM $\rightarrow$ LBIM).
- If $p < 0.05$, mediation is supported.

The mediation analysis (Figure 12) confirms that the relationships BBIM $\rightarrow$ SBIM $\rightarrow$ LBIM and RBIM $\rightarrow$ SBIM $\rightarrow$ LBIM are significant. Since the p-values are below 0.05, mediation is validated. This supports hypothesis H4, indicating that BBIM and RBIM negatively impact LBIM through SBIM.

Figure 11: Path Coefficients

Path coefficients - Mean, STDEV, T values, p values						Copy to Excel/Word	Copy to R
	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (O /STDEV)	P values		
BBIM -> SBIM	-0.362	-0.405	0.113	3.206	0.001		
RBIM -> SBIM	-0.347	-0.346	0.105	3.298	0.001		
SBIM -> LBIM	1.000	1.000	0.000	3474.228	0.000		

Figure 12: Specific Indirect Effects

Specific indirect effects - Mean, STDEV, T values, p values						Copy to Excel/Word	Copy to R
	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (O /STDEV)	P values		
BBIM -> SBIM -> LBIM	-0.362	-0.404	0.113	3.206	0.001		
RBIM -> SBIM -> LBIM	-0.347	-0.346	0.105	3.299	0.001		

4.4 Conclusion

Hypothesis	Result	Ref.
Hypothesis 1: Barriers to BIM Implementation (BBIM) negatively influence Leveraging BIM for Sustainable Construction & Integrated Project Delivery (LBIM).	False	Hypothesis 1
Hypothesis 2: Risk Factors in BIM Implementation (RBIM) negatively influence Leveraging BIM for Sustainable Construction & Integrated Project Delivery (LBIM).	False	Hypothesis 2
Hypothesis 3: Success Factors for BIM Implementation (SBIM) positively influence Leveraging BIM for Sustainable Construction & Integrated Project Delivery (LBIM).	True	Hypothesis 3
Hypothesis 4: Barriers to BIM (BBIM) and Risk Factors in BIM (RBIM) have an indirect negative effect on Leveraging BIM for Sustainability (LBIM) through Success Factors for BIM (SBIM) as a mediating variable.	True	Hypothesis 4

5.0 Conclusion

Using Building Information Modelling (BIM) in sustainable building offers a significant chance to maximize resource management, lower carbon emissions, and improve energy efficiency. According to research, building information modelling (BIM) enables stakeholders to collaborate on projects and make well-informed decisions at every stage of a building's lifecycle. Building information modeling encourages creative solutions that support decarbonization and economic feasibility by incorporating sustainable practices into the design

and construction stages. Nevertheless, obstacles, including the substantial upfront cost, the requirement for qualified personnel, and opposition to change, may prevent its broad adoption. To fully utilize BIM in the creation of sustainable built environments, it is necessary to overcome these challenges. In the end, the building sector can greatly contribute to a more sustainable future if it adopts BIM while improving operational efficiencies and reducing environmental impacts. The final interpretation of analysis reveals that H1 & H2 are not supported, indicating that BBIM and RBIM do not have a direct significant negative effect on LBIM. However, H3 is supported, confirming that SBIM positively influences LBIM. Additionally, H4 is validated, showing that SBIM successfully mediates the relationship between BBIM, RBIM, and LBIM. This highlights the importance of addressing success factors (SBIM) as a crucial element in enhancing BIM adoption within sustainable construction.

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CHAPTER 94

Location Choice for Real Estate

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ABSTRACT

This study examines the factors influencing location choice in real estate development from the developers' perspective. The primary objective is to identify and evaluate the key determinants that guide developers in selecting sites for residential and commercial projects. The research employs a mixed-methods approach, combining a survey of few real estate developers with in-depth interviews with industry experts. The findings reveal that proximity to infrastructure, accessibility to transportation, and socio-economic demographics of the area are the most significant factors considered by developers. Additionally, market demand, land acquisition costs, and regulatory policies also play critical roles in location selection. The analysis indicates that developers prioritize locations that offer growth potential and low-risk investment opportunities, while also balancing economic viability with community needs. This research contributes to a deeper understanding of decision-making processes in the real estate sector and provides insights for policymakers and urban planners. By aligning development strategies with developers' location preferences, more sustainable and strategically planned urban growth can be achieved.

Keywords: Real estate development; Location choice; Developers' perspective; Urban planning; Market demand.

1.0 Introduction

1.1 Background

The selection of an optimal location is critical for successful real estate development, especially amid rapid urbanization and sector growth, which drive demand for residential, commercial, and mixed-use projects while presenting challenges like land scarcity and congestion. Key factors influencing location decisions include connectivity, infrastructure, market demand, investment potential, and future development opportunities, as well as proximity to social amenities like schools, healthcare, and commercial hubs (Zhang *et al.*, 2023; Bai *et al.*, 2024). spaces play a vital role in attracting buyers and investors (Raza *et al.*, 2022; Rahmati *et al.*,).

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Additionally, environmental considerations, government regulations, pricing trends, and cultural and lifestyle preferences such as vibrant communities and recreational 2024; Kauko, 2006). Understanding these factors help developers, investors, and policymakers make informed decisions that align with market trends and urban development goals.

1.2 Aim and objective

The aim of this research is to develop a comprehensive location assessment framework for real estate development. The study's objectives include identifying key location assessment parameters from literature, evaluating selected sites based on physical parameters through observation and expert opinion, and ultimately recommending critical aspects that influence location decisions along with a structured assessment process. This framework will assist developers, planners, and investors in making informed site selection choices aligned with market and urban development needs.

1.3 Study area and market analysis

This study examines four strategic real estate markets across Pune and Mumbai, each with distinct characteristics and investment potential. Koregaon Park in Pune represents a premium, established market for luxury residential and commercial projects, benefiting from its vibrant urban lifestyle and IT sector proximity. Mahalunge, also in Pune, emerges as an attractive mid-market option with affordable pricing and promising infrastructure development near key IT corridors. In Mumbai's metropolitan region, Ghansoli stands out as a rapidly developing mixed-use hub with strong corporate demand, while Palghar offers budget-friendly residential opportunities supported by upcoming port infrastructure. The analysis highlights how Pune's market is primarily driven by IT sector growth, whereas Mumbai's development is more influenced by large-scale infrastructure projects. Both cities demonstrate the critical importance of connectivity, local amenities, and future development potential in shaping real estate values and investment decisions, with each location catering to specific market segments ranging from luxury buyers to value-conscious investors.

2.0 Literature Review

2.1 General

The literature review highlights the critical role of location choice in real estate development, emphasizing economic, social, and environmental factors. Classical theories by Von Thünen & Alonso (1964) provide foundational insights into spatial dynamics, while modern research underscores the influence of urbanization, infrastructure, and market demand (Zhang *et al.*, 2023; Bai *et al.*, 2024). Key parameters include accessibility (proximity to transport hubs), neighborhood characteristics (safety, amenities), and future development potential (Raza *et al.*, 2022). Micro-market trends, such as localized demand for schools or

commercial hubs, further refine site selection (Kauko, 2006). Case studies, like Mumbai's Bandra-Worli Sea Link, demonstrate how infrastructure projects can transform real estate markets by improving connectivity and boosting property values. The literature collectively stresses a balanced assessment of physical, economic, and regulatory factors to optimize location decisions.

2.2 Literature parameters

Neighborhood, Accessibility, Traffic Dynamics, Comparable Homes (If Residential), Public Transportation, Amenities, Hospital/Schools, Safety and Security/Police Station, Natural Environment, Local job market, Cost and Availability, Buyers/User preference, Future Development Plans (Developers Perspective)

3.0 Methodology

This study employed a six-step methodology to evaluate four strategic real estate locations across Pune and Mumbai, representing diverse market segments from premium to affordable developments. Key parameters including neighborhood quality, accessibility, amenities, and future potential were identified through literature review and tailored to different project types.

Figure 1: Site Images



Source: Google Earth

On-site surveys assessed physical conditions and infrastructure, supplemented by digital traffic analysis. Expert opinions from real estate professionals were collected using a standardized 1-3 scoring system, with results aggregated into suitability matrices for comparative analysis. Koregaon Park emerged as the top residential location (27/30), while Ghansoli scored highest for mixed-use development (30/30). The findings provided tailored recommendations, prioritizing accessibility, neighborhood characteristics, and growth potential, with specific proposals like residential projects in Mahalunge and mixed-use developments in Ghansoli. This comprehensive approach combined field research, expert insights, and data analysis to create a practical framework for location assessment, ensuring alignment with each area's unique market strengths and investment potential while addressing diverse real estate needs across the premium, emerging, and affordable segments.

4.0 Site Analysis

4.1 Site Observations

Parameters	Site 1	Site 2	Site 3	Site 4
Neighborhood	Mixed residential and commercial, vibrant area.	Primarily residential, emerging area	Mixed residential and commercial.	Small residential houses, semi-rural.
Accessibility	Excellent connectivity to main roads and amenities.	Well-connected to IT hubs and expressway.	Strong road links and highway access.	Proximity to Mumbai-Ahmedabad highway.
Traffic Dynamics	Heavy traffic due to narrow roads.	Minimal congestion.	Low congestion with broad roads.	Minimal issues.
Public Transportation	Metro access and good e-transport options.	Limited metro access; relies on buses.	Local trains and buses; no metro.	Limited; relies on e-transport.
Amenities	Abundant (hotels, cafes, shopping centers, green spaces).	Shopping malls, resorts, and food courts.	Hotels, restaurants, shopping centers, sea views.	Resorts and recreational facilities; lack malls.
Hospital/Schools	Multiple prestigious institutions nearby.	Schools are available, but hospitals are farther.	Multiple reputed institutions nearby.	Schools available, hospitals scarce.
Safety and Security / Police station	High, with nearby police and fire stations.	Concerns due to recent incidents; police station far.	High, with nearby emergency services.	Adequate, with nearby police and fire stations.
Natural Environment	Tree-lined streets, parks.	Scenic hills and lakes, pleasant climate.	Mangrove forests, sea views, parks. And natural parks are nearby.	Hills, lakes, and serene climate.
Local job market	Strong local employment opportunities.	Proximity to IT hubs (Hinjawadi).	Thriving, with corporate parks nearby.	Industrial (power plants, Tata Steel); upcoming port.
Cost and Availability	Expensive.	Competitive pricing with varied options.	More affordable than central Mumbai.	Affordable housing potential.

Buyers/User preference	Buyer preference is good.	Buyer preference is good as majorly less traffic and near to city.	Buyer preference is good.	Buyer preference is okay as majorly less traffic.
Future Development (Developers Perspective)	Established but with scope for new projects.	Growing due to successful past projects.	Ongoing infrastructure developments.	High, driven by Asia's biggest upcoming port.

4.1 Site Details

Site 1- Koregaon Park, Pune: Koregaon Park, Pune's premium neighborhood, offers luxury residences, high-end retail, and vibrant commercial spaces with excellent connectivity to the airport (5.8 km) and railway (3.8 km). Despite moderate traffic (17.9 km/hr avg), it boasts upscale amenities (parks, museums, Osho Ashram), top schools/hospitals, and lush greenery along the Mula-Mutha River. Property prices average ₹16,000/sq ft (₹60L–₹13.1Cr range), supported by metro/bus networks. The diverse job market and upcoming projects (Godrej, Basil Group) reinforce its status as a prime high-end investment hub.

Site 2- Mahalunge, Pune: Mahalunge, Pune is an emerging residential hub with excellent connectivity to IT centers (Hinjewadi, Baner) via Mumbai-Pune Expressway, offering affordable housing (₹8,544/sq ft avg; 2BHK: ₹67-71L) in projects like Kul Ecoloch. With planned metro expansion, amenities (Ecoville Farm, High Street), schools/hospitals, and scenic greenery, it attracts mid-income buyers. Thriving job market (construction, IT) and future developments (Godrej Hill Retreat, infrastructure upgrades) enhance its investment potential.

Site 3- Ghansoli, Navi Mumbai: Ghansoli, Navi Mumbai is a thriving mixed-use hub with excellent connectivity (1km to railway, 15km to Navi Mumbai Airport) and premium properties (₹25K/sq ft avg). Features include corporate hubs (Reliance Jio), lush mangroves, top schools, and amenities like Aurum Mall. Future projects (Satyam Alliance Icon, Greenscape Cyber Works) reinforce its status as a prime residential-commercial investment destination.

Site 4- Palghar, Mumbai: Palghar's Panchali offers affordable housing (₹4K/sq ft) with industrial potential, featuring good highway/rail connectivity (10-12km to Boisar Station) and natural assets (Vandri Lake, coconut groves). Key amenities include resorts, schools (Rahul International), and hospitals (TIMA). Future-ready with Mahindra's 800-unit project, Tata's industrial plans, and infrastructure upgrades, it's a budget-friendly growth corridor near Mumbai.

5.0 Expert Opinion for Site 1- Koregaon Park, Pune

Parameters	Real Estate Expert	Broker	Construction Developer
Premium Lifestyle	Ideal for high-end developments, attracting NRIs, expatriates, and affluent buyers.	Thriving social scene (cafes, fine dining) appeals to lifestyle-focused buyers.	Affluent demographic seeks luxury apartments and retail spaces.

Commercial Hubs	Proximity to Mundhwa/Kalyani Nagar boosts demand for co-working spaces and retail.	Strong demand from IT professionals and corporate executives.	Proximity to IT parks ensures office space demand.
Sustainability and Cost	High land prices necessitate premium, eco-conscious projects.	Steady price appreciation favors luxury condos with eco-features.	High property rates justify innovative, high-value designs.
Traffic Dynamics	Narrow roads and congestion may impact project viability.	High foot traffic benefits commercial ventures.	Bustling area suits commercial projects but may deter residential buyers.
Regulations	Stricter rules on building height, parking, and environment.	Limited land availability pushes redevelopment/vertical expansion.	Complex approvals for height, parking, and eco-compliance.
Amenities	Hotels, museums, and green spaces enhance value.	Prime plots scarce; focus on redevelopment.	Noise/traffic may require soundproofing for residential projects.
Safety	Secure with nearby police and fire stations.	Safe environment with emergency services nearby.	Competition demands unique amenities (e.g., smart homes).

6.0 Results and Discussions

Selecting optimal real estate locations requires evaluating multiple factors that influence property value and usability. Thriving neighborhoods with amenities and safety suit mixed-use/residential projects, while accessible highway-adjacent areas favor commercial developments.

Site 1: KOREGAON PARK						
Parameters	Residential	Industrial	Commercial	Institutional	Hospitality	Mixed Use
Neighborhood	3	-	3	3	3	3
Accessibility	3	1	2	2	2	2
Traffic Dynamics	2	1	1	1	1	2
Transportation	3	3	3	3	3	3
Amenities	3	-	3	3	3	3
Hospital/Schools	3	-	3	-	-	3
Safety	2	2	2	2	2	2
Environment	2	1	2	2	2	2
Future Developments	3	1	3	3	3	3
Regulations	3	1	2	2	2	2
Site 2: MAHALUNGE						
Parameters	Residential	Industrial	Commercial	Institutional	Hospitality	Mixed Use
Neighborhood	3	1	3	2	3	3

Accessibility	3	3	3	3	3	3
Traffic Dynamics	3	3	3	3	3	-
Transportation	2	1	2	1	2	2
Amenities	3	3	3	3	3	3
Hospital/Schools	2	-	2	-	-	2
Safety	1	1	1	1	1	1
Environment	2	1	2	2	2	2
Future Developments	3	3	3	3	3	3
Regulations	3	1	2	1	2	3
Site 3: GHANSOLI						
Parameters	Residential	Industrial	Commercial	Institutional	Hospitality	Mixed Use
Neighborhood	3	-	3	3	1	3
Accessibility	3	1	2	2	2	3
Traffic Dynamics	3	1	1	1	1	3
Transportation	3	3	3	3	3	3
Amenities	3	-	3	3	3	3
Hospital/Schools	3	-	3	-	-	3
Safety	3	2	2	2	2	3
Environment	2	1	2	2	2	3
Future Developments	2	1	3	3	3	3
Regulations	2	1	2	2	2	3
Site 4: PALGHAR						
Parameters	Residential	Industrial	Commercial	Institutional	Hospitality	Mixed Use
Neighborhood	3	2	1	1	1	1
Accessibility	3	2	1	1	1	3
Traffic Dynamics	3	2	1	2	1	2
Transportation	3	3	1	1	1	3
Amenities	3	2	1	2	2	2
Hospital/Schools	3	3	-	-	-	3
Safety	2	2	2	2	1	2
Environment	3	1	1	2	1	2
Future Developments	3	3	2	3	3	3
Regulations	3	2	1	1	1	2

High-traffic zones benefit retail, and public transit proximity enables multi-family housing. Nearby hospitals/schools attract families, and secure areas appeal to gated/senior communities. Scenic natural environments support eco-friendly projects, and strong job markets enable commercial/industrial parks. Affordable areas allow budget housing, while buyer preferences dictate urban/smart home designs. Future-ready locations with planned infrastructure offer high appreciation potential, making them ideal for high-density or mixed-use

developments. Each parameter - from accessibility to local economics - provides critical insights for aligning projects with location-specific advantages and market demands.

7.0 Conclusion

The analysis identifies four prime real estate locations with unique advantages: Koregaon Park (Pune) excels for luxury residential projects; Mahalunge (Pune) suits residential/commercial growth; Palghar offers affordable housing potential; and Ghansoli (Navi Mumbai) is ideal for mixed-use development. Key factors like connectivity, amenities, safety, and future prospects drive their viability, emphasizing the need for location-specific strategies to maximize returns.

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CHAPTER 95

Logistics Costs and Competitiveness of Indian Products in Global Market

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ABSTRACT

Logistics costs have several components, such as order processing, inventory control, warehousing, transportation, material handling, storage, logistical packing, and information flow. If any of these logistics components are decreased, the overall logistics cost is reduced, creating a positive cascade effect in the economy by increasing revenue generation. Therefore, logistics play an important role in the economy. As per studies by the National Council of Applied Economic Research, the report published by the Department for Promotion of Industry and Internal Trade suggest that the logistics cost in India is 12-14% of the Gross Domestic Product (GDP), which is very high compared to developed countries, where it ranges between 8-10% (NITI Aayog, 2022) of the GDP. Due to this, the price of products increases, making them less competitive in the global market. The main factor responsible for the high logistics cost is the heavy dependence on road transport. Other contributing factors include poor infrastructure, a fragmented transportation sector, a lack of proper documentation, and insufficient automation. The Indian Government has implemented various initiatives to reduce logistics costs and enhance efficiency. These include the National Logistics Policy, which focuses on lowering logistics expenses; Bharatmala Pariyojana, which aims to enhance freight movement; and the Gati-Shakti Multi-Modal Cargo Terminal Policy, which aims to establish new cargo terminals. Additionally, the Sagarmala Pariyojana seeks to improve port connectivity and reform the logistics sector, while the National Rail Plan is designed to enhance logistics and goods movement via rail. The Dedicated Freight Corridor is a new railway corridor dedicated to freight transport, and Multi-Modal Logistics Parks enhance connectivity between different transport modes. Also, organizations like Logistics Ease Across Different States (LEADS) have been established to assist in reducing logistics costs.

Keywords: Logistics; Bharatmala; Gati-Shakti; Sagarmala; LEADS

1.0 Introduction

1.1 Background

Logistics plays an important role in how efficiently trade flows and how competitive a country is in the global market.

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It encompasses transportation, warehousing, inventory management, and supply chain coordination. These components of logistics cost need to be managed separately to reduce logistics cost because the increase in logistics cost generates a cascading effect on the economy in monetary terms. In India, logistics cost accounts for approximately 13-14% of the GDP, which is significantly higher than the global standard of 8-10%. This extra 3-5 %, if saved, would be invested somewhere else and would generate a cascading effect on the economy. These high logistics costs serve as a disadvantage as due to this increased cost, Indian products become expensive in the global market and hence reduce their competitiveness. To process the function of the logistics, the major components include description, technical details, delivery period, payment terms, and other commercial terms.

In India implementation of Information Technology (IT) is a new issue and most of companies follow traditional methods that are time-consuming which as a result increases the ordering time and as a result increases the cost associated with the product. Inventory management is another function of the logistics activity, and the carrying cost of inventory is very high in India due to the absence of infrastructure in many places. Most companies need to keep huge amounts of inventory for the satisfaction of the customers, and that results in an increase in the cost associated with the logistics activity.

Warehousing is the backbone of logistical activity, but the management and construction of warehouses require a huge amount of investment. One of the studies shows that approximately 7% (McKinsey & Company, 2024) of the greenhouse gases of the world are generated by warehousing activities, so to comply with the rules and regulations, warehouse construction becomes trickier. Due to most of the material being handled with the help of human aid in India, it becomes more complicated to measure productivity in terms of cost and time effectiveness.

The major problem with India is the absence of data in terms of Logistical activities. Even the government doesn't have data on many activities related to logistics due to an unorganized fleet of trucks and many more reasons. Due to this reason, the government can't formulate a proper policy which as a result leads to further increases in logistics costs. Now, if we work efficiently, then the money that we are currently spending on logistics will be reduced to half, and half of the money will be used somewhere else that will further bring more development, so it is necessary to reduce logistics costs.

1.2 Research objective

This study will have the following broad objectives:

- To analyze factors contributing to high logistics costs in India.
- To examine their impact on the competitiveness of Indian exports.
- To evaluate government initiatives aimed at reducing logistics costs.
- To recommend strategies to improve India's logistics efficiency.

2.0 Literature Review

India's logistics industry is responsible for giving the nation its trade efficiency and competitiveness globally. Logistics costs in India, nonetheless, remain at 13-14% of GDP, much greater than the worldwide benchmark of 8-10%. The high-cost results from excessive use of road transport, poor multimodal connectivity, congestion at ports, as well as old warehousing infrastructure (World Bank, 2023). Over time, the industry has evolved from a dispersed chain of transporters to a consolidated supply chain system, with third-party logistics (3PL) and fourth-party logistics (4PL) vendors assuming an increasingly important role (Samir et al., 2006). Even during times of enhanced efforts, India ranks behind other countries in global logistics rankings. India was ranked 44th on the Logistics Performance Index (LPI) in 2018 because of delays at customs, weak port performance, and high last-mile transportation expenses (World Bank, 2018). By 2023, India's ranking improved to 38th, thanks to investments in freight corridors and digital tracking systems (McKinsey & Company, 2024).

However, road freight still accounts for nearly 60% of total cargo movement, significantly increasing costs compared to China, where rail and waterways dominate (Verma & Joshi, 2021). Second, India's 55-hour port dwell time, significantly above developed economies 40-hour level, delays export and raises transport costs (Sarkar & Banerjee, 2023). Lastly, the deficiency of cold storage and automated warehousing is the other significant hindrance, costing \$11.6 billion a year, specifically in agriculture (Gupta & Kumar, 2021).

To tackle these issues, the National Logistics Policy (NLP), which was launched in 2022, plans to bring down logistics costs to 8% of GDP by 2030 by enhancing digital integration, multimodal transport, and Artificial Intelligence (AI) based logistics management (Department for Promotion of Industry and Internal Trade, 2022). Other initiatives by the government, including Bharatmala and Sagarmala, have been quite successful. Bharatmala Pariyojana has added 60% of the country's highway network since 2014 by prioritizing freight corridors and expressways for streamlining trucking efficiency (Press Information Bureau, 2024). In a similar way, the Sagarmala Programme promises to produce \$5 billion per annum savings through improving coastal shipping and port connectivity (Sagarmala Report, 2023). The Dedicated Freight Corridor (DFC), planned to raise the rail freight capacity to 1,600 million tonnes by 2025, is another flagship program to curb congestion and minimize transport costs (Indian Railways Freight Policy, 2024). The Gati Shakti program, with an outlay of ₹100 trillion, brings road, rail, and waterways together under one single logistics umbrella (Ministry of Railways, 2023). Technology is revolutionizing India's supply chain. Blockchain technology has been expanding in use to enhance tracking of shipments, boost security, and minimize fraud during logistics transactions (Goyal & Kumar, 2020).

Artificial Intelligence is also having a great impact, AI-based route optimization has enabled logistics companies to save costs by up to 15% (Sharma & Yadav, 2019). Growth in e-commerce has further redefined the industry, with smart last-mile delivery solutions cutting

down transit times by 30% in urban localities (Mishra & Roy, 2021). Looking at the world's best practices, China has rationalized logistics by giving top priority to rail freight, inland waterways, and high-speed cargo rail systems (Kumar & Gupta, 2019). European countries like Germany and the Netherlands have also been able to effectively deploy AI-based customs clearance and predictive analysis for real-time tracking of cargos, ensuring greater efficiency in logistics activities (McKinsey & Company, 2021).

Yet, India continues to have several obstacles in the complete adoption of multimodal transport systems. Today, rail and waterways transport only 34% of freight, lagging far behind China's 60% (Khan & Jain, 2023). It is also imperative to encourage green logistics solutions like electric trucks and solar-powered warehouses, which can potentially save up to ₹1.2 lakh crore per year in fuel expenses (NITI Aayog, 2022). Also, the lack of a common National Logistics Data Bank impacts real-time visibility of freight movement, resulting in inefficiency (Deloitte, 2022). To enhance India's logistics competitiveness globally, India needs to attempt to decrease road dependency, increase multimodal infrastructure, and expedite digitalization. Investment in AI-based logistics, blockchain-based freight tracking, and green supply chains will be pivotal in lowering logistics costs to 8% of GDP and enhancing India's export competitiveness.

3.0 Research Methodology

This study relies on secondary data from the World Bank's LPI reports, the Government reports (NITI Aayog, Ministry of Finance, Ministry of Road Transport & Highways), academic research papers and industry reports. A comparative analysis of India's logistics costs with global benchmarks is conducted. Government policies are evaluated based on their impact on reducing logistics inefficiencies.

4.0 Analysis and Discussion

4.1 High logistics costs and their impact on trade

India's logistics inefficiencies lead to increased costs for exporters. The average cost of road freight in India is ₹2.3 per ton-km, whereas in China, it is ₹1.7 per ton-km and more than 60 percent of trade volume if India is handled through roadways (Transport Corporation of India Limited, 2014-15). Port dwell time in India is around 55 hours, compared to 40 hours in developed nations due to which indirect cost increases hence increasing logistics costs (Economic Survey of India 2020-21). Inventory holding costs in India are higher due to inadequate warehousing infrastructure. The modal split- freight movement in India in 2022 is 3.05 trillion ton-km which is 66% of the total and by rail is 0.82 trillion ton-km which is 31% of the total, by shipping medium it is 1108 million metric ton which is 3% and by air it is 2068 million ton-km which is 1% of the total freight movement (Economic Survey of India 2022-23).

In terms of infrastructure the roadways infrastructure present is 63.73 lakh km, the railways present are 1.08 lac km, waterways contain 12 major and 200+ non-major ports and a number of airports in India is 131. For support infrastructure 129 inland container depot. 168 Container Freight stations, 1 multimodal logistics park currently under construction, and a 300 sq. ft warehouse is present in India (Economic Survey of India 2021-22). Currently, 62% of logistics cost in India is attributed to transportation and 34% to inventory management. China's average vessel size is 1.12 times larger than India's, and its median time in port is approximately 11% shorter (Logistics Performance Index Report 2022). This difference is likely due to superior systems, processes, and a higher level of digitization in Chinese ports. The road sector in India handles approximately 10000 commodities with employment of 22 million people but it is one of the most fragmented sectors as 10% of this sector is only handled by organized players. India loses around \$11.6 billion (₹92,651 crore) worth of agricultural goods every year due to insufficient storage and poor transport infrastructure (Economic Survey of India 2018-19).

4.2 Impact on competitiveness

Higher logistics costs reduce the price competitiveness of Indian exports. Sectors such as agriculture, textiles, and electronics are particularly affected. Comparatively, China's efficient supply chain management enables it to dominate global exports.

Table 1: Comparison Table of Logistics Costs as a Percentage of GDP for Different Countries, using India as a Reference

Country/Region	Logistics Cost (% of GDP)
India	14%
USA	8-10%
Europe	8-10%
China	9%
Global Avg	8%

Source: Reimagining India's Supply Chain, CII Report, 2020

India has significantly higher logistics costs, accounting for 14% of its GDP. In contrast, developed regions like the USA and Europe have logistics costs between 8-10% of their GDP, which is 4-6% lower than India's. Similarly, China has a logistics cost of 9% of GDP, making it 5% more cost-effective than India. Globally, the average logistics cost stands at around 8% of GDP, meaning India spends 6% more than the rest of the world. These high costs make the movement of goods within India more expensive, creating challenges for businesses and impacting the country's economic efficiency.

4.3 Government initiatives

NLP Implementation: The National Logistics Policy (NLP) is a framework to improve India's logistics sector and make it more efficient and cost-effective. The policy was released in

September 2022 by the Indian government. Major objectives of this policy include to reduce Logistics costs by improving India's logistics performance index ranking, creation of a data-driven decision mechanism for an efficient logistics ecosystem, generating employment opportunities and making Indian products more competitive in global market.

Infrastructure Investments: The government is building a 2 lakh-kilometer national highway network by 2025 (Economic Survey of India 2021-22). Over the last 10 years, the national highway network has grown by 60%, increasing from 91,287 km in 2014 to 146,145 km in 2023. The length of highways with four lanes or more has also expanded significantly, growing 2.5 times from 18,387 km in 2014 to 46,179 km in 2023 (Economic Survey of India 2023-24). There are currently 108 port connectivity road projects that cover a total of 3,700 km. So far, 294 km have been completed, 1,808 km have been awarded for construction, and 1,595 projects are now in the planning stage (Economic Survey of India 2022-23). These projects will improve connectivity and lower logistics costs.

The Bharatmala Pariyojana aims to make the movement of goods across the country more efficient. It focuses on building a specific length of national highways and includes developing economic corridors, and feeder routes, improving national corridor efficiency, and enhancing border and international roads, coastal and port connectivity, and expressways. To date, 27,384 km have been awarded for construction, and 15,045 km have been built. Under the Bharatmala project, multimodal logistics parks (MMLPs) are being set up. A network of 35 MMLPs will be developed, with an investment of 46000 crores. Once these parks are operational, they will handle 700 million metric tonnes of cargo (Economic Survey of India 2022-23). The MMLPs will act as hubs for transporting goods from various industrial and agricultural areas to consumer markets and seaports. In some cases, MMLPs are being built alongside inland waterway terminals as part of the Sagarmala project. This approach will help reduce the cost of moving cargo inland compared to traditional road transport. India has 87 ports that are either operational or under development along its coastline (Economic Survey of India 2021-22). All major ports have last-mile road connections with at least four lanes. The Ministry of Road Transport and Highways (MoRTH) and its agencies plan to develop 108 Port Connectivity Road (PCR) projects, which will cover about 3,700 km to enhance last-mile connections for these ports (Economic Survey of India 2022-23).

The Sagarmala Programme, launched with a focus on port-led development, operates across four core pillars: port modernization and development, connectivity enhancement, port-led industrialization, and coastal community development. Through these interventions, the programme has successfully reduced logistics costs by approximately US\$5 billion annually, improved port efficiency by minimizing turnaround times, and strengthened multimodal connectivity by integrating road, rail, inland waterways, and coastal shipping networks (Economic Survey of India 2021-22). Additionally, the creation of Coastal Economic Zones (CEZs) has attracted investments, stimulated regional industrial development, and generated employment, while promoting environmentally sustainable coastal shipping has contributed to

lowering carbon emissions. The Dedicated Freight Corridor (DFC) aims to modernize rail freight infrastructure, enhance port connectivity, and lower logistics costs, with a target of reducing logistics costs from 14% of GDP to single digits (Economic Survey of India 2021-22). The DFC supports national initiatives such as 'Make in India' and 'One District One Product,' enabling faster movement of goods from production hubs to domestic and international markets. As of FY 2023-24, the DFC operates 241 freight trains daily, a 42% increase from the previous year's 170 trains, and has resulted in the saving of 11.62 lakh liters of diesel, thereby reducing carbon emissions by 3,075 tonnes (Economic Survey of India 2023-24).

Gati Shakti Multi-Modal National Master Plan (GMNMP): The Gati Shakti Multi-Modal National Master Plan (GMNMP) is introduced with a massive investment of ₹100 trillion. This initiative aims to streamline the nation's transport and logistics sectors by improving multi-modal connectivity and breaking down the traditional barriers between departments, ensuring different modes of transport work together seamlessly. The Ministry of Railways launched the Gati Shakti Multi-Modal Cargo Terminal (GCT) policy in December 2021. This policy focuses on expanding and improving cargo terminals to boost India's rail freight capacity. Although railways offer a reliable and environmentally friendly way to transport goods, the number of freight terminals hasn't kept up with the rising demand. In 1951 India's freight traffic was 73 million tonnes which increased by huge amount to 1210 million tonnes in 2021. But freight terminals have remained same in number, due to which congestion and larger turnaround times for wagons- upto 120 hours on average (Economic Survey of India 2022-23). To improve this the policy of GTC has been introduced which aims to fix these issues by promoting the construction of new cargo terminals and also upgrading the existing ones to handle the increasing freight traffic. The main goal of it is to cut down the present congestion by 50 percent and increase the railway freight capacity to 1,600 million tonnes by the year 2024-25 (Economic Survey of India 2021-22). Due to this effort that is focused on improving the infrastructure and logistics, India is aiming to meet the growing transportation needs, strengthen its economy and setting the stage for further growth. Due to the development of new hubs in Gati Shakti Cargo Terminals (GCTs), the rail cargo handling would be more efficient and streamlined. Till now, 15 of this cargo terminals have been set up, and 96 additional locations are identified as the potential sites for setting up of these terminals in future (Economic Survey of India 2022-23). The main goal of GTC is of having and running 100 Gati Shakti Cargo Terminals over the next three financial years (Economic Survey of India 2023-24).

The government has increased the budget for Indian Railways for the fiscal year 2024-25 by 5.8%. The aim of India is to invest approximately 135-145 lakh crore over the course of next 25 years. It is the target to increase the railway share in freight transport to 40-45% by 2030 (Economic Survey of India 2023-24). Another target is to develop seven hyperloop lines out of which two are dedicated only for cargo.

Zero Emission Trucks (ZETs) & Logistics Cost Reduction: Niti Aayog mentions Zero emission trucks are a solution to many problems related to logistics. Transportation is a big part

of logistics expenses in India, making up about 62% of the total and contributing 14% to the country's GDP. Given that diesel costs dominate transportation expenses, switching to Zero Emission Trucks (ZETs) could bring significant savings and have a positive ripple effect on the economy. Diesel fuel takes up a huge share of transportation costs, so a shift to ZETs can make a real difference. While ZETs come with higher initial purchase prices compared to diesel trucks, they make up for it with much lower running costs. Over their lifetime, ZETs can cut fuel costs by as much as 46%. This could lead to a 17% reduction in total logistics costs, which directly benefits consumers by reducing the price of goods. The benefits of adopting ZETs are substantial. By 2050, widespread use could save India from consuming 838 billion liters of diesel. This would lower oil import expenses by an estimated ₹116 lakh crore (NITI Aayog, 2022). The result? Lower national expenditure on oil and stronger economic stability, helping India manage its resources more effectively and sustainably.

5.0 Findings and Implications

5.1 Key findings

India's logistics costs stand at approximately 13-14% of GDP, significantly higher than the global benchmark of 8-10% in developed countries. This directly impacts the competitiveness of Indian products in global markets, increasing product prices and reducing export competitiveness. The Sagarmala Programme has reduced logistics costs by approximately US\$5 billion annually through improved port efficiency, reduced turnaround times, and better port connectivity via new and upgraded road, rail, and inland waterway links. Development of Coastal Economic Zones (CEZs) has attracted investments, fostered regional economic growth, and created employment opportunities. The Dedicated Freight Corridor (DFC) is enhancing rail freight efficiency, with 241 trains operating daily in FY 2023-24 (a 42% increase from 170 trains in FY 2022-23). The truck-on-train service saved 11.62 lakh liters of diesel and reduced carbon emissions by 3,075 tonnes, significantly improving both cost efficiency and environmental sustainability. Both programs promote greener logistics, Sagarmala encourages inland waterway transport, reducing emissions, while the DFC supports Track on Green initiatives, which include tree plantation, energy-efficient infrastructure, and solar power installations. Sagarmala's focus on coastal community development through skill training, tourism promotion, and fisheries infrastructure has directly improved livelihoods in coastal areas. Similarly, DFC's infrastructure development, including Gati Shakti Cargo Terminals, is boosting industrial output, enhancing supply chain efficiency, and creating job opportunities.

5.2 Policy implications

These reduced logistics costs would decrease the cost of Indian products and, hence, make them more competitive in global markets. This, in turn, would support 'Make in India'

and also increase the export of Indian products. The investments that are made in ports, rail, and multimodal infrastructure would generate a cascading effect that would attract private investments, enhance regional development and boost GDP growth. Due to these policies, there would be a reduction in dependency on road transport, and other alternatives would be promoted, like railways and waterways, which are greener; therefore, all these programs would also contribute to India's climate change reduction goals, and they would also align with sustainability. In Sagarmala, the approach taken is a community-centric approach, and hence, it also supports social equity, therefore ensuring that economic development benefits local populations through job creation and enhanced livelihood opportunities.

6.0 Conclusion and Recommendations

6.1 Conclusion

Lowering logistics costs is crucial for enhancing India's competitiveness in global trade. Government initiatives like Sagarmala and the Dedicated Freight Corridor (DFC) are key steps in transforming India's logistics sector. Sagarmala focuses on port-led development, improving connectivity, boosting efficiency, and driving industrial growth along the coastline. This initiative is expected to cut logistics costs by \$5 billion annually and promote sustainable coastal development. Meanwhile, the DFC is modernizing freight transport by increasing rail capacity and integrating multimodal logistics, resulting in faster cargo movement, a 42% rise in daily freight trains, diesel savings, and reduced carbon emissions. Other reforms include promoting startups, digital platforms like ULIP, and allowing 100% FDI in key infrastructure sectors. These initiatives make India's logistics more efficient, sustainable, and globally competitive while supporting regional growth. However, challenges like high road transport dependency, inefficiencies in multimodal transport, delays in clearances, outdated regulations, and limited digital adoption persist. Strategic investments in technology, policy reforms, and infrastructure are crucial to reducing logistics costs to 8% of GDP, making Indian products more competitive globally. The key lies in enhanced infrastructure development, technological adoption, and streamlined policy frameworks.

6.2 Recommendations

Continuous investment in port infrastructure, freight corridors, and multimodal logistics parks is critical to maintaining momentum. Future expansions should integrate technology, including smart port systems and digital freight management, to further reduce turnaround times and enhance supply chain visibility. The implementation of real-time cargo tracking, blockchain-enabled documentation, and port community systems should be accelerated to enhance transparency and reduce delays, particularly at customs checkpoints. Enhanced collaboration between government bodies and private investors can accelerate project delivery and ensure efficient operations through private sector expertise and capital infusion.

Comprehensive policy harmonization across transport modes (road, rail, waterways, and air) should be pursued under the National Logistics Policy, ensuring smooth modal shifts and encouraging businesses to adopt cost-efficient transport combinations. Continued emphasis on green infrastructure (solar-powered terminals, energy-efficient equipment), increased share of rail and waterways, and incentives for low-carbon technologies (like electric trucks) can align logistics transformation with India's climate commitments. Training programs for port workers, logistics managers, and freight operators should focus on digital literacy, green logistics, and global supply chain management, ensuring a future-ready workforce. Developing a National Logistics Data Bank to track logistics performance metrics, analyze bottlenecks, and guide evidence-based policy reforms will be essential for continuous cost optimization and competitiveness improvement.

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CHAPTER 96

Managing Time Overrun in Indian Real Estate Projects

Kshitij Jagdale¹, Siddhesh Kalekar², Shreyas Beldar¹ and Yashraj Ingole¹

ABSTRACT

In the construction of systems in houses, time overruns are veritably pivotal factors which are related to cost, satisfaction of affected stakeholders and the completion of the design on schedule. This exploration establishes that the main factors leading to design detainments are as follows factors related to detainments in carrying necessary blessings or warrants, redesigns, lack of finances, shy number of workers, and ineffective construction operation. The exploration uses a multipurpose approach, empirical studies through literature reviews and stakeholder interviews, to address the linked enterprises and formulate an applicable result frame. The proposed frame considers the factors like enhancing design pretensions, operation of interest groups, and searching for advancements of work processes or operation of new technologies. Aimed at practicable recommendations, this study is anticipated to contribute to the enhancement of design completion in real estate sector and reduce the time and further sustainable practices within the sector.

Keywords: Time overrun; Real estate delays; Project lifecycle optimization; Mitigation strategies; Construction project efficiency.

1.0 Introduction

The real estate sector is a vital component of India's economy, significantly contributing to GDP, employment, and urban development (National Real Estate Development Council, 2020). However, time overruns delays in project completion beyond scheduled timelines pose a persistent challenge, leading to increased costs, stakeholder dissatisfaction, and reputational damage (Gupta, 2021). Time overruns in Indian real estate projects often stem from regulatory delays, poor project planning, resource shortages, and environmental factors (Ministry of Housing and Urban Affairs, 2021). For instance, obtaining approvals for land acquisition and permits is frequently delayed, while labor shortages and material supply disruptions exacerbate scheduling issues (Krishnan, 2020). These challenges not only inflate costs but also erode buyer confidence and lead to legal disputes under frameworks like RERA (Jain & Mehta, 2020).

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While advancements like Building Information Modeling (BIM) and regulatory reforms under RERA have shown potential, their implementation in India remains inconsistent (Singh & Verma, 2023). This study examines the causes and impacts of time overruns in Indian real estate projects and proposes a framework to mitigate delays through better planning, stakeholder collaboration, and technological adoption.

2.0 Literature Review

Construction delays also known as ‘overruns’ present a serious problem in the India’s construction industry for timely project handover, cost containment and stakeholder satisfaction. In India, Such problem is much more pronounced in construction urban centres like Pune as intertwining factors such as regulatory procedures, lack of skilled labour and volatile pricing of the construction materials tend to cooperate and compound this situation (Mukherjee, 2021; Ministry of Housing and Urban Affairs, 2021). On a global perspective, political unrest, stringent regulatory environments coupled with internal factors such as lack of operational planning and effective resource utilization contributes to this issue (Chan & Kumaraswamy, 1997; Krishnan, 2020). Approval delays, unavailability of subordinates and off-season working manpower are prime constituents of construction delay factors and chronic project completions (Gupta & Patel, 2020; RERA Annual Report, 2022). Changes in any aspect of the project coupled with poor stakeholder communication and heavy rainfall are other contributing factors to further construction delays (Sharma & Rao, 2021). Time overruns have a plethora of implications including cost overruns, damage to companies’ goodwill, and resulting legal complexities. Besides, any RERA complaint breach by the development unit could cause significant damage to their economy ratio while the use of more materials than expected and more workers only extend the time (Jain & Mehta, 2020; Gupta, 2021). In addition to everything mentioned above, there is also customer dissatisfaction caused by the late handover of properties. should have figure captions mentioned below the figure and must be cited in the main text. Authors should provide the source of the figure if adopted from other sources.

3.0 Methodology

The research adopts a secondary data analysis approach on the cause effects and mitigation of time overruns in Indian real estate projects. In the analysis, the findings from literature, regulatory reports, and case studies are collated to arrive at a clear understanding of systemic inefficiencies and contextual factors resulting in project delays. The strategy involves using a descriptive and analytical approach which is typical of construction management studies to enhance reliability and applicability of the findings Doloi *et al.* (2012).

3.1 Research design

The examination employs a descriptive and analytical design in order to analyze the height of the time-overruns’ problem. Descriptive studies aid in the grouping of postponement

causes such as regulation barriers and inadequate workforce, while advanced research methods assist in message interpreting and relationship discerning among the problem determinants. This two-pronged strategy is crucial in resolving the problem and formulating the most appropriate intervention framework. The collection of all secondary data allows for reduced costs of acquiring and analyzing a more comprehensive body of work, as exemplified in studies on the Indian construction industry (Singh *et al.*, 2018).

3.2 Data collection

Data for this study was obtained from secondary sources that were selected based on their reliability in relation to the Indian Real estate project environment. Construction management peer-reviewed journal articles published in Scopus and Elsevier databases offered critical information on international best practices and the context of time management related issues of construction projects. Regulatory documents, MOHUA reports and RERA schedules among others were greatly helpful in appreciating the project which were more to do with the delays of the project. Also, case studies of Indian real estate in Delhi, Pune and Bangalore were critically examined in order to compare the theoretical evidence with practical evidence. The review of literature was conducted in a rigid manner where keywords such “time overruns in Indian construction,” “data collection secondary sources” and “ways to address delays in real estate” were used. Studies done from the year 2015 to 2023 were given priority to avoid irrelevance and furthermore thematic assessment was done so as to classify the findings into regulatory and administrative concerns, improper management and allocation of resources and inclusion of all stakeholders.

3.3 Analysis of data

Three main steps were engaged in the data analysis. In order to derive both qualitative insights into the root reasons and quantitative measurements, such as the frequency and cost effects of delays, the identified studies were first evaluated. Second, to enable a structured analysis, the retrieved data were categorized into broad thematic groups. Environmental delays, operational inefficiencies, and regulatory obstacles were the main categories found. Third, to guarantee consistency and dependability, the results were compared to case studies that had been documented. According to Doloi *et al.* (2012), this triangulated approach is consistent with accepted research procedures in construction management.

3.4 Restrictions

Secondary data has inherent limits even though it allows for a thorough and economical study. Findings are dependent on the completeness and correctness of the original sources due to the use of pre-existing data. Furthermore, secondary data could not adequately convey the subtleties of regional or project-specific difficulties. By using primary data from field surveys and interviews with real estate industry stakeholders, future research can fill in these gaps.

4.0 Analysis and Outcomings

The main reasons for schedule overruns in Indian real estate projects are methodically identified and categorized in the study paper's analytical part. Using secondary data from case studies, regulatory reports, and literature reviews, it takes a triangulated approach. Three primary categories that contribute to delays are identified by the analysis:

- *Environmental Delays*: Unfavorable weather patterns have a big influence on project schedules and disrupt building operations.
- *Operational Inefficiencies*: Inadequate planning and unrealistic scheduling are examples of poor project management techniques that result in resource misallocation and longer project durations.
- *Regulatory Barriers*: Significant bottlenecks are created by bureaucratic delays in acquiring required approvals and permits, which impede progress right away.

Table 1: Key Insights on Time Overruns in Indian Real Estate Projects

Category	Specific Causes	Effects	Mitigation Strategies
Environmental	- Heavy rainfall - Unfavorable weather patterns	- Project delays - Increased costs	- Seasonal scheduling - Contingency planning
Operational	- Ineffective planning - Resource misallocation	- Extended timelines - Stakeholder dissatisfaction	- Implementing BIM - Enhanced training programs
Regulatory	- Approval delays - Complex legal processes	- Stalled projects - Cost overruns	- Streamlining regulations - Digital approvals
Resource-related	- Labor shortages - Material supply disruptions	- Delayed progress - Increased procurement costs	- Workforce development - Supplier diversification

5.0 Conclusion

The conclusions drawn from this analysis emphasize several actionable strategies to mitigate time overruns:

- *Streamlining regulatory processes*: Simplifying the approval process can significantly reduce delays, allowing projects to progress more smoothly.
- *Modernizing project management practices*: Implementing tools like Building Information Modeling (BIM) can enhance scheduling accuracy and resource allocation, helping to identify potential delays early.
- *Strengthening stakeholder collaboration*: Fostering better communication among all parties involved can minimize conflicts and improve overall project efficiency.
- *Investing in technology and training*: Enhancing workforce skills and adopting advanced construction technologies will address resource shortages and improve productivity.
- *Future research directions*: The study suggests that future research should incorporate primary data through surveys and interviews to gain deeper insights into specific regional challenges that secondary data may not fully capture.

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CHAPTER 97

Mapping EV Infrastructure: Insights from Correlation and Regression Analysis

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ABSTRACT

Electric Vehicles (EVs) are emerging as a transformative solution for achieving sustainable transportation, offering numerous benefits such as low carbon emissions, high energy efficiency, and reduced reliance on non-renewable resources. However, to fully realize the potential of EVs in fostering sustainable mobility, the development of a well-planned and efficient charging infrastructure is critical. This infrastructure not only addresses range anxiety for EV users but also ensures convenience and accessibility, which are key factors for widespread adoption. This research aims to analyse and identify strategic locations for EV charging infrastructure using Geographic Information System (GIS) tools, specifically QGIS. A comprehensive approach will be undertaken, involving the collection of primary data through structured questionnaires and personal interviews with stakeholders, including EV users, urban planners, and policymakers. Secondary data, such as demographic, traffic flow, and land use data, will also be incorporated to ensure a robust sampling process. The analysis will focus on land suitability and multi-criteria decision-making (MCDM) to evaluate and prioritize locations based on factors like accessibility, population density, energy demand, and environmental considerations. By integrating these parameters, the research will identify strategic location for developing charging infrastructure. In addition, the study will propose suitable amenities and services, such as rest areas, retail outlets, and maintenance facilities, to enhance user experience and encourage EV adoption. The findings aim to provide a strategic roadmap for urban planners and policymakers, contributing to the creation of a sustainable and user-friendly EV ecosystem.

Keywords: GIS; EV charging infrastructure; Location analysis; Proximity analysis; Range anxiety.

1.0 Introduction

Climate change has gained political prominence throughout the world with carbon dioxide pollution bringing about environmental degradation, dwindling supply of water, and increased coastal flooding. The automobile sector in India is one of the fastest in growth, and since India is the world's most populated country, higher emissions originate from it.

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Private vehicles contribute to 12% of the world greenhouse gases emissions while transport vehicles cause higher emissions, accounting for 22%. Hence, the EV infrastructure talk is being done as a panacea for these emissions. The study carries out correlation and regression tests to analyze variables influencing the needs for EV infrastructure. Regression analysis is used to analyze development factors, while Spatial surveys using GIS technology are used to analyze the household needs regarding the location and land use study for charging station. It is focused on Balewadi and Hinjewadi areas of Pune for determining strategic locations for charging stations of electric vehicles.

EVs resolve many environmental and economic issues inasmuch as they offer major benefits over internal combustion engine vehicles (ICEVs) by replacing fossil fuels with electricity. But problems like range anxiety, charging time, price sensitivity, government schemes, and inadequate charging infrastructure slow down its acceptance. Despite advancements in battery technology, expansion of charging networks still lags behind. In a way to improve user experiences for themselves and further influence the buying decision-making process, it is vital to plan EV charging stations well. While elements influencing EV adoption have received much treatment qualitatively, the quantitative analysis has received little attention. The most significant research gap is about effective locations for stations relative to applied EV adoption. As all surveys indicate, these specific barriers include the time taken to charge, the installation costs, and a lack of standardization.

Infrastructure gaps were identified in Balewadi and Hinjewadi by surveying users on charging station usage, EV integration into local economies, and adoption rates. Factors included demographics, frequency of charging, distance to station, and the problem of range anxiety. Therefore, it is very important to develop highly developed charging stations to meet increasing EV demand. The adoption of PEVs, including PHEVs and BEVs, could change the entire energy sector in India. However, since India depends on coal for the bulk of its electricity, there needs to be a systematic transition. More than two-wheeler demand in India is placed after that of China, and this preference for two-wheelers is likely to continue through at least 2035. Government initiatives such as the National Electric Mobility Mission Plan (NEMMP 2020) aimed to deploy 400,000 passenger BEVs by 2020, creating a basis for further research on modern EV infrastructure.

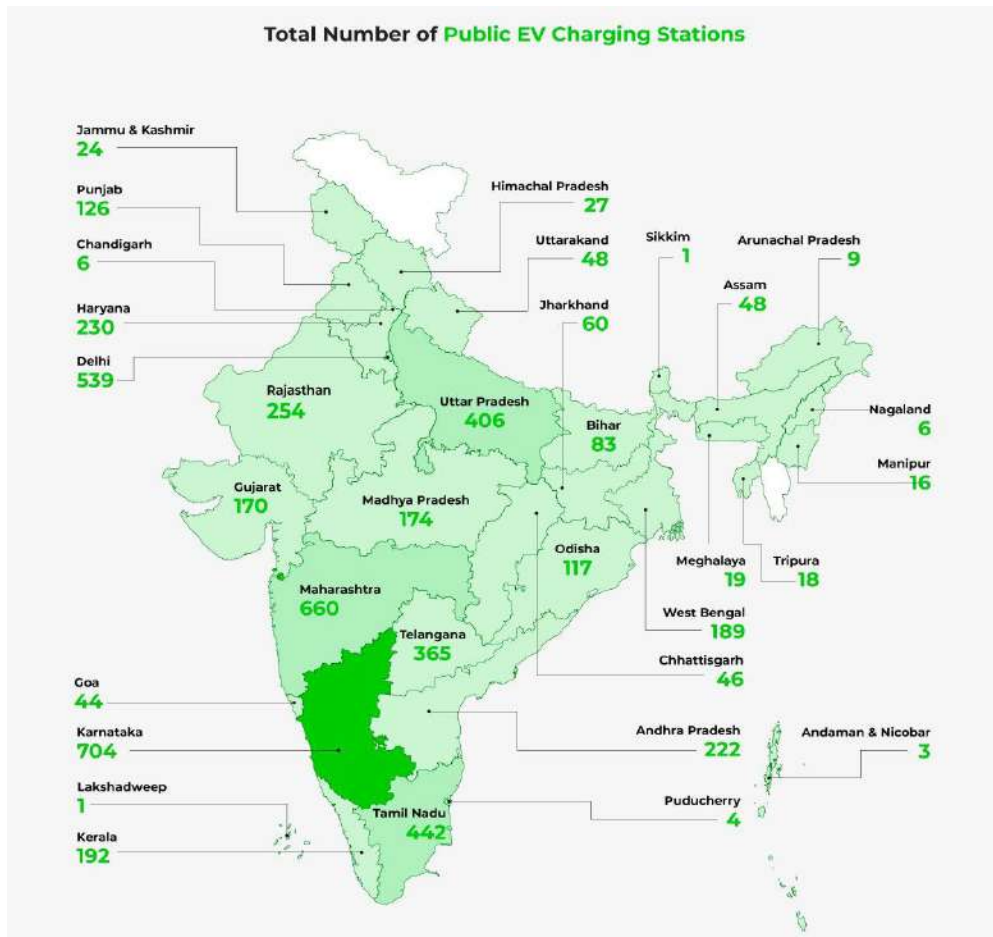
1.1 Scope of research

The use of Plug-in Electric Vehicles (PEVs), such as PHEVs and BEVs, can redefine India's energy profile and decrease environmental footprint. But with the dominant power being coal, the transition needs to be well-planned. Two-wheelers overwhelm India's market because of value for money and efficiency, and demand is not likely to slump until 2035. Notwithstanding gradual penetration of EVs (slightly more than 1%), the government has strived to adopt through measures such as NEMMP 2020. Further studies are pivotal to enhancing infrastructure for EVs and hastening growth.

1.2 Objective of research

- Use GIS to analyze the transportation infrastructure, population density, and EV distribution. Use GIS analysis for the identification of the optimal locations for laying charging stations for EVs.

Figure 1: Total No. of Public EV Charging Stations in India (Bharadwaj, 2023)



- Studying the EV facilities of Pune.
- Promote the adoption of EVs to minimize carbon footprints.
- Explore the technical components of the EV infrastructure.
- Guarantee economic viability in accordance with government policies.
- Recommend the preferable locations based on a variety of parameters.

2.0 Systematic Literature Review

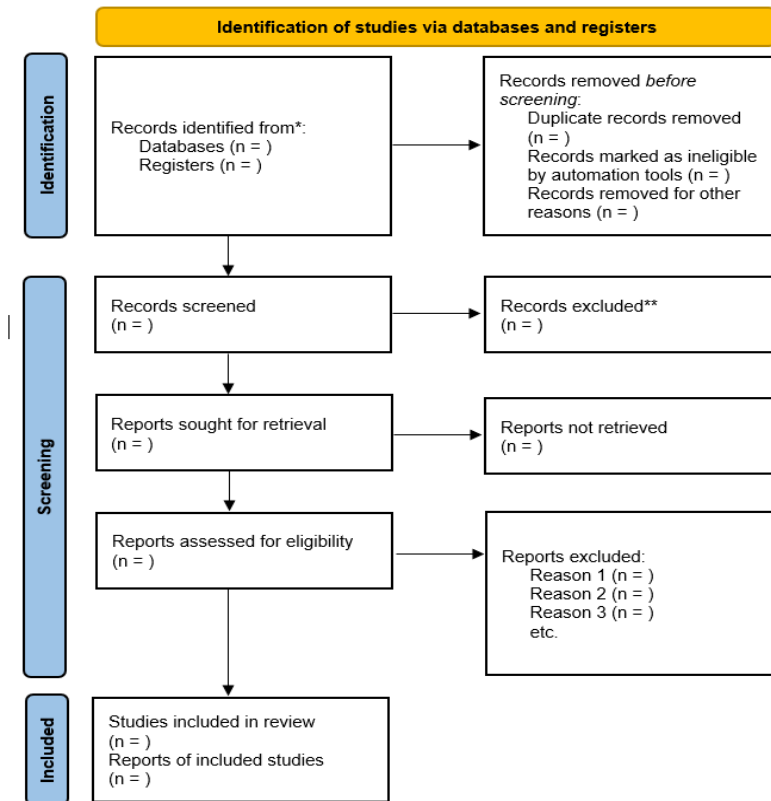
This review is a systematic study on charging infrastructure planning for the electric vehicle (EV), focusing on its optimization with Tools in GIS. This study was developed and reported under the adherence to the PRISMA-P standards. This systematic review brings together research across diverse fields around EV charging infrastructure, GIS-based spatial analysis & Correlation & Regression Analysis. The papers considered are from 2015 until December 2023. A thorough search for additional studies from the gray literature, which included conference papers, research reports and thesis, expert opinions and relevant journals, was conducted. Two complementary methods were employed: retrospective method: review of citation lists of included articles, and search through Google Scholar. Studies were eliminated for the following reasons: a) while having a focus on EV infrastructure, there were no methodologies on GIS or spatial analysis b) in the planning of charging infrastructure, there was neither consideration for accessibility, user preferences, nor environmental impact; or c) if it is book chapters, systematic reviews, scoping reviews, or letters to the editor, then it was not available for full-text access. There exists no language restriction; however, due to accessibility issues, non-English articles were also precluded.

A literature survey was conducted by using various up-to-date electronic bases to find suitable studies from 2015 to December 2023. The main databases used for the literature search were Scopus, IEEE Xplore, ScienceDirect, Web of Science (WOS), and Google Scholar. Other search terms included “electric vehicle charging,” “EV infrastructure planning,” “GIS for charging stations,” AND “multi-criteria decision-making for EVs.” Some new MeSH terms, information from notable experts, and articles related to the actual topic of study were used as well. The syntax study involved three main components: First was “electric vehicle” OR “EV adoption” OR “EV charging infrastructure” OR “EV stations placement” OR “EV charging site selection.” The second one was GIS OR “geographic information system,” “spatial analysis,” “multi-criteria decision-making,” OR simply MCDM. The third was “charging station optimization,” “EV range anxiety,” “charging infrastructure accessibility,” OR “land-use suitability analysis.”

The research team out of NICMAR conducted an all-around intensive search using key terms across a number of databases, including Scopus, IEEE Xplore, ScienceDirect, Web of Science, and Google Scholar. Titles and abstracts were reviewed for relevance, after identifying articles. Then two reviewers analyzed the full texts of the remaining articles according to pre-established inclusion and exclusion criteria. Disagreement was resolved by authors’ consensus; thus, no articles were eliminated due to lack of consensus. Initially, from 80 articles found, 65 survived after removal of duplicates, with 50 falling too far away from the subject of study to be included. The full text of the remaining 15 articles was reviewed and included in the final analysis, thus ensuring that a solid reference base was created for the study.

3.0 Methodology

Figure 2: Literature methodology



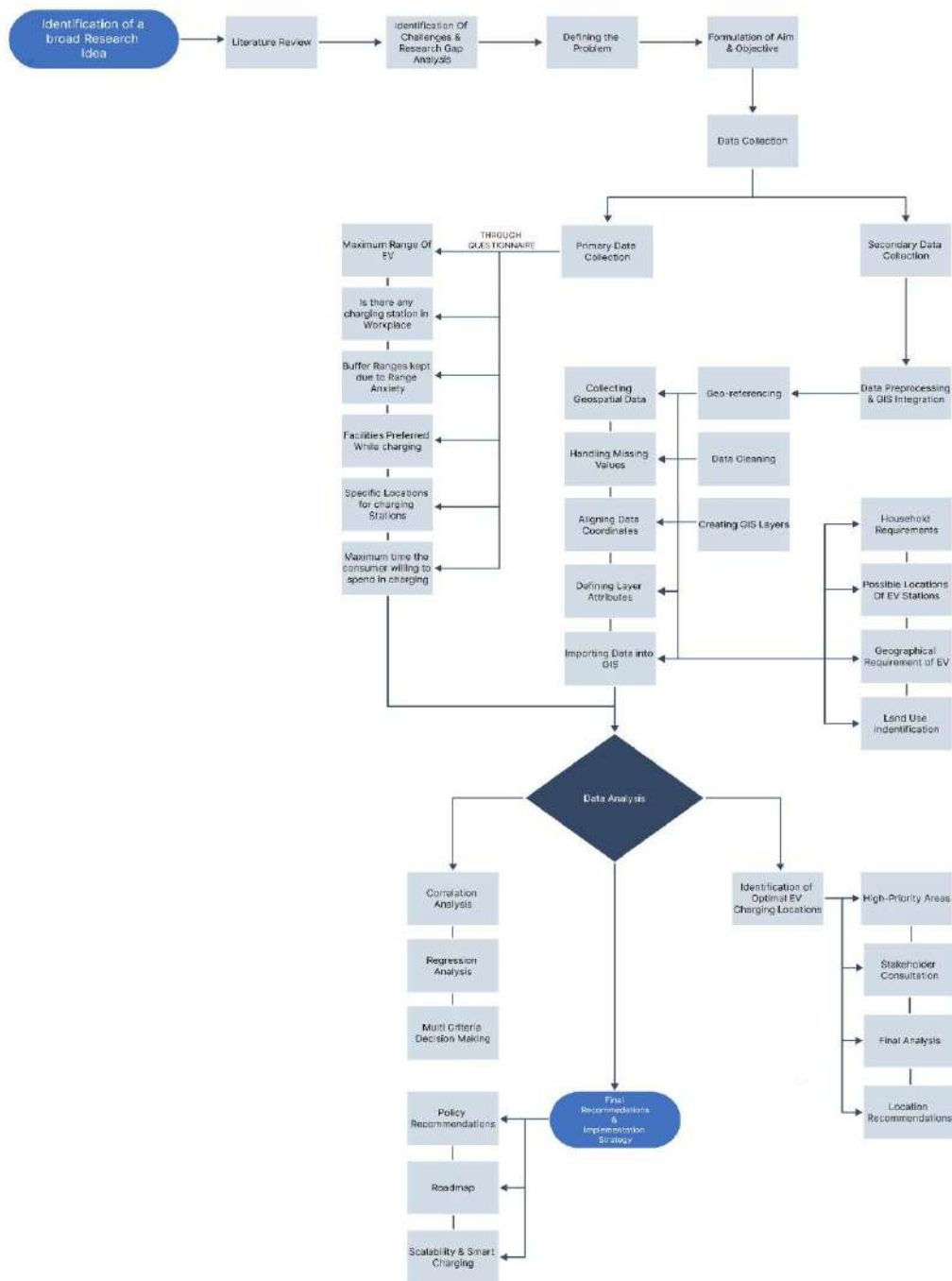
3.1 Questionnaire survey

A structured survey of users and non-users of electric vehicles in Pune collected feedback regarding favorable charging locality, duration of session, costing, complete infrastructure problems. Online and offline surveys were taken, field visits were set to Baner and Hinjewadi, and interviews were conducted with urban planners to collect the data.

3.2 Correlation and regression analysis

This method looks into factors affecting EV charging demand in Pune based on correlation analysis to evaluate associations between various important variables, for instance, EV density versus charging demand, while regression analysis will be within the ambit of predicting future demand using historical survey data, existing station data, and GIS-based traffic reports.

Figure 3: Research methodology



3.3 Geographic information system analysis

In this study, GIS tools overlay spatial data to visualize and systematically select charging station sites for electric vehicles by mapping road networks, population densities, and commercial zones. This proximity analysis helps calculate the distances between these potential sites and other important areas, which guarantees that the EV charging stations are all within easy reach for their users.

4.0 Data Collection

4.1 Sampling method

The systematic sampling technique was employed to guarantee reliable data for regression and correlation analysis. A standard formula involving population size, margin of error, z-score, and confidence level was used for the calculation of the sample size. Based on census data and an estimated growth rate, the population of the 20-50 age group in Balewadi and Hinjewadi was anticipated for 2025, thus leading to a predicted sample of 350 respondents.

$$\text{Sample Size} = z^2 \times p(1-p) / e^2 / 1 + \left(\frac{z^2 \times p(1-p)}{e^2 N} \right)$$

According to the 2011 Census, the population of Balewadi & Hinjewadi was 31,972 & 23,995 of which 3,995 were in the age group 0-6 years. As my study is on EV vehicle usage, I have to take into account only the age group 20-60 years, excluding younger age groups. So, in 2011, an estimated 13,666 & 11,400 people were in the 20-50 age group. Assuming an annual growth rate of 1.5% to 2.5%, we can estimate the population in 2025

Using the formula: $P_t = P_0 \times (1+r)^t$

Where: $P_0=13,666$ & $11,400$ (population in 2011)

r = growth rate (1.5% to 2.5% per year)

t = 14 years (2025 - 2011)

Estimated Population in 2025

With a 1.5% growth rate → 14000 & 13000 people

With a 2.5% growth rate → 16000 & 15500 people

By averaging the 1.5% and 2.5% growth rates, the estimated sample size for both areas turns out to be around 350.

4.2 Questionnaire survey

A total of 400 responses were analyzed in the survey study (taking into consideration the aim of 350), which were collected online and offline in Balewadi and Hinjewadi, which are major business and IT hubs. The survey focused on respondents who were either professionals or self-employed and investigated demographic variables along with charging habits and expectations of infrastructure for the placement of an EV charging station. A pilot study (50 responses) was conducted to revise the sampling for accuracy.

These questions were designed to measure the following:

EV Ownership	Whether respondents owned an electric vehicle (Yes/No).
Maximum Range of EV	Different range options were provided to understand vehicle capabilities.
Charging Station Usage	How frequently respondents used charging stations.
Range Anxiety:	Whether respondents experienced concerns about their vehicle running out of charge before reaching a charging station.
Preferred Charging Infrastructure Location	Where respondents would like charging stations to be placed (e.g., residential areas, commercial hubs, highways, workplaces, etc.).
Additional Facilities at Charging Stations	Preferences for amenities such as WiFi, co-working spaces, cafes, rest areas, or other conveniences that could enhance user experience.
Willingness to Spend on Charging	How much respondents were willing to pay for charging services.
Availability of Nearby Charging Facilities	Whether respondents had access to any existing recharging facilities in their vicinity.

5.0 Data Analysis

5.1 Questionnaire analysis

Ownership of electric vehicles: 55.06% (223 respondents) own an EV, while 44.94% (182 respondents) do not, thus indicating room for market expansion. Driving an electric car should be based on charging preferences: 65.47% of EV drivers prefer home charging, thus highlighting the lack of public charging stations in the country. Travel distance to a charging station: 73 of the respondents have chance to travel 5-10 km more to reach it, with 57 respondents wanting charging stations within a much shorter distance due to a fear of range anxiety. The EV range: Most people drive between 100 km-200 km on a daily basis while long-range EVs seldom appear due to high battery costs coupled with high charging convenience constraints. Preferred charging speed: 73% wish for a charging duration of 30 minutes or shorter, which fuels the needs for fast-charging technology. Infrastructure changes: Majority, that is, 89.24% of them said they find it difficult to access charging stations, except for only 0.9% of EV drivers who said they never face such issues. The drivers follow the next factor which influences charging station choice: Proximity (151), speed (191) to charge, and cost are the most considerable reasons taken into account for an electric car to recharge. Amenities that people demand the most include restrooms (148), wi-fi-enabled work pods (145), cafes/restaurants (137), and waiting lounges (178). The most abundant charging stations could be located on parking lots (176), malls (98), highways (162) and some residential areas (149). The speed of charging is a major factor here: one of the significant worries owing to range anxiety is that only 73% of the respondents would wish for a charging duration within 35 minutes at the maximum, dropping to 62% at a limit of 45 minutes. Barriers to the adoption of EVs: High up-front cost (102), lack of after-care support (43) and inadequate charging stations (24).

5.2 Correlation and regression analysis

- *Sub Model 1.1: How often do you use public charging vs how much do you currently pay*
 $R^2 = 0.166$: The cost per kWh only explains 16.6% of the variance in the frequency of charging in public stations.
 Improvement in RMSE: 1.370 $\rightarrow$ 1.255: Very slightly more accurate.
 The model was highly significant (F-statistic=29.125; a probability below 0.001).
 Coefficient=0.495: For every unit increase in cost per kWh, the use of public charging increases by 0.495 units.

Summarizing, the logic links higher prices to locking the public charging point. It could be ambitious demand areas that are short on private charging points and are therefore generally convenient. Aside from this, charging behavior is also influenced by a number of other factors.

- *Sub Model 1.2: Public Charging Usage vs. Near Office Spaces, Speed of Charging and Price Paid per kWh*
 $R^2 = 0.301$: 30.1% of public charging frequency variation is explained by charging near offices, speed, and price per kWh.
 F-statistics = 10.118, $p < 0.001$: Model is highly significant.

Key findings:

Charging near offices (0.535, $p = 0.008$): Significant positive impact—closer workplace charging increases public charging usage.

Speed of charging (0.260, $p = 0.331$): No significant effect.

Price per kWh: Certain price points (e.g., 3 & 4) increase public charging use, while others do not.

Conclusion: Workplace charging boosts public charging reliance, cost matters more than speed, and pricing strategies should be optimized to encourage EV adoption. Expanding workplace charging infrastructure could improve usage patterns.

Sub Model 1.3: Maximum Time Willing to Spend at a Charging Station vs. Price Currently Paying per kWh.

A low R^2 value of 0.088 shows that an estimated 8.8% of the variation in waiting time is accounted for by price per kWh, thus implying a weak relationship. The F-statistic for the model of 14.153 is not less than the 0.001 significance threshold, signifying that in a statistical sense, the model is quite significant, though price isn't such a strong predictor. Key takeaways: A coefficient of 0.194 at an alpha of 0.001 indicates that, ceteris paribus, with increases in price per kWh, the waiting time increases by a slight amount, although this amount is very small. There is a very slight improvement in RMSE at values of 0.708 and 0.739, respectively. Conclusion: Price per kWh really does hold only a small leverage factor in determining how long the users will wait, though one would guess that much stronger influences may be speed, convenience, or necessity.

Sub Model 2.1: Proximity vs Restrooms: The results further indicate that restroom availability is an important predictor of how people value a location with an 17.8% variance

accounted for in the roster. The significance of a positive coefficient is that people will go for options closer to such amenity provision for selecting sites for public infrastructure. This model performs significantly ($p < .001$), which means with high confidence that restroom availability is one of the strong transitory determinants for preference regarding closeness, implying that users will consider restroom convenience in deciding the locations for charging stations, public facilities, and transit stops.

Sub Model 2.2: Restrooms vs Willingness to pay: The association between the willingness to pay extra for the availability of restrooms in charging stations is quite weak, with the willingness to pay accounting for 7.5% of the variance in restroom availability. R^2 is used to show that the slight adjustments to quite a big portion of what is unexplained could be accounted for by which the linear regression function was adjusted, as in comparison: Excellent=0.7-0.9; Good=0.4-0.69; Fair=0.19-0.39; and Poor=0.1-0.19. A sort of contrasting explanation would include the meaning that the ANOVA under R^2 explains the total variability in the response data around the mean.

Sub Model 2.3: Wifi Working pods vs Time to spend in charging stations: The linear regression model has been developed to understand the relationship between Wi-Fi working pods and the time to spend in charging stations by fitting a linear equation to the observed data. Information from an ANOVA table summarizes in the following way: (R^2) Interpretation of the table states 8.0%: The model demonstrates 8 percent of the variability in terms of how much time people would spend at a charging station, given the fact that they were interested in Wi-Fi-enabled work pods. It affirms the conclusion that while these pods have some effect, it is not very notable regarding the period of stay at a charging station. Adjusted $(R^2 = 0.074)$: The lower adjusted (R^2) indicates that while work Wi-Fi-enabled pods contribute something toward the model, they are not good predictors of time spent. RMSE (0.711) vs 0.739: F-statistic: (12.686) , $p < 0.001$ → indicates model significance, denying their association as non-random between wait time at a charging station and Wi-Fi-enabled work pods. The very low (R^2) suggests that many other factors could explain variance in time spent waiting at a charging station. Intercept=1.625 will be the maximum time users will wait at the charging station in cases when Wi-Fi-enabled working pods do not exist by default. Coefficient of Wi-Fi Enabled Working Pods=0.429: A positive correlation could be seen, as maximum waiting time to charge increased with increasing interest in working pods.

Analysis for non-EV users:

Sample: 172 respondents, including users and non-users.

Key Insights:

The majority of respondents do not know much about EVs.

Charging station availability is a great concern that harbors EV adoption.

A vast majority of respondents think that the better charging infrastructure would encourage future EV purchases.

Key findings: While the level of awareness regarding electric vehicles among the 79%

driving 120-150 km a week is encouraging, it is not a match for those that support it. Most of them drive an EV with a range of 250-400 km. Electric vehicles have a lower running cost, low service cost (less number of parts), no oil change, little brake wear, etc. Lower carbon dioxide emissions and a decrease in reliance on fossil fuels when renewables charge them. This means that the existing electric vehicles are capable of meeting daily travel needs, but better accessibility to charging facilities will ensure higher levels of adoption.

5.3 GIS integration analysis

5.3.1 Data gathering

Relevant data pertaining to EV sites for currently operational charging stations are included in the datasets collected, which were easily integrated with the already in existent fuel stations, petrol pump locations, thus making available existing charging stations mapping the existing network. Facilities include proximity to parking, office, commercialization hubs, and residential areas.

5.3.2 Techniques that analyze GIS

Overlay Analysis: This analyzes the land use, traffic movement, existence of stations, and amenities with different layers. It prioritizes areas that have a heavy population of commercial hub areas and very busy areas. The result of this analysis will give major areas of the first wave deployment for EV stations.

Proximity Analysis: Normative distances include the categories of residing and commercially centered by train tracks or highways or malls, offices, and parking. This directly informs the infrastructure placement to enrich the experience of end users.

Scoring system for site selection: The candidate site will be ranked as: Proximity to Major Roads (easy access earns higher scores). Traffic Density (high traffic areas get priority). Land Use Suitability (influenced by zoning regulations). Amenities nearby (shops, banks, and public transport). Electric Grid Strength (stability of power supplied). Safety & Security (well-lit, staff presence in areas). Distance from Existing Stations to Each Other (to make sure coverage is maximized). The final stage of analysis selects location with high scores as optimum sites for the deployment of EV stations.

5.3.3 Findings of great importance

Commercial spaces, IT parks, malls, and public pay parking are the most promising areas. Stations are conveniently placed near highways and centers of cities. Distribution of charging stations therefore is even, thereby reducing range anxiety among electric vehicle users in Pune. Summary of considerations inherent in the shortlisted final sites vary among factors such as traffic density, population density, existence of charging facilities, petrol pumps, and occupational sites.

- Uniform coverage throughout Pune means fewer gaps.
- After thorough Spatial and Non-Spatial Analysis we found out probable EV locations where various factors were concluded like traffic, population density of EV vehicle in that area, existing EV station, petrol pumps & working spaces.
- Green rectangles: Probable location for EV station.
- Red rectangles: Existing EV stations.

Figure 4: Probable EV Station Location in Hinjewadi Phase III



Source: Compiled by author

Figure 5: Probable EV Station Location & Existing EV Stations in Hinjewadi Phase II



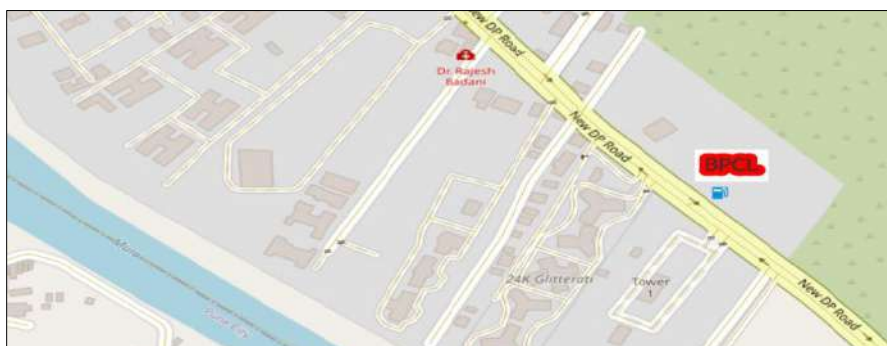
Source: Compiled by author

Figure 6: Existing HPCL Petrol Pump in Hinjewadi Phase II



Source: Compiled by author

Figure 7: Existing BPCL Petrol Pump in Pimple Nilakh



Source: Compiled by author

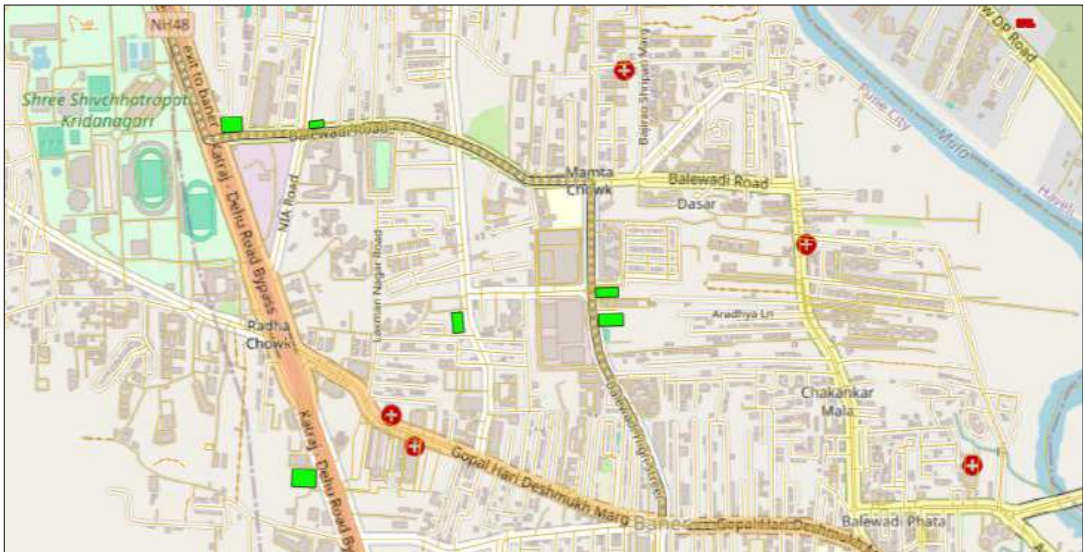
Figure 8: Probable EV Location & Existing HPCL Petrol Pump & EV Station in Hinjewadi Phase II



Source: Compiled by author

- Toilets: Essential for comfort while waiting for charging.
- Wi-fi-enabled work pods: Allowing users to productively spend their time while waiting.
- Cafeteria or outlets for quick food: Beneficial to users during long charging hours.
- Waiting lounge: Providing space for users while their vehicles are charging.

Figure 11: Probable EV Station Location in Balewadi



Source: Compiled by author

From the regression and correlation analysis, it appears clear that there exists a strong preference amongst the majority of users for spending more time in the charging stations if such facilities are available. The cost per unit and rate of charge being also important factors for the public charging activity further emphasize the need for strategic locations with proper facilities.

7.0 Conclusion

The analysis suggests that Balewadi and Hinjewadi are ideal sites for the establishment of electric vehicle (EV) charging stations. This information could further benefit businesses like Tata and other established companies regarding maximizing the installation of charging stations in high demand and user-demand areas. Then, station operators could enhance user convenience and encourage EV uptake through other incentives like restrooms, including workstations with Wi-Fi connection, and eating areas. Infrastructure provision in these zones thus requires urgent policymaker attention incentives and regulatory support. Public private partnerships can speed restrictions that should be eased for the changeover to electric mobility by accelerating

infrastructure development efforts. Advances that continue in battery chemistry combined with good charging speed and compatibility for renewable energy source charging will also emerge as important differenters in optimizing the long-term productivity from EV charging stations.

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CHAPTER 98

Marketing Strategy for Premium Housing Segment in Pune

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ABSTRACT

This research investigates the marketing strategies utilized in Pune's premium housing segment, focusing on developers' efforts to meet the rising demand for high-end residential properties. The study examines the role of digital marketing, on-ground promotions, and referral programs as primary strategies. Digital marketing emerges as the most prominent approach, with developers employing social media, search engine optimization, and virtual property tours to attract affluent buyers. On-ground promotions, including property exhibitions and site visits, maintain importance for fostering personal engagement, though they are less frequently employed. Referral programs, while underutilized, exhibit potential for building customer trust and leveraging satisfied clients' networks. The study also explores the spatial distribution of premium housing projects, emphasizing high growth areas such as Wakad, Baner-Balewadi, and Hinjewadi, which benefit from IT hubs, robust infrastructure, and lifestyle amenities. Established regions like Koregaon Park cater to niche luxury markets, while emerging localities such as Pimple Nilakh and Akurdi offer opportunities for affordable premium housing development. Using a combination of quantitative and qualitative methodologies, the research identifies a trend toward multi-channel marketing strategies tailored to consumer preferences in the premium housing sector. Recommendations for developers include enhancing their digital presence, innovating on-ground promotional activities, and leveraging referral networks to ensure sustained customer retention. These findings provide actionable insights for stakeholders in Pune's real estate market, contributing to a nuanced understanding of marketing dynamics in the premium housing segment.

Keywords: Premium housing; Digital marketing; On-ground promotions; referral programs; Pune real estate.

1.0 Introduction

Pune's Premium Housing offers developers the lucrative opportunity to serve wealthy buyers looking for exclusiveness, luxury and lifestyle enrichment. The deeper understanding of the efforts and motivations of highly networked individuals pays off in this market.

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Nuances and strategic approaches of premium apartments reveal excellent placement by developers. For the luxury segment of the Pune real estate market, that's offering residential buildings that afford comfort, status and a little bit of fame. Pune's appeal to the wealthy is mixed and cultural, cosmopolitan and driven by mad buyer preferences for the kind of places that can call themselves luxury anything. The city's well-earned reputation as the kind of place to go for an education that really means something, not to mention the half-dozen top-notch universities and several globally fluent, life science inflected entrepreneurial communities that it serves, has made Pune a priority entry point for business schools. The way that the place's climate, topography and blend of historic and modern architecture conspire to make its two most visited neighborhoods—Koregaon Park and Kalyani Nagar—call here and call you here, seals the deal for many. Although some luxury buyers apparently place a premium on green and smart home technology components, which was promised here during the Pune International Business Summit in March of this year, the main feature by which developers can sell the smarthomes of Koregaon Park and Kalyani Nagar is also the main thing that's supposed to make these developments not just residential but also real and living communities.

2.0 Review of Literature

Reviews highlight the increasing impact of online platforms like Luxurystate.com on luxury real estate transactions. They emphasize how these platforms enhance accessibility, convenience, and visibility, reshaping the buyer-seller interaction dynamics (Online Platforms' Influence, 2016). A conceptual framework introduced in the literature emphasizes a comprehensive marketing approach for luxury residential properties.

It stresses the integration of functional, experiential, and symbolic dimensions, suggesting that successful marketing goes beyond physical attributes to incorporate emotional and symbolic appeals (Holistic Marketing Strategies, 2018). The studies underscore the economic significance of natural amenities in urban property valuation. They indicate that proximity to such amenities influences housing choices, with buyers willing to pay a premium. This highlights the importance of environmental conditions in property valuation and conservation efforts. (Natural Amenities' Value, 2019).

The examination of market volatility's effects on developers' profitability perceptions reveals insights into the real estate market complexities. It underscores how bounded rationality and learning behavior influence developers' decisions, impacting profitability and supply, particularly in volatile markets (Market Volatility's Impact, 2021). Literature stresses the need for strategic marketing regardless of economic conditions. It suggests that developers should differentiate themselves and adopt proactive marketing strategies to attract potential buyers amidst market fluctuations, thereby navigating both booming and declining economies effectively (Strategic Marketing Amid Economic Fluctuations, 2023).

3.0 Objectives of the Study

- To Explore the current landscape of the premium housing segment in Pune, including demographic trends, market dynamics, and competitive forces.
- To Identify key factors influencing buyer preferences and decision-making processes within the premium housing market of Pune.
- To Analyze the effectiveness of existing marketing strategies employed by developers and marketers targeting the premium housing segment in Pune.
- To analyze emerging trends and innovations in luxury living experiences, including sustainable design, technological integration, and lifestyle amenities in Pune.
- To Develop a comprehensive understanding of the unique challenges and opportunities encountered by stakeholders operating within Pune's premium housing sector.

4.0 Research Methodology

The following steps achieve a qualitative and quantitative approach to data collection instead of a mixed methodology approach. Locations of sample projects and developers can be approached and surveyed, plus information derived from those on commission at the project site located. For example, in the research inquiry, the interview questions are focused on the success and failure of marketing due to attunement to elite demographics and needs of buyers. Success stories will be documented for further micro-marketing success in this arena.

- *Step 1: Literature Review:* There exists a literature review relative to the existence of nature. A literature review will include premium housing segment history, the state of the real estate market, how premium products are marketed across metropolitan India and Pune. The literature review will conclude with a case study of Pune which resonates with good marketing of premium housing projects.
- *Step 2: Market Assessment:* A market assessment of premium housing in Pune will be constructed of developers and premium housing projects, current housing schemes, housing performance projections, expectations of premium housing developments and their subsequent marketing.
- *Step 3: Customer Surveys and Interviews:* Valid inquiries need to be generated from real estate developers, brokers, architects in Pune, India, and any high-net-worth individuals to gauge their feedback relative to valid pricing, challenges vs. expectations for potential housing development and revenue-generating projects for premium housing. Inquiries will revolve around value relative to growth and brand perception, and what should never be upheld when pricing something above general equity value pricing.
- *Step 4: Customer Segmentation:* Using the information gathered from this step, premium housing customers can be segmented into groups of need with relative priority for value of potential housing features and real estate marketing efforts.

- *Step 5: Data Analysis:* An analysis of this step will reveal the greatest concerns of prospective premium housing customers which will inform assessment for any group looking for a marketing effort for this buyer demographic. It will also show how to set one's effort apart from any other housing effort in Pune, marketing this new luxury undertaking as not what everyone else desires.
- *Step 6: Marketing Strategies:* Up until this step of the research project and understanding relative to segmentation, the answers gleaned will provide the appropriate avenues for this audience per segmentation answer, required messaging, and additional promotional efforts required for successful marketing.

5.0 Data Collected

The information for this project pertains to marketing strategies from secondary research conducted by the various real estate firms involved in this project. The determined strategies include positioning relative to such findings and customer engagement and responsiveness learned. These come from questionnaires and interview answers from field research and case study projects from Dream Works Realty, Nandan Buildcon, Kasturi Housing, SSD Group, Jethani Group, Clone Properties, etc. The learnings in regard to marketing, target audience, customer service, and projects in development. For instance, Dream Works Realty emphasized affordability with a first-time homebuyer target niche that did not need digitally oriented exposure to project effectively enough by referral and word-of-mouth. On the other hand, developers such as Vikram Developers and The Arista emphasized high-end luxury housing, digitally branded developments, private parties, and even engagement with local influencers as marketing engagement to attract. High Net Worth Individuals.

Furthermore, the research provided quantitative data regarding the marketing focus. For instance, attributes that drive enterprise intentions include sustainability, luxury, cost-effectiveness, smarthome technology, consumer customization, and regional integration. Many are leveraging technological advancements to enhance buyer experience, such as VR tours, social media marketing, and engagement/content creation on Instagram and Facebook. In addition, the study advocated a path not taken by the referral programs—namely, a second study to suggest that those developers create more long-term clients through bonus loyalty and referrals to new clients. Finally, those developers who did use a combination of online and offline marketing also generated more leads—especially from experiential even and workshops. Ultimately, this analysis will contribute to the body of knowledge concerning the evolving role of marketing in the luxury/residential real estate sector of Pune. When a perpetually expanding market is in play, it's crucial for developers to understand intermediary digital professionals and personalization and positioning strategies.

6.0 Data Interpretation

The current property market in Pune is actually molded by certain patterns and specific advertisements employed by the companies that are into real estate. The sustainability factor has become an extremely important decision maker criteria for buyers, as the developers like Nandan Buildcon, Kasturi Housing, and RGS Forte are now infusing their projects with cool-tech systems, rainwater harvesting, and holistic living. The themes of luxury and exclusivity stand tall in this sector, as companies such as The Arista, La Moda, ANPCorp in particular are focusing on their most ritzy residential amenities - private elevators, concierge services, and high-end finishes. Specific marketing tactics which involve by invitation only property showings and VIP memberships are yet another factor that makes them more attractive. Digital marketing and technological advancements in the property industry are now massive influences in buyer engagement such as Dream Works Realty and Ace prime Infra who are using 3D virtual tours, social media campaigns, and IoT-enabled smart home options to catch the attention of tech-savvy consumers.

Not least, personalized customer experiences are on the rise, thus the examples of this practice by Kasturi Housing and ANP Ultimusas they deliver the customers a private property tour, which is different from the others on the market, as they also offer interpreted colors, and post-sales services check-ins that help build a strong and loyal customer base. Apart from that, the strategic location and the ease of accessibility play a very important role in the case of the property developers like Kings Marque and ANP Corp, who primarily settle in well-connected regions, near business centers, educational institutions, and other important services, thus challenging properties to working professionals and increasing market value if not in the way of better road communication.

7.0 Visual Interpretation

The overwhelming reliance according to the Pune real estate market is digital marketing; nearly every firm leverages features to sell online and whether that means social media, paid digital ads, or virtual reality tours, the prevalence suggests a media-heavy population and an opportunity and advantage rendered more online through targeted efforts. However, while online efforts are the main source of funding for campaigns, marketing on the ground is used to a far lesser extent. This subverts the dependence upon tangible resources which generate greater trust and connection—property expos, kiosks, and open houses are all efforts that put a proverbial (or literal) name to face and allow brokers of these high-stakes endeavors to get personal—but to a far lesser extent.

These are more selective, expensive, and less transferable than their digital counterparts which allow for ease of access and replication. The referral program is not something transferable across the board; firms may find it's too variable based on their own networks and

if customer satisfaction is high enough to refer within the luxury real estate market. But it can be effective as a program if it brings in well-networked members of the luxury class. Thus, a cross-section of the firm indicates a multi-pronged approach engages the consumer best. retain, whereas in-person and word-of-mouth efforts allow for better engagement with the clientele. For instance, Bakthi Group, Dream Works Realty, and Jethani Group appear to do some of both, but ANP Ultimus and 66 Avenue Group only operate online because of cheaper expenses and the potential for greater reach. Ultimately, however, these agencies need to pay attention to firm professionalism.

7.1 Digital marketing insights

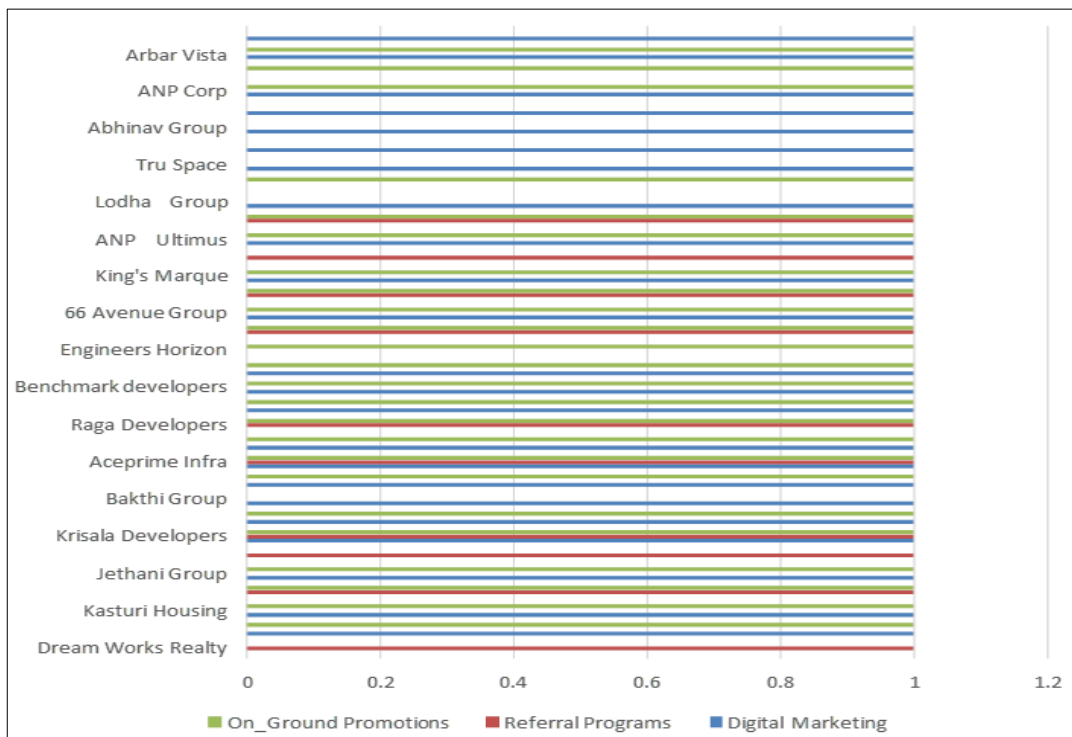
Ultimately, increased on-ground efforts are needed to supplement digital marketing options with social media ads, influencer outreach, and more active assets like Augmented Reality/Virtual Reality tours. Many of the housing options rank high on Google due to local SEO efforts, so the housing companies can earn more equity with high-end real estate customers searching for housing options specifically in Pune. In addition, more on-ground efforts would be brand equity building for the brands and of interest to consumers with membership experience and niche tours. Even integrating referral campaigns could be one immediate tapped option within the luxury housing sector for bonuses on both sides. Ultimately, while digital marketing has the upper hand for one of the housing options over the rest in Pune, there are still on-ground efforts needed to establish consumer trust and experiential offerings. In addition, while referral campaigns represent one of the least tapped opportunities, those housing companies not afraid to think outside the box with strategic loyalty campaigns could see this as a successful opportunity for implementation down the line. Ultimately, a hybrid of the two is needed for all housing options to properly sustain themselves in this emerging market. Pune's real estate market is highly enmeshed in expected marketing efforts via digital.

Figure 1: Engagement

Engagement 📊					
Metric	lodhagroup.com	truspacehomes.com	aksuranadevelopers.co...	abhinavgroup.co.in	rgsrealty.com
📅 Monthly visits	88,856 🏆	401	749	1,392	625
👤 Monthly unique visitors	45,296 🏆	67	477	581	305
👤 Visits / Unique visitors	1.96	6.03 🏆	1.57	2.40	2.05
🕒 Visit duration	00:01:08	N/A	00:01:07	00:02:55 🏆	00:00:57
📄 Pages per visit	2.80	1.02	2.31	3.23 🏆	1.97
📉 Bounce rate	61.28%	40.46% 🏆	60.38%	63.74%	40.65%
📄 Page Views	248,794 🏆	408	1,734	4,496	1,234

Almost every cited avenue employs online efforts to connect with their potential markets. Social media, virtual tours, and targeted online opportunities are ubiquitous, as a digitized first impression aesthetically benefits time and assures motivation clarity for buyers, sellers, and investors. Yet where foundations of other markets exist, ground-level participatory efforts exist only somewhat, meaning a secondary approach capitalizes on human interactions, which builds trust for deeper investment. Companies do expos, kiosks in malls and sports arenas, and open-house tours.

Figure 2: Strategies used by Companies

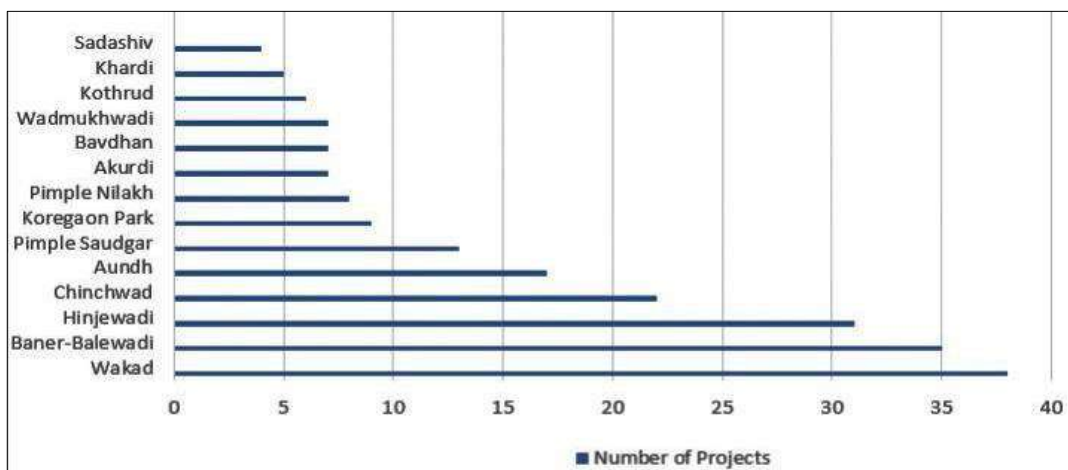


These multichannel typical efforts emphasize the success of physical outreach for highly personal investments; yet these efforts are more costly and less manageable than a pure digital effort. Finally, it seems minimal companies utilize referral programs, as this effort requires investment from both company and buyer sentiment. Unfortunately, such efforts are too tenuous for the high-stakes housing game. However, for agents who aren't opposed to working with more networked clients with complicated lives and schedules, this works nicely in the luxury realm. Yet otherwise, others rely upon their referral program as the secondary effort among others.

Yet as long as industry trends suggest that referring real estate programs works to market real estate in all channels (Dream Works Realty's secondary channel is referral programs), ANP Ultimius and 66 Avenue Group focus on marketing opportunities digitally only for better stabilization of cost-value efforts long-term.

Companies should focus on the future for the potential of continued digital supremacy; targeting ads, influencer outreach, and AR/VR technology could also help. They even rely upon local SEO for potential buyers from out of town hoping to settle roots in Pune; yet ground-level opportunities need to improve via luxury-level events and personalized home showings for better market sentiment. They can include high-end referral programs to achieve this previously unused channel for incentive gain in luxury housing as well. Ultimately, digital marketing is the mandate of real estate marketing efforts in Pune; however, physical participatory levels build credibility for trust and experiential opportunities with little interest in referral programs that could be idiosyncratic into creatively loyalty-driven facets on behalf of companies hoping to change perception. A hybridized approach across the blended channels will keep companies competitive within this saturated yet growing market.

Figure 3: Strategic Location Preferences



Pune is a prime example when it comes to unique trends in the real estate sector with the distribution of projects and marketing strategies. The west is the most advanced region, especially Wakad, Baner-Balewadi, and Hinjewadi, which are preferred residential areas because of their location near the IT offices and their developed infrastructure. Located in the green and posh surrounding, Koregaon Park is famous for its luxury properties, while areas like Akurdi are also showing promises for future expansion. Digital marketing is the dominating avenue of promotional strategy, with companies using targeted advertising, social media, and

virtual property trips to attract buyers. However, traditional on-ground methods, such as property exhibitions and open houses, also play a significant role in establishing confidence and engaging the potential buyers. Referral plans, although not so typical, could perform in the premium sector of housing as an instrument that personifies the specific property.

Website traffic and engagement metrics suggest a trade-off—while some high-traffic sites battle with user retention, lower-traffic websites often display stronger visitor engagement. Search engine optimization, immersive terrain and data-based campaigns are effective digital marketing strategies that can boost visibility and conversion rates. Also, joining sustainability programs, customer-oriented buying procedures, and region-oriented marketing are the tools for a brand to stand out in the tough luxury real estate competition. Besides, Developers are able to improve customer loyalty, if this way of thinking follows them by organizing community-based activities, exclusive events, and tailored experiences. These findings indicate that a full-scope marketing strategy—fusing digital innovation, offline connection, and customer-oriented improvements—is the fundamental requirement for the durable success of the new landscape at the Pune real estate market.

8.0 Analysis

Focus is laid on Pune, India, as the mainstay of this project is a wide-ranging study that brings out the fine details of marketing strategies that aim at the premium housing segment, specifically in Pune, India. As researchers, we go through this time and again to single out and know the nitty-gritty of the luxury market at this locale. The paper adds human meticulous research to its key element that gives it the weight to offer invaluable insights into the consumer's mind, highlighting the driving forces that influence them. Such a grasp of consumer habits sets the baseline for the development of strategic proposals. This study, in turn, can provide actionable plans that ensure prime properties not only remain unique but that they also have a 'wow factor' for potential buyers. Among other things, the strategies may involve digital platforms to enable affluent audiences to reach that will be achieved through effective marketing of the product, a captivating story that appeals to the aspired lives as well as making sustainability a central part of the value proposition a very big influence in the discerning choices of the luxury buyers will be.

Moreover, it is more than possible that the document will be woven into an intricate web of theoretical and practical references when the author refers to the literature. The report under consideration may combine empirical and theoretical studies as it reflects on the serious side of the implications through detailed analysis of the literature. This academic paper mostly focuses on customer psychology, market analysis, as well as marketing fundamentals, which are the main theoretical sources that have been used to develop and then refine the suggested strategies. The persuasive presentation of the intersection of market demand and consumer behavior, with the help of company players is an instrument for them to conceive of and execute

convincing strategies that stay in line with the target audience, which in turn results in the success of the sector in Pune.

9.0 Recommendation

To compete in the premium accommodation market of Pune, developers must perform better digital marketing strategies. Increasing social media campaigns, virtual tours, and 3D walkthroughs together with SEO-driven content will be an excellent move to attract customers from within this target audience. These two companies have definitely proven that these methods work by creating inquiries successfully, not to mention the effective marketing of Ace prime Infra and Skyline Enterprises.

Sustainability is once again the most critical thing that companies are focusing on as it affects the nature around them, with companies participating in this effort like Kasturi Housing and Nandan Buildcon, integrating green features like LEED/IGBC certifications, solar power systems, and rainwater harvesting to attract environmentally conscious buyers. Providing a personalized experience for their customers is a key prerequisite for their satisfaction, and this is something that ANP Ultimus and Kasturi Housing do, by offering personalized property tours, interior design consultations as well as post-sale support. Developers should invest in CRM systems to enhance customer interactions along with other aspects, build long-term loyalty. Strategic location marketing is also valuable as demonstrated by Kings Marque and Prasanna Param who put connectivity issues to business hubs and essential services at the forefront making the luxury living more convenient for professionals and families. Furthermore, community engagement through exclusive events, open houses, and online forums should be encouraged as one of the Raga Top Towers and Lifestyles' Royal Oak's practices and it can help to strengthen buyer relationships and enhance brand loyalty. By implementing these strategies, developers can build and enhance their market positioning power in the luxury housing segment.

10.0 Conclusion

The marketing strategies compared for luxury/residential properties in Pune found digital marketing to be the most utilized, ground marketing as relatively used, and the referral program as the least used. Digital marketing has the widest reach and cost-effective possibilities from social media and targeting within the residence location/online; ground marketing creates non-scalability but a curated personal subscription experience through site visitation and property exhibitions. The opportunities for improvement/growth based on geographical distribution were found mostly in Western Pune—Wakad, Baner-Balewadi, Hinjewadi—as the most established areas of current/increased equity predicted in the future. The emerging cities are Pimple Nilakh and Akurdi, which have a greater amount of developments as of late but do

not have equity as of now for resale or price for infrastructure. Other emerging cities have been established for longer— Koregaon Park, Aundh—and Sadashiv and Kothrud only had a few developers—redevelopments versus new developments.

Developers acquire their clients through a multi-channel approach, but this is primarily from experiential marketing after digital leads have been accumulated. Developers rarely compel a consistent long-term customer retention strategy through the referral program. Thus, real estate agencies should integrate digital and ground efforts for their equity, focus on the more recently developed micro-locations for infrastructure efforts, and include creative out-of-the-box collaborative engagement efforts. Following this research and applying it with real-world successful technological efforts (i.e., virtual reality tours) and experiential efforts will gain a reliable foothold in the market while catering to consumer needs within the luxury/residential property market of Pune.

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CHAPTER 99

Monopile Foundations in Marine Infrastructure Projects

Madhanraj Murugesan¹ and Pratibha M Alandkar²

ABSTRACT

The construction of bridges in marine environments poses unique challenges that demand innovative solutions to save the ecosystem along with the time and construction cost. Monopiles have emerged as a pivotal component in such conditions and have much reduced impact on marine environment and ecosystem. Monopile foundation is studied to find a good idea for design. It primarily illustrates why a large diameter pile foundation is preferable than a group pile bridge foundation. The motivation behind this study is to analyze the performance of monopile foundation over group pile foundation in marine conditions. This study explores the challenges and advancements, scheduling in utilizing monopiles for such critical infrastructure projects. Through case studies and technical discussions, the paper aims to provide valuable insights for those who are involved in marine and bridge engineering projects.

Keywords: Monopile; Deep foundations; Infrastructure; Marine; Reverse circulation drilling.

1.0 Introduction

The Monopile foundation consists of a single, generally large-diameter structural element that supports the entire load of the above-surface structure. This system is followed because time consumption is less compared to other foundation techniques. Monopile is a hard engineering method of construction in marine conditions where the wave impact is more, and climate is not helpful for the construction works.

The pile foundation undergoes very high combined loading (vertical & lateral), so it is necessary to test the pile for both vertical loads to understand the bearing capacity and for lateral loads to understand the flexural capacity. We will look deeper into the challenges in monopile construction, technologies used in construction, case studies of successful projects, and outline future research directions. Through this study, we aim to study the benefits of Monopiles over pile groups in offshore bridges with case study.

The main objective of this paper is to study the geotechnical parameters and design parameters of Monopiles along with the construction method and time cycle of Monopiles and group piles through actual site visit and case study.

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Figure 1: Bridge Cross Section with Monopile

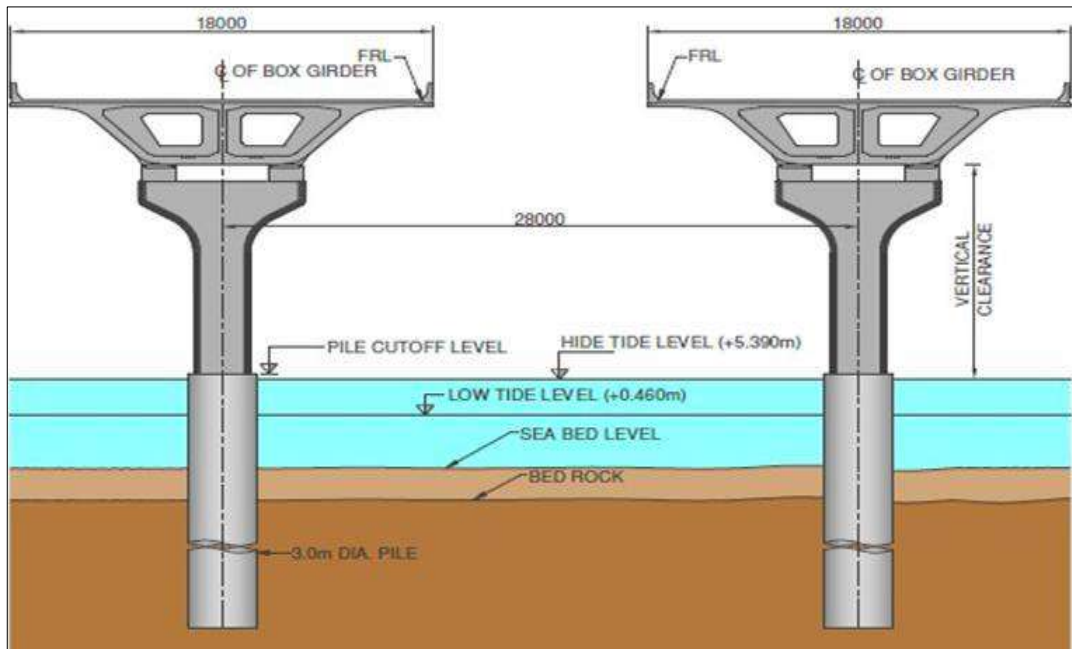
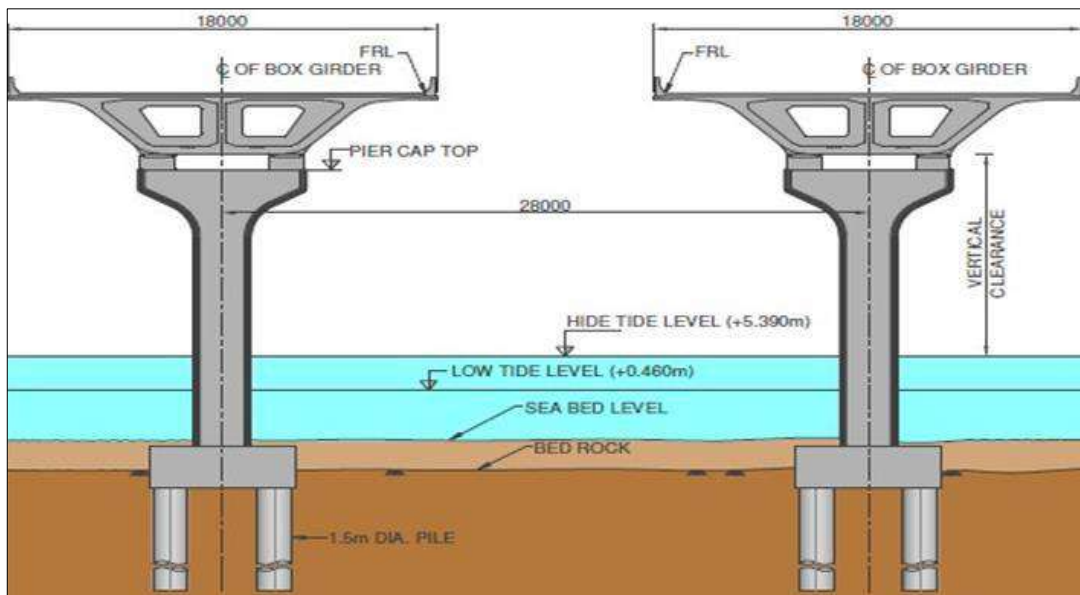


Figure 2: Bridge Cross Section with Group Pile



1.1 Advantages and disadvantages

Monopile construction has several advantages over the group pile system in a marine construction project.

- The construction time can be reduced to a large extent.
- The cost-effective technique compared to the group pile system.
- Minimal disruption to the marine ecosystem as one location is drilled.
- Reduced barge movements and positioning which in turn reduced the carbon footprints.
- No necessity for pile cap construction and its design.
- Reduced the overall cost of the project.

There are some disadvantages in the construction of Monopiles like,

- The preliminary design and its cost are more.
- Expert involvement is required, which in turn increases the cost.
- High precision is required in design and execution.

2.0 Case Study

The construction work of Mumbai's Coastal Road project was recently completed and opened to the public.

Figure 3: Model Representation of Monopile and Bridge Deck



The preliminary design of the project included group pile system both in land and marine sections. The group pile system found to be time-consuming, and the Engineer agreed to introduce the new technologies to ensure timely completion of work and decided to go with Monopile technology (Leibach 2003). Total 99 piles were done using this technology in Package-1 of Mumbai Coastal Road project.

This technology is environmentally friendly as it reduces construction time and costs significantly. Generally, while constructing a bridge above sea, river, lake, creek among others the ground pile technology is mainly used. However, in this technology for each pier, four or more piles need to be built. While in large diameter pile technology a single pile of large diameter can be raised at one span. Following which, the numbers of piles have been reduced to 99 from 426. By using the large diameter pile technology each pile diameter was of 2.5 meters, 3.2 meters and 3.5 meters.

3.0 Reduction in Scope of Foundations with Monopile

With the use of monopile technology in the project, the number of pile foundations reduced drastically, and it helped the team to complete the project within the timeline. The following tables (see, table 1 & 2) show the reduction in pile foundations with the adoption of Monopile technology. Also, we can see the probable savings (see, table 3), (Khan *et al.*, 2024) with the adoption of monopile technology.

Table 1: Original Scope

Item	Amarsons Interchange	Haji Ali Interchange	Main Bridge
Total Length	1825m	6696m	1410m
No. of spans	60	224	48
No. of footings	64	232	58
No. of piles	256 no's	928 no's	462 no's

Table 2: Scope Change with Monopile

Item	Amarsons Interchange	Haji Ali Interchange	Main Bridge
Monopiles	32 no's	50 no's	17 no's
Group Piles	48 nos	728 nos	205 nos
Reduction in piles	176 nos	150 nos	240 nos

The total of 1646 piles (approx.) was reduced to 1080 piles with the inclusion of monopiles in the seafront area of the project alignment.

Table 3: Probable Savings and Additional Costs

S. No	Probable Saving Items	Probable additional cost Items
1	Number of piles	Design and Analysis
2	Reinforcement	Construction Expertise
3	Concrete (Pile cap)	Drilling Equipment (RCD)
4	Cofferdams (For pile cap)	Additional costs

4.0 Geotechnical Investigation and Design

Geotechnical Investigations are very important for the design of Monopiles. Unlike group piles, we need the GTI for each and every Monopile. The GTI included Ground characterization and detailed analysis of the geological data in each pile location. The same has been carried out for the design of Monopiles. The geological Profile is developed first. Then derive characteristic values of geotechnical parameters appropriate for each design limit state, the design ground model will be presented in updates of the GIR. Pile load bearing capacities based on the design standards are then produced followed by the identification of critical load cases for the determination of the rock socket length based on compression and lateral load capacity. The monopile rock socket length is then determined based on the lateral pile capacity calculation and the same is checked. Finally, using L-Pile analysis, derive P-Y curves to model the stiffness of the ground supporting the monopile and in the Midas model which combines the behaviour of the monopiles and superstructure.

4.1 Ground characterization

The ground characterization includes the soil description and basic geology of the location along with the starta in that particular work location. It is also concentrating on Soil strength, Soil stiffness and Rock Quality Designation (RQD) (Gurnani *et al.* 2018).

4.2 Detailed analysis

In the detailed analysis, soil models, testing, Geotechnical reports were assessed, and the data is used in the design of the monopiles. The Geotech reports include the Factual report and Interpretative report and with both the geotechnical design is carried out. This also gives the data about the pile socket length (Krolis *et al.* 2010) depending on the load coming from the structures.

The guidelines for large diameter pile design include the calculation of,

- Rock mass modulus
- Lateral Stiffness
- Pile socket length
- Shaft Bearing Resistance
- Pile Settlement
- Lateral resistance.

5.0 Structural Design

5.1 Design loads

Dead loads: Unit weights of materials are defined in IRC: 6-2017, Cl. 203, are as per the following:

Material & Unit Weight
Plain Cement Concrete - 25 kN/cu.m
Reinforced Cement Concrete (RCC) - 25 kN/cu.m
Pre-stressed concrete - 25 kN/cu.m
Structural steel - 78 kN/cu.m
Earth compacted - 20 kN/cu.m
Asphaltic concrete in wearing coat - 22 kN/cu.m

In addition to the above, unit weight of mass concrete and green concrete will be taken as 24 kN/m³ and 26kN/m³ respectively.

5.1.1 Superimposed dead loads

A load of 5.0 kN/m is considered for utility services which is proposed to be carried through the inside of main line box girder (load to be confirmed based on MEP requirements). For interchange arms, no additional load will be considered for utilities. A load of 0.9 t/m is considered for weight of each crash barrier. Noise barrier loading is to be considered for those stretches where it is required, and load will be considered as per the cross section of noise barrier.

5.1.2 Water current forces

The portion of bridge which may be submerged in running water shall be designed to sustain the horizontal pressure due to force of water current as per the stipulations of Cl. 210 of IRC:6-2017. Maximum mean velocity of water current shall be taken as 1.5 m/s in any direction for design purpose based on the current speed data.

5.1.3 Buoyancy force

100% buoyancy will be considered while checking stability of foundation irrespective of their resting on soil/weathered rock/or hard rock. However, the maximum base pressures shall also be checked under an additional condition with 50% buoyancy in cases where foundations are embedded into hard rock.

5.1.4 Wave and abnormal wave forces

The effect of waves on the structure will be considered in accordance with Cl. 5.7 of IS 4651 Part 3 -1974. For abnormal wave loads, for the design wave heights (taken as 1.89 m as per NIO report). Based on chapter 3 of NIO report, the maximum amplitude of tsunami wave is only 0.73 m and hence it is considered as less critical.

5.1.5 Wind loads on structure

The basic wind speed to be adopted in the wind load determination is defined as per Cl. 209 of IRC: 6-2017. The basic wind speed at 10 m height in Mumbai, for 50-years return period, is 44 m/s. As per Cl. 209.2 of IRC:6-2017, the wind force is based on hourly mean wind speed (V_z), and horizontal pressure (P_z). The corresponding values to a basic wind speed of 33 m/s, return period of 100 year, for bridges in flat topography is presented in Table 12 of IRC:6-2017.

5.1.6 Differential settlement

Differential settlement of supports is considered as a permanent load. The piles are socketed in rock and there might not be any differential settlement as such. However, for design purpose, 6mm differential settlement between the supports will be assumed as long-term loading.

5.1.7 Earthquake (Seismic)

The seismic design is based on the IRC:6-2017, being the design spectrum defined as per the assuming seismic Zone-III and Zone factor Z of 0.16 and Importance factor I of 1.5.

5.1.8 Barge impact on bridges

The Barge impact force and kinetic energy shall be calculated as per Cl.220 IRC:6-2017. All the piers in the navigational spans of the Main Viaduct shall be protected by providing suitable fender type protection system. IRC:6-2017 states that the bridge should be designed to minimise the risk of structural failure of a bridge component due to collision with a barge. The risk of damage to the barge should also be minimised.

5.1.9 Scour analysis

The purpose of the scour analysis is to estimate the total scour depth at the base of the bridge piers structural supports. The main purpose of this analysis is to evaluate the depth and extent of scour (Da-Wei Guan et al. 2021) during design working life operation of the bridge, so that its potential effect on the design capacity of the bridge foundations can be assessed.

5.2 Design of monopile

The design of monopiles follows the international standards as well as the Indian Standards. The following table (see, Table 4) shows the details of the codes used in the design of monopiles.

6.0 Timecycle for Monopile Construction

The construction time of monopiles is much less compared to the pile group system. The monopile construction normally takes 5-7 days depends on the pile depth and geology of the pile location.

Table 4: Monopile Design Codes

S. No	Design Standards
1	AASHTO LRFD Bridge Design Specifications (2017)
2	GEC-09: FHWA Design, Analysis, and Testing of Laterally Loaded Deep Foundations that support Transportation Facilities design Methods
3	GEC-10: FHWA-NHI 18-024: Drilled Shafts - Construction Procedures and Design Methods
4	IRC – 078 (2014): Standard specification and code of practice for road bridges, Foundations and Substructure.
5	IS 2911-1-2 (2010): Design and Construction of Pile foundations – code of practice, Part 1 Concrete Piles: Section 2 Bored cast in-situ concrete piles.
6	IS 1892 (1979): Code of practice for subsurface investigation for foundations.
7	IS 12070 (1987): Code of Practice for Design and Construction of Shallow Foundations on Rock.
8	IS 14593 (1988): Design and construction of bored cast in situ piles founded on rocks
9	BS 5930 (1999): Code of Practice for Site Investigation.
10	Caltrans (2015) <i>Bridge Design Practice</i> (Volume 2: Substructure Design, Chapter 16 – Deep Foundations)

Table 5: Timecycle for Monopile

Activity	Days
Guide frame positioning and Liner & RCD Installation	1
Drilling	2-4
Rebar cage lowering (In parts)	1
Concrete Pour	1
TOTAL DAYS FOR 1 PILE (On average)	5 – 7 days

The piles are constructed using the Reverse Circulation Drilling technique which considerably reduced the construction time. Table-5 gives a simple insight of the activities associated with monopile construction.

7.0 Timecycle for Group pile construction

The group pile system will take more time (see, table 6) when compared with the monopile method. The pile group system is effective for small scale infrastructure projects. In marine infrastructure projects, monopile system is found effective as the timelines are very critical compared to a project in land. Moreover, the monopile system eliminates the construction of pile cap works which takes much time.

The construction of a 4-pile group will take approximately will take a minimum of 10 days (Maddela Jyothi Kiran et al. 2021). Once the piles are constructed, pile cap construction begins. The timeline of pile cap construction is given below (see, Table 7),

Table 6: Timecycle for Group Pile

Activity	Days
Guide frame positioning & Liner Installation	0.5
Drilling (Hard Rock)	1-2
Rebar cage lowering (In parts)	0.5
Concrete Pour	0.5
TOTAL DAYS FOR 1 PILE (On average)	2.5 - 3.5 days

Table 7: Timecycle for Pilecap Construction

Activity	Days
Cofferdam installation with pile cap base slab	1-2
Reinforcement installation	3
Formwork and Alignment	1
Concrete pour	1
Formwork removal	1

On average the pile cap construction will take about 7-8 days which is not necessary in case of monopile. In short, the time taken to construct a monopile up to pier starter will take maximum 7 days whereas in group pile system it will take minimum 20 days which is comparatively more time consuming (Smita & Varghese 2022). On an average 60% of time is saved by adopting the monopile technique which helped the contractor to achieve the target on time.

8.0 Monopile Construction using RCD Technology

Monopile construction was done using Reverse Circulation Drilling (RCD) technology. The construction of Monopile includes the following steps.

8.1 Liner pitching and driving

The prefabricated liner with bottom shoe is shifted to the location and is lifted with the help of the Service crane. The liner is then placed in the piling platform and lowered gently till it reaches the seabed level. After that, the position of the liner (verticality) is checked. Once it is found within the limits, the liner is driven into the seabed with the help of vibro-hammer (Figure 4) of suitable capacity (12.5 MT capacity used). During the driving, care should be taken to avoid the liner deformation at the bottom and the liner position is checked after the completion of driving.

8.2 RCD mounting and drilling

The mast of RCD is lifted with the crane and is mounted on the pile casing. Once positioned on the casing top, the mount is arrested with the help of clamping unit. The drill

string unit or Bottom Hole Assembly (BHA) is lifted and installed inside the liner and loaded with the drilling unit on the mast. This is followed by the installation of drill pipe (normally 3m long and variable dia) and the swivel assembly and drill string are fixed (Fig-5).

Figure 4: Liner Driving with Vibro-hammer

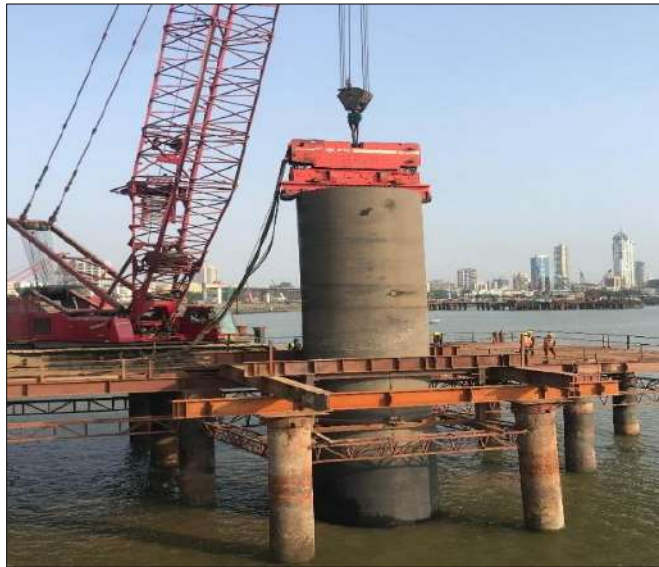


Figure 5: Drilling Setup and BHA Installation in RCD



The air hose is then connected with a compressor and the outlet delivery hose is connected to the collection bin/tank. Water (salt/fresh) will be pumped inside the bore through a pump attached with RCD or through a separate pump. The water will enhance smooth drilling operation. Add the drill pipes and add the Drill Rod Stabilizer (DRS will be added for every 3no's drill rod installed). The cutters can be changed based on the boring strata. The addition of drilling pipes will continue till the borehole reaches the design toe level. Once the drilling works are done up to the design level, bore flushing will be done.

8.3 Rebar cage installation

The rebar cages are fabricated in the yard and later shifted to the pile location. The cross-hole sonic logging (CHSL) tubes should be tied strongly with the inner reinforcement to avoid any deformation. The cages are shifted in parts (as per the crane capacity and boom length) and care must be taken that position of lapping/couplers must be the same. Any mismatch in position will be time-consuming during installation and is difficult to fix the couplers. The installation of the steel cage inside the excavated shaft will proceed by using the service crane (Fig-6). After installing all the elements, the rebar cage is rested at its design level with the help of cage hangers fixed on the casing top. All the CHSL tubes should be water-tight to prevent any slurry entry during the concrete pour.

Figure 6: Rebar Cage Installation



8.4 Tremie installation and airlifting

Airlifting is done with water/stabilization fluid. The aim is to remove the slush/debris from the bottom of the borehole. Airlifting is done with the help of an air compressor by blowing

in the air to the bottom of the borehole and the pressure shift cleans the bottom surface and the slush/water will come up through the pipes (200mm dia). Water will be poured from top of the borehole and the airlifting should continue till the entire borehole is cleaned. At the end of tremie installation, make sure that the minimum space (normally 300mm) is maintained between the tremie bottom and borehole bottom.

8.5 Concrete pour

Concrete can be either transported to the location with a Transit Mixer. A concrete pump (Fig-8) with hose supporting boom will be provided to supply the concrete to the tremie hopper during casting. To prevent contamination and segregation of the concrete during it falling inside the tremie pipes, a “sacrificial buffer” made of lightweight material (such as vermiculite or similar material or ball) will be introduced inside the tremie hopper prior to the start of concreting operations.

Figure 7: Concrete Pour with Two Placer Booms



A charge plug will be paced at the bottom of the hopper/tremie neck, and the hopper is filled with concrete and is charged with the help of a service crane. Once started, there should not be any delays in concrete supply as the choking chances are higher. Make sure that the tremie pipe bottom is always inside the concrete (maintain at least 2m to 3m inside the concrete). Remove the tremies as per the volume of concrete filled inside the bore and concrete should be stopped either after overflow and 1m above cut-off level. The hopper can be replaced with a smaller one during the first set of tremie removal.

9.0 Recommendations for Monopile Construction

After a careful examination in the construction method of large diameter pile by RCD technique, the following things are recommended for the smooth Construction of Large diameter piles in marine conditions.

- The liner shoe is mandatory for the liner driving in hard strata.
- Additional water supply pumps must be deployed in case of head loss inside the pile liner.
- Sonic tubes must be water-tight till the completion of the concrete pour.
- Pile-penetration ratio is mandatory for the end bearing piles.
- The volume of the concrete funnel must be equal to one meter built-up inside the shaft.
- The concrete overflow must be more than one meter above the cut-off level.
- Pile top flooding must be done after the concrete in order to avoid de-bonding effect during Cross-Hole Sonic Logging test.

Figure 8: Bridge Deck with Monopile (Actual Picture)



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CHAPTER 100

Musculoskeletal Disorders of Construction Workers

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ABSTRACT

This study explores the causes, effects, and remedies of musculoskeletal disorders (MSD) among construction workers. MSD represents a major challenge and source of agony with impaired mobility and economic burden on the healthcare of construction workers. It also affects productivity as it leads to absenteeism. There are risks associated with construction workers involving repetitive motion, awkward postures, heavy lifting, vibrations, and improper ergonomic practices. A study was conducted on construction workers to find MSDs faced by construction workers. The sample size of this study was 153. The study was conducted using convenience sampling. The result of the study is likely to be analyzed statistically. Finally, significant measures and recommendations will be discussed for such work-related MSDs.

Keywords: Musculoskeletal disorder; MSD; Health; Construction worker; Risk.

1.0 Introduction

1.1 Background of study

Even for the skilled workforce, repetitive construction work can be tedious given that it comprises manual and physical tasks, and often their execution is done under harsh conditions. Engaging in activities like lifting heavy materials into place, holding uncomfortable positions, and undertaking cyclic movements are the greater contributors to musculoskeletal disorders (MSDs) (Guo, 2004). This leads to chronic pain reduced mobility, and increased absenteeism affecting both the individual and the overall industry productivity.

1.2 Problem statement

Even with the implementation of various occupational safety measures, construction workers are still at a higher risk of developing MSDs ((OSHA), 2000). The absence of ergonomic aids and poor safety standards in the workplace help to make sure these conditions do persist. This study attempts to analyse the reasons and consequences of MSDs and try to propose effective strategies to control them.

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1.3 Objective of the study

- To investigate how common MSDs are amongst construction workers.
- To determine occupational risk factors of MSDs.
- To assess and analyse the consequences of MSDs on workers' life and work performance.
- To suggest ergonomic measures and policy changes aimed at the prevention of MSD.

1.4 Research questions

- What are the main risks of posing MSDs in construction work?
- In what ways do MSDs affect workers' productivity and the general well-being of their lives?
- Which actions can be taken for the prevention of MSDs?

1.5 Scope of the study

This research targets construction workers who are engaged in manual labour such as masons, carpenters, electricians, and operators of heavy machines. The study looks at different types of occupational diseases, working environments, and ergonomic management of MSDs.

2.0 Literature Review

2.1 Overview of musculoskeletal disorders

The diverse group of injuries known as MSDs affect both muscles and joints together with nerves. These injuries develop because of continuous strain and excessive pressure together with prolonged situations of uncomfortable postures (Holmström, 1992). A substantial number of MSDs affect construction workers because their occupations involve physical labor.

2.2 Occupational risk factors

The development of MSDs in construction workers is associated with several factors. Extended time performing the same actions creates muscle fatigue together with joint distress.

- Excessive weight-bearing during heavy lifting exceeds acceptable ergonomic thresholds which produce spinal injuries that strain musculoskeletal system structures.
- Extended positions requiring bending, twisting, and kneeling affect the musculoskeletal system so that chronic pain develops along with reduced mobility.

2.3 Impact of MSDs

MSDs impose serious negative effects on employee well-being by producing long-term pain durations along with disabilities that force workers to lose their jobs (Arias *et al.*, 2022). Economic strain on employers occurs due to medical expenses together with compensation payments and decreased work output caused by MSDs. Extended MSD exposure triggers emotional problems that produce symptoms such as stress alongside anxiety and depression.

2.4 Preventive measures and ergonomics

Different ergonomic measures exist to reduce the risks of MSDs (Sousa *et al.*, 2023):

- Ergonomic task design aims to reduce repetitive strain combined with awkward postures at the workstation.
- Workers can reduce manual handling through the implementation of mechanical lifting aids as assistive devices.
- Training Programs deliver education about both secure lifting methods and early detection of symptoms to workers.

3.0 Research Methodology

3.1 Research design

The survey data of construction workers regarding their exposure to Musculoskeletal Disorder (MSD) risk factors and its influence on their work-life balance was analysed using the quantitative approach.

3.2 Data collection

Primary data was gathered using closed-ended questionnaires among a sample of 153 construction workers. The questionnaire captured information about the construction worker's job roles, work setting, experienced frequency of musculoskeletal pain, and ergonomic treatment practices.

3.3 Data analysis

Analytic techniques performed were descriptive and inferential statistics, including:

- Mean value, standard deviation, and frequency distribution were calculated for descriptive statistics.
- T-tests and Analysis of Variance (ANOVA) were employed to find the prevalence of MSD across different groups of workers.
- Regression Analysis was utilized to find the causes of MSD, or the risk factors that predict the occurrence of MSD.

4.0 Data Analysis and Findings

4.1 Descriptive statistics

Table 1 provides the average, the standard deviation, and the frequency distribution for the MSD risk factors of the individuals who responded to the survey (Guo, 2004). Repetitive Motions (Mean = 3.7190) has the highest mean value, indicating that repetitive motions are the most common activity. Heavy Lifting (Mean = 2.8431) is lower, suggesting it is a less frequent activity. Among pain variables, Pain in Lower Back (Mean = 2.0915) and Pain in Shoulder

(Mean = 2.0327) have the highest mean values, indicating these areas are more frequently affected. Pain in Hip (Mean = 1.0784) and Pain in Ankle (Mean = 1.0588) have the lowest means, suggesting these areas are less commonly affected. Negatively skewed variables indicate that pain levels are often on the higher side (e.g., Repetitive Motions, Lower Back Pain), whereas positively skewed variables suggest that lower levels of pain are more common (e.g., Hip Pain, Ankle Pain).

Table 1: Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Repetitive_Motions	153	1.00	5.00	3.7190	1.21101	-.772	.196	-.294	.390
Heavy_Lifting	153	1.00	5.00	2.8431	1.11873	.058	.196	-.677	.390
Pain_Neck	153	.00	4.00	1.6993	1.32330	.277	.196	-1.136	.390
Pain_Shoulder	153	.00	4.00	2.0327	1.33977	-.127	.196	-1.146	.390
Pain_UpperBack	153	.00	4.00	1.8824	1.32258	-.040	.196	-1.156	.390
Pain_LowerBack	153	.00	4.00	2.0915	1.35413	-.265	.196	-1.126	.390
Pain_UpperArm	153	.00	4.00	1.7516	1.24224	.046	.196	-1.021	.390
Pain_Elbow	153	.00	4.00	1.3595	1.12749	.370	.196	-.747	.390
Pain_Forearm	153	.00	4.00	1.5294	1.13008	.148	.196	-.900	.390
Pain_Hip	153	.00	4.00	1.0784	1.30045	.980	.196	-.239	.390
Pain_Knee	153	.00	4.00	2.0261	1.30257	-.121	.196	-1.013	.390
Pain_Ankle	153	.00	4.00	1.0588	1.18230	.950	.196	-.086	.390

4.2 Inferential analysis

Statistical tests found significant differences in the levels of MSD for different job categories and years of experience. It was found in the analysis that construction workers who performed repetitive actions for long durations experienced the highest levels of pain (Holmström *et al.*, 1992). All variables in Table 2 have p-values = .000, meaning they are highly significant ($p < 0.05$). This indicates that the mean values of all reported factors (repetitive motions, heavy lifting, pain levels) are significantly greater than zero. Further, all results are statistically significant, confirming that these issues are widespread and not due to chance.

4.3 Regression analysis

The researchers conducted a regression analysis to examine how different risk elements influence MSDs in construction workers. The research model analyzed Pain Impact as the dependent factor while examining repetitive motion and heavy lifting activities and body part pain in regions such as the neck, shoulder, upper back, lower back, upper arm, elbow, forearm, hip, knee, and ankle.

Table 2: Inferential Statistics of One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Repetitive_Motions	37.986	152	.000	3.71895	3.5255	3.9124
Heavy_Lifting	31.435	152	.000	2.84314	2.6644	3.0218
Pain_Neck	15.884	152	.000	1.69935	1.4880	1.9107
Pain_Shoulder	18.767	152	.000	2.03268	1.8187	2.2467
Pain_UpperBack	17.605	152	.000	1.88235	1.6711	2.0936
Pain_LowerBack	19.105	152	.000	2.09150	1.8752	2.3078
Pain_UpperArm	17.441	152	.000	1.75163	1.5532	1.9501
Pain_Elbow	14.914	152	.000	1.35948	1.1794	1.5396
Pain_Forearm	16.740	152	.000	1.52941	1.3489	1.7099
Pain_Hip	10.258	152	.000	1.07843	.8707	1.2861
Pain_Knee	19.240	152	.000	2.02614	1.8181	2.2342
Pain_Ankle	11.077	152	.000	1.05882	.8700	1.2477
Pain_Impact	16.233	152	.000	1.08497	.9529	1.2170

Table 3: Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.371	.202		1.842	.068
	Repetitive_Motions	-.083	.052	-.122	-1.591	.114
	Heavy_Lifting	.025	.061	.034	.408	.684
	Pain_Neck	.190	.051	.304	3.735	.000
	Pain_Shoulder	-.015	.062	-.024	-.243	.809
	Pain_UpperBack	.116	.067	.186	1.743	.083
	Pain_LowerBack	.159	.063	.261	2.523	.013
	Pain_UpperArm	.004	.068	.006	.063	.950
	Pain_Elbow	.091	.073	.125	1.243	.216
	Pain_Forearm	-.001	.068	-.001	-.013	.990
	Pain_Hip	-.013	.053	-.021	-.246	.806
	Pain_Knee	.048	.060	.075	.793	.429
	Pain_Ankle	-.099	.061	-.141	-1.616	.108
a. Dependent Variable: Pain_Impact						

The value of R as 0.632 suggests a moderate correlation between the predictors and Pain Impact with 40% of the variance in Pain Impact is explained by the model. Also, the value of Durbin-Watson as 1.992 suggests no major autocorrelation issues in residuals. The regression model is statistically significant ($p < 0.001$) about ANOVA results, meaning at least one predictor significantly influences Pain Impact that marks for the meaningful regression model. Further, Table 3 confirms that intervention should focus on reducing Neck and Lower Back Pain since they significantly contribute to Pain Impact.

4.4 Discussion of findings

The study revealed that neck and lower back pain are the most frequently reported among the conditions of the MSD for the respondents. This subsequently made it difficult for them to move about, concentrate, and perform their work. From these findings, it is evident that greater emphasis should be placed on ergonomic designs that aim to ameliorate the working conditions of the employees.

5.0 Conclusion and Recommendations

5.1 Summary of findings

Construction workers have been confirmed to have a high prevalence of MSDs. High-risk tasks were heavy lifting, repetitive motions, and prolonged awkward postures (European Agency for Safety and Health at Work, 2002).

5.2 Recommendations

- Ergonomic Interventions: Implementing adjustable workstations and mechanical lifting aids.
- Workplace Safety Policies: Developing mandatory ergonomic training programs.
- Regular Health Screenings: Getting regular medical exams to catch early signs of MSDs.
- Job Rotation Strategies: cutting down the risky work extended for a long time.

6.0 Future Research and Policy Implications

6.1 Further research should explore

- The long-term impact of ergonomic interventions on MSD prevalence.
- Wearable technology's ability to prevent work-related injuries.

6.2 Policy implications

Enforcement of safety regulations and the creation of an all-around MSD prevention program relies on government agencies and industry stakeholders helping with each other (European Agency for Safety and Health at Work, 2002).

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CHAPTER 101

Optimization of Last-Mile Delivery in Construction Projects: Improving Efficiency Through Routing Algorithms and Technology Integration

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ABSTRACT

Cost overruns and project delays caused on by ineffective supply chains and last-mile logistics are a common problem in the construction industry that this paper seeks to address. The primary goal of this research is to be helpful in enhancing project outcomes while attempting to optimize logistical operations by identifying latest tactics and technologies. This research uses a combination of simulations, literature reviews, and analysis of methods such as the Vehicle Routing Problem (VRP) algorithm, GPS integration, and Just-In-Time (JIT) delivery systems. Simulations costs and efficiency and efficacy of proposed solutions in smoothing delivery routes, saving fuel costs, and reducing stoppages. The report indicates that last-mile logistics are significantly enhanced by the application of GPS technology, use of VRP algorithms, and JIT delivery systems. Such techniques reduce on-site handling and storage costs due to streamlined route planning, real-time decision-making, and timely material delivery. The results depict reduced project schedule delays, cost overruns, and improved supply chain performance. This research is a valuable contribution to the construction industry with its comprehensive approach to last-mile logistics optimization, practical benefits of utilizing modern logistics techniques, and practical recommendations for industry adoption. These findings give construction managers useful strategies to streamline logistics and minimize delays and cost overruns, which enhances operational effectiveness and project success.

Keywords: Construction logistics optimization; Just-in-time delivery (JIT); GPS integration; Vehicle routing problem algorithm (VRP); Last-mile delivery.

1.0 Introduction

The prompt and effective transportation of supplies and machinery to the job site is crucial to the construction sector. This includes multiple stages like procurement, loading, dispatch, transportation, tracking, site delivery, unloading, inspection, on-site management, etc. Due to population growth and urbanization, the final step of logistics or transportation is becoming increasingly important which is also called last-mile delivery stated in (Demir *et al.*, 2022).

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This stage involves multiple challenges like congestion, limited site access, and specific time for delivery due to space or security constraints on the construction site leading to delays, increased costs, and disruptions to the project schedule. To mitigate these challenges, technologies like GPS, VRP, and JIT delivery systems have become important tools for improving last-mile logistics. So, Improving and optimizing the route assigned to vehicles of the fleet, it is highly possible to reduce time and cost overruns. (Calabrò *et al.*, 2020). Real-time tracking of individual vehicle locations along with real-time status visibility is available using a global positioning system (Michaelides *et al.*, n.d.). Using (VRP) vehicle routing problem algorithms helps optimize routes and delivery paths to avoid traffic and congestion (Calabrò *et al.*, 2020). Just-In-Time (JIT) is a material management system that aims to reduce inventory and ensure the materials are available when they are required on time which helps in increasing productivity, quality, and efficiency, decreasing inventory cost, etc (Ozalp *et al.*, 2010)

Urban building sites are most likely to be located in densely populated areas with narrow streets and restricted site access. This is further exacerbated by the increasing number of delivery trucks, resulting in longer delivery times and congestion (Bakogianni & Malindretos, 2021). To reduce disruptions, city governments also establish narrow delivery windows, meaning construction logistics managers must plan material arrival very carefully. Since conventional routing models rely on static plans that do not include actual-time considerations like traffic, weather, or site-based restrictions, inefficient routing worsens the last-mile delivery. This leads to inefficient routing, raising operating costs and delivery times. Research has indicated that using AI-based dynamic routing models can greatly improve productivity by lowering delivery times and fuel usage (Casado-Vara *et al.*, 2020).

2.0 Literature Review

2.1 Last-mile delivery and its challenges

Logistics refers to the organized movement of products from the origin to distribution points and finally to consumers. A specially located warehouse near the customer location is the source of last-mile delivery, with a short drive to the final destination. The effectiveness of this process is utmost, as it has a direct impact on customer satisfaction, operating costs, and overall supply chain efficiency (Sorooshian *et al.*, 2022a). Urbanization and online shopping have further contributed to the complexity of last-mile delivery, making it necessary for sophisticated logistics solutions such as real-time tracking, route optimization, and autonomous delivery mechanisms to enhance efficiency and minimize delays (Batan *et al.*, 2020). Last-mile delivery can simply be said to begin from a previously determined warehouse near the customer's address, which travels a few miles to reach its intended recipient. (Sorooshian *et al.*, 2022b)

The last mile delivery (LMD) segment that ends the supply chain involves the conveyance of construction materials from the warehouse or distribution center to the construction site. To finish the project within the specified time and reasonable cost, the last part

of the supply chain is crucial (Mbhele & Rambaran, 2021). Because construction projects usually depend on timely scheduling, supply chain delays at the last mile may result in significant project delay, higher cost, and inefficiencies (Mangiaracina *et al.*, 2019). Because of constraints like heavy traffic, site-restricted access, and difficult delivery schedules, LMD is a complex but critical element of construction logistics. (Galkin *et al.*, 2019b). The use of the advance technologies, such as Just-In-Time (JIT) inventory management, GPS navigation, and artificial intelligence (AI) route optimization, has been the primary way of enhancing LMD efficiency.

This final leg of the supply chain is crucial for ensuring timely project completion and cost efficiency. (Galkin *et al.*, 2019a). The complexity of LMD stems from the need to meet customer expectations for speed, timeliness, accuracy, and individual delivery precision (Sorooshian *et al.*, 2022b). LMD involves many individual deliveries, typically in highly congested urban areas where parking and access restrictions add to the complexity of the task, compared to bulk shipments transported over long distances by efficient logistical networks. Logistics companies are using technology-based solutions, such as AI-based route planning, real-time tracking, and automated delivery systems, to counter these challenges (Galkin *et al.*, 2019b). To determine the most effective delivery routes for delivery vehicles, machine learning-based route optimization technologies analyze historic delivery patterns and real-time traffic information. (Oloko, 2025).

2.2 Vehicle routing problem algorithm (VRP)

The term “VRP” denotes a broad class of problems. It is stated by Dantzig and Ramser in 1959 that it is one most difficult optimization problems, more than 40 years back. It aims at developing the best routes possible for an inventory of cars that is meant to service a particular set of clients (Bell & McMullen, 2004). The objective of the problem is to serve all the requirements of a group of customers with minimum possible truck route costs, which starts and ends at the same depot. (Santillán *et al.*, 2012a).

Numerous Variants of VRP for Optimization of Logistics Management Problems Based on computational knowledge, VRP typically is a standard NP-hard problem; that is to say, it is impossible to find the optimal solution. Heuristics methods were applied to most real-world vehicle routing problems (Santillán *et al.*, 2012b). Practical Applications of VRP can be applied to a number of practical situations depending on the nature of the activity undertaken such as collection and distribution whilst considering following constraints: vehicle capacity, multiple depots. It has been reported that the effective cost minimization of those issues could successfully yield significant savings in the tune of 5% to 20% of the total cost of the products (Cattaruzza *et al.*, 2017). All the routes should begin and end at the depot. Every point may only be visited once, and only one vehicle per location could be used, and the capacity cannot be over exceeded by the vehicle (Belka & Godlewski, 2021). Real-world applications vary depending on operational specifics. Examples include pickup and delivery scenarios, incorporating factors like

vehicle capacity and multiple depots. (Santillán *et al.*, 2012a)

2.3 Just in time delivery (JIT)

Just In Time (JIT) delivery, a concept originating from the Toyota Production System, aims to provide the necessary materials at the precise time and in the exact quantity needed for each stage of a process. The ultimate objective is to eliminate waste, such as excessive wait times and large inventories, by minimizing storage and handling, thereby streamlining operations. (Tommelein & Li, 1999) It is called “Just-In-Time” (JIT) because materials arriving on a construction site will be transported directly to their intended installation sites and subsequently installed immediately, thus not disrupting the process because they are not put into laydown or staging. The Toyota Production System, also known as the lean manufacturing paradigm in English, was established by Japanese engineers and forms the foundation of the concept of Just-In-Time. The basic idea of Just-In-Time manufacturing is the delivery of all materials at the right time and in the right quantities at every step of the production process (Ozalp *et al.*, 2010).

Traditional construction logistics involve heavy handling, storage, and transportation, which is fuel- and emission-heavy (Bookbinder & Dilts, 1989). JIT reduces carbon footprints, maximizes fleet utilization, and reduces transportation frequency through material delivery optimization. In addition, since materials are less likely to be damaged or wasted through over-ordering, waste creation is reduced when material storage on site is reduced (Bookbinder & Dilts, 1989). Since the supply chain relies on correct scheduling, even an interruption-be it in the form of tardy transport, lack of availability of suppliers, or unforeseen changes in project timelines-can prove calamitous (Tezel *et al.*, 2020). Companies must spend money on real-time monitoring software, maintain cordial relations with suppliers, and construct contingency plans to minimize such threats. These are overcome through good communication, team planning, and project management on computer platforms (Dallasega, 2018).

Traditional procurement practices must be modified in order to make JIT delivery in the construction industry possible. Contractors must change to a more responsive and demand-driven approach rather than buying in bulk and stocking resources for later use. This includes collaboration with suppliers to maintain quick response times, the use of data analysis to accurately forecast material needs, and simplifying logistics networks to provide just-in-time delivery (Ng *et al.*, 2009). With real-time visibility into inventory, material flow, and any interruptions, next-generation technologies like IoT-based sensors, GPS tracking, and AI-based predictive analytics further facilitate JIT deployment (Michaelides *et al.*, 2010).

2.4 Potential of GPS technology integration

In the latest periods, ICTs have emerged as critical enablers of coordinating and synchronizing geographically dispersed manufacturers, suppliers, and logistics providers within global supply chains (Brusselaers *et al.*, 2022). Mass diffusion and widespread deployment of ICTs has significantly increased the complexity of technological solutions that can be offered to

complex systems of supply chains because of the explosion of mobile technologies (Bányai, 2018). Advanced internet solutions that deploy in conjunction with mobile technologies, such as GPS, GPRS, and GIS, really improve the transparency and accuracy of the information on the location and traceability of shipments as well as the current status of deliveries to supply chain partners (Michaelides *et al.*, 2010). These advances have improved efficiency and responsiveness through real-time data sharing, predictive analytics, and automated logistics process management. Businesses can integrate cloud-enabled supply chain management tools whereby they gain immediate visibility into inventory levels, order tracking, and transport plans, thus reducing delays and improving decision-making.

Enhanced risk management, demand forecasting, and route planning capabilities of ICT are further enhanced by a mix of AI and machine learning, which helps strengthen supply chain operations (Giuffrida *et al.*, 2022). These technologies help to mitigate disruptions from unforeseen elements such as weather, traffic jams, and geopolitical events (Ozalp *et al.*, 2010). These developments have promoted efficiency and responsiveness by making possible real-time exchange of information, predictive analytics, and logistics operations automation. Cloud supply chain management software that enables companies to access at a moment's notice inventory levels, order status, and transport schedules can be incorporated (Michaelides *et al.*, 2010). With the fusion of AI and machine learning further developing ICT capabilities, the improvement of supply chain operations' risk management, demand forecasting, and route planning also ensues (Bányai, 2018).

These technologies alleviate disruptions generated by unforeseen conditions like weather, traffic, and geopolitical action. Besides that, through offering unalterable transaction records, blockchain technology is transforming supply chain transparency and security and guaranteeing stakeholder accountability and trust. Smart contracts reduce administrative costs and fraud risks through enabling automatic transactions and conformity checks. Firms can build more dynamic and robust supply chains that can respond to fast-paced market evolution and rising customer expectations by leveraging ICTs (Özarık *et al.*, 2024). According to many researchers, real-time monitoring of physical objects greatly improves logistics efficiency, cost, and customer satisfaction (Bányai, 2018).

3.0 Research Methodology

The aim is to study the ways in which advanced technologies and routing algorithms are able to make last-mile delivery more efficient for the construction projects. In order to do so, a structured, multi-phase approach is applied, as below.

3.1 Research design

The study uses the qualitative approach to explore last-mile delivery challenges in construction, with phases for identifying issues through interviews and literature (Exploratory

Phase) and validating solutions through surveys (Validation Phase).

3.2 Data collection

Data was gathered using primary sources through questionnaires, targeting construction project managers, supply chain coordinators, and logistics professionals with 60 volunteers from different companies via purposive sampling.

3.3 Data analysis techniques

The data was analyzed using comprehensive strategic evaluation of last-mile delivery optimization by using Descriptive Analysis to summarize problems and trends, Statistical Analysis of the primary data and SWOT Analysis to assess the effectiveness of VRP algorithms, GPS, and JIT in routing optimization.

3.4 Validation of results

The results were validated through stakeholder feedback from logistics experts and project managers, ensuring the proposed solutions are reliable and applicable for improving last-mile construction delivery.

4.0 Data Analysis and Findings

The data analysis in this study focuses on exploring the factors that influence the adoption of better logistics technology in the construction industry. By analyzing data from surveys conducted with construction managers, the research evaluates the impact of technologies such as GPS integration, Just-In-Time (JIT) delivery systems, and Vehicle Routing Problem (VRP) algorithms. The analysis highlights significant differences in the familiarity and implementation of these technologies, and their collective role in improving logistics efficiency, reducing costs, and minimizing delays in construction projects.

Table 1: Descriptive Analysis

What is your highest qualification?	Qualification	Count	Column N %
	High School Diploma	17	8.30%
	Higher Secondary School Diploma	38	18.40%
	Bachelor's Degree (Engineering, Business, etc.)	47	22.80%
	Master's Degree (MBA, MTech, etc.)	98	47.60%
	Ph.D. or Doctorate	6	2.90%
Please specify your role in the construction industry.	Role	Count	Column N %
	Project Manager	1	0.50%
	Project Director / Senior Management	84	40.80%

	Project Manager / Construction Manager	46	22.30%
	Site Manager / Site Engineer	33	16.00%
	Logistics Coordinator / Supply Chain Manager	18	8.70%
	Supplier / Vendor	22	10.70%
	Other	2	1.00%
What is your company's approximate annual turnover?	Turnover Range	Count	Column N %
	Less than 1 crore	2	1.00%
	1–10 crore	7	66.50%
	10–50 crore	42	20.40%
	50–100 crore	19	9.20%
	More than 100 crores	6	2.90%
How many years of experience do you have in the construction industry?	Experience	Count	Column N %
	Less than 2 years	83	40.30%
	2–5 years	21	10.20%
	6–10 years	69	33.50%
	More than 10 years	33	16.00%
Which age group do you belong to?	Age Group	Count	Column N %
	18–25 years	81	39.30%
	26–35 years	19	9.20%
	36–45 years	69	33.50%
	46–55 years	18	8.70%
	Above 55 years	19	9.20%
What type of construction projects are you primarily involved in?	Project Type	Count	Column N %
	Residential	82	39.80%
	Industrial	48	23.30%
	Infrastructure	40	19.40%
	Commercial	36	17.50%
	Less than 2 years	83	40.30%
	2–5 years	21	10.20%
	6–10 years	69	33.50%
	More than 10 years	33	16.00%
Which age group do you belong to?	Age Group	Count	Column N %
	18–25 years	81	39.30%
	26–35 years	19	9.20%
	36–45 years	69	33.50%

Source: Compiled by authors

The descriptive breakdown provides a critical analysis of respondents' attributes that

provide information regarding their qualifications, job positions, company turnover, experience, age, and association with projects within the construction field. In qualifications, the respondents are predominantly comprised of those having a master's degree (47.6%) and then come those with a bachelor's degree (22.8%). Another smaller percentage hold a Higher Secondary School Diploma (18.4%), while minimal respondents have a High School Diploma (8.3%) and a Ph.D. or Doctorate (2.9%). In regard to occupation in the construction sector, most are employed as Project Director/Senior Management (40.8%), then Project Managers/Construction Managers (22.3%) and Site Managers/Site Engineers (16%).

Less are Logistics Coordinators/Supply Chain Managers (8.7%) or Suppliers/Vendors (10.7%), with a minority (1%) listing other occupations. For business turnover, a large percentage of respondents (66.5%) indicated that their businesses have an annual turnover of 1-10 crore, and 10-50 crore was indicated by 20.4%. 50-100 crore and over 100 crore categories had lesser percentages (9.2% and 2.9%, respectively). Just 1% of businesses indicated a turnover of less than 1 crore. In terms of years of experience, the majority of the respondents (40.3%) have 2 years or less experience in the construction sector, followed by a significant percentage (33.5%) with 6-10 years of experience. 10.2% have 2-5 years of experience, and 16% have over 10 years of experience.

By age, the most represented respondents are in the 18-25 years age group with 39.3%. The 36-45 years group is next at 33.5%, followed by 26-35 years, 46-55 years, and over 55 years (with the last three being smaller proportions at 9.2%, 8.7%, and 9.2%, respectively). Finally, the respondents are mostly engaged in residential building projects (39.8%), followed by industrial projects (23.3%) and infrastructure projects (19.4%). The smallest portion is engaged in commercial projects (17.5%). As a whole, the descriptive analysis depicts a multifaceted pool of participants that includes different educational backgrounds, titles, experience levels, and activities within various categories of construction work. This information helps to frame understanding of the construction industry's workforce and dynamic influences that potentially contribute to last-mile delivery problems.

Table 2: Challenges in Last-mile Delivery for Construction Projects

Short Variable	t-value	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference
Last-Mile Delive Challenge	37.669	205	0	3.17	3.00 - 3.34
Impact of Delivery Delays on Timelines	30.308	205	0	1.859	1.74 - 1.98
Average Delivery Delay	33.377	205	0	2.447	2.30 - 2.59
Consequence of Delivery Inefficiencies	25.898	205	0	2.481	2.29 - 2 67
Concerns About Adopting Advanced Technologies	28.447	205	0	2.908	2.71 - 3.11

Source: Compiled by authors

The above table identifies major last-mile delivery challenges in construction projects. The first question, “Last-Mile Delivery Challenge,” indicates a large mean difference (3.170) that participants recognize a huge challenge in last-mile delivery. The second question, “Impact of Delivery Delays on Timelines,” indicates that delivery delays have a huge impact on project timelines (mean difference of 1.859), illustrating the effect on project efficiency. The third question, “Average Delivery Delay,” indicates that last-mile inefficiency delays are also significant, with an average difference of 2.447, implying significant delays in deliveries. The fourth question, “Consequence of Delivery Inefficiencies,” indicates that delivery inefficiencies have a discernible effect on projects (average difference of 2.481), with an effect on the outcome of projects. Finally, the question “Concerns About Adopting Advanced Technologies” identifies key concerns (mean difference of 2.908), indicating resistance or hindrances to the adoption of new technology in last-mile delivery management, which can further lead to inefficiencies. Overall, these findings emphasize that delivery issues, delays, inefficiencies, and technology adoption concerns are key problems in construction project logistics.

Table 3: ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	231.088	2	115.544	589.545	.000 ^b
	Residual	39.786	203	.196		
	Total	270.874	205			
a. Dependent Variable: How many years of experience do you have in the construction indust?						
b. Predictors: (Constant), How frequently do last-mile delivery delays impact your project timelines? What is the most common last-mile delivery challenge you face in construction projects?						

Source: Compiled by authors

ANOVA results for the model that explores how last-mile delivery delays and issues impact years of experience in construction reveal a very significant relationship. The regression model accounts for a very high percentage of the variance in the dependent variable, “How many years of experience do you have in the construction industry?” The model’s sum of squares equals 231.088 with 2 degrees of freedom for the predictors, and hence the mean square equals 115.544. The F-statistic of 589.545 is very high, with a p-value of 0.000, which shows that the overall model is statistically significant and that the predictors - “How often do last-mile delivery delays affect your project timelines?” and “What is the most frequent last-mile delivery issue you encounter in construction projects?” - are significant in explaining the variation in years of experience. The residual sum of squares is 39.786 with 203 degrees of freedom, indicating that although the model is a good fit, there is still some unexplained variability.

Generally, the results indicate that last-mile delivery delays and challenges have a strong impact on years of experience in the construction sector. The coefficients table provides

further insights into the relationship between last-mile delivery challenges, delivery delays, and years of experience in the construction sector. The constant value of -0.303 represents the expected years of experience when both predictor variables are zero. However, this value does not carry meaningful interpretative significance unless it is statistically significant. The coefficient for the variable “What is the most frequent last-mile delivery difficulty that you experience on construction projects?” is 0.251, with a standardized beta of 0.264.

Table 4: Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.303	.088		-3.448	.001
	What is the most common last-mile delivery challenge you face in construction projects?	.251	.035	.264	7.245	.000
	How frequently do last mile delivery delays impact your project timelines?	.947	.048	.725	19.913	.000
a. Dependent Variable: How many years of experience do you have in the construction industry?						

Source: Compiled by authors

This suggests that a one-unit increase in reported last-mile delivery difficulties is associated with an increase of approximately 0.251 years in construction experience. The corresponding t-value of 7.245 and p-value of 0.000 confirm that this predictor is statistically significant. This finding implies that industry professionals with greater experience tend to report a higher awareness of last-mile delivery challenges. Similarly, the coefficient for “How often do last-mile delivery delays affect your project timelines?” is 0.947, with a standardized beta of 0.725, indicating a stronger association with years of experience.

Table 5: One-Sample Test Results for VRP, GPS, and JIT

Variable	t-Value	Sig. (2tailed)	Mean Difference	95% Confidence Interval
VRP (Vehicle Routing Problem)	22.98	0	1.87	1.71 - 2.03
GPS (Global Positioning System)	22.08	0	2.05	1.87 - 2.23
JIT (Just-In-Time Delivery)	22.01	0	2.03	1.85 - 2.22

Source: Compiled by authors

A one-unit increase in the frequency of delivery delays corresponds to an approximate 0.947-year increase in industry experience. The t-value of 19.913 and p-value of 0.000 confirm that this predictor is also highly significant. The larger standardized beta suggests that the frequency of last-mile delivery delays has a more pronounced association with industry experience compared to general last-mile difficulties. Overall, the results indicate that both last-mile delivery challenges and the frequency of delivery delays are significantly associated with

years of experience in the construction sector. However, this analysis does not establish a causal relationship but rather suggests that more experienced professionals are more likely to encounter and recognize such logistical issues. Among the two predictors, the frequency of last-mile delivery delays exhibits a stronger association with years of experience, highlighting its dominant role in last-mile logistics concerns within the construction industry.

**Table 6: SWOT Analysis of Last-Mile Delivery Optimization
(JIT, GPS, VRP) (Tezel *et al.*,2020)**

Category	Key Factors	Implications
Strengths	Optimized Delivery Routes & Cost Savings	VRP is capable of saving up to 20% on fuel and travel time, which reduces operational expenses.
	Real-Time Visibility & Tracking	GPS incorporation increases delivery tracking and supply chain transparency.
	Reduced Material Handling & Storage Costs	JIT reduces handling and storage expenses by ensuring that materials only arrive when needed.
	Enhanced Supplier Coordination	Improved material scheduling minimizes delays and increases supplier dependability.
	Environmental & Regulatory Benefits	In compliance with green logistics regulations, VRP route optimization reduces carbon emissions.
Weaknesses	High Initial Implementation Cost	JIT logistics, GPS tracking, and VRP software all demand a large upfront cost.
	Need for Skilled Workforce & Training	VRP system adoption may be slowed by the need for employee training.
	Integration Issues with Existing Systems	Proper deployment may be delayed by incompatibilities with legacy logistical software.
	Scalability Challenges in Large Projects	Large-scale dynamic projects are difficult for VRP to handle, whereas JIT relies on precise forecasting.
	Predictive Analytics & AI Integration	Real-time decision-making and route optimization are improved by AI-driven dynamic VRP models.
Opportunities	Government Incentives for Smart Logistics	Adoption of JIT, GPS, and VRP is financially rewarded by policies which encourage smart logistics.
	Autonomous & Smart Delivery Systems	In constructing logistics, drones and automated vehicles increase last-mile efficiency.
	Expanding JIT & VRP in Construction	Equipment handling and staff scheduling are two areas where JIT principles can be applied.
	Cybersecurity & Data Risks	Cloud-based VRP systems and GPS tracking are susceptible to hacking and cyberattacks.
	Unexpected External Delays	Last-mile efficiency can be impacted by weather-related delays, traffic jams, and supplier reliability problems.
Threats	Resistance to Change	AI-based route optimization may be resisted by conventional logistics teams.
	Regulatory Uncertainty	Implementation may be impacted by legal limitations on GPS data usage and autonomous delivery.

Source: Compiled by authors

Table 5 gives the statistical findings that evaluate the efficacy of three alternative systems— Vehicle Routing Problem (VRP), Global Positioning System (GPS), and Just-in-Time (JIT) delivery systems - for optimizing delivery routes. The t-values for each of the three variables are strongly positive (22.98 for VRP, 22.08 for GPS, and 22.01 for JIT), showing strong statistical evidence that the three systems make a significant difference in the process of optimizing deliveries. The p-values (Sig. 2-tailed) for all three systems are 0.000, which is significantly less than the standard significance level of 0.05, further indicating that the results are statistically significant. The mean differences found - 1.87 for VRP, 2.05 for GPS, and 2.03 for JIT illustrate that all three systems result in a significant improvement in optimizing routes for delivery. The three systems are of similar effectiveness in cutting down inefficiencies in route planning. The 95% confidence intervals for all three mean differences (1.71-2.03 for VRP, 1.87-2.23 for GPS, and 1.85-2.22 for JIT) add to the confidence that the observed effects are not only consistent but also reliable. In summary, the evidence clearly testifies to the aim of determining the efficiency of these routing algorithms, GPS technology, and JIT delivery systems in optimizing delivery routes, as their impact on operational efficiency is evident and considerable.

5.0 Conclusion

The conclusions of this study present an exhaustive overview of the issue of last-mile delivery in construction projects and identify the efficiency of Vehicle Routing Problem (VRP) algorithm, Global Positioning System (GPS) tracking system, and Just-In-Time (JIT) delivery practices in optimizing logistics operations. The research affirms that last-mile logistics inadequacies are a major reason for initiating project delays, cost escalation, and supply chain disruption, hence the need to implement advanced technological tools to make material transport more efficient and remove inefficiencies. Statistical analysis in this research reveals that delivery delays have a significant impact on project duration, with a mean effect of 1.859 and a t-value of 30.308 ($p = 0.000$).

Similarly, delivery inefficiencies (mean = 2.481, $t = 25.898$, $p = 0.000$) are also reasons for increased project duration and cost overruns. The findings identify the pressing need for construction companies to enhance their logistics management practices. The results also confirm the effectiveness of advanced logistics technologies in optimizing last-mile delivery operations. The use of Vehicle Routing Problem (VRP) algorithms greatly enhances delivery efficiency, as reflected in a t-value of 22.98 and a mean difference of 1.87 ($p = 0.000$), thus highlighting that optimized route plans can reduce delays and fuel consumption. GPS tracking is a key driver of supply chain visibility, as it enables real-time monitoring of the movement of materials, thus reducing the occurrence of misplaced items and enhancing delivery accuracy ($t = 22.08$, mean difference = 2.05, $p = 0.000$). In addition, the JIT supply system minimizes over-storage and material handling to the bare minimum, such that resources are accessed at the point

of need and thus increase site productivity ($t = 22.01$, mean difference = 2.03, $p = 0.000$). Regression and analysis of variance (ANOVA) analysis also indicate that experience levels have a major role in the determination of last-mile delivery inefficiencies. ANOVA results ($F = 589.545$, $p = 0.000$) indicate that increased levels of experience among industry practitioners enable them to better understand such inefficiencies and the resulting delays on project timeliness. Additionally, regression analysis indicates that delay frequency in last-mile delivery ($B = 0.947$, $\beta = 0.725$, $p = 0.000$) indicates the highest correlation with project inefficiencies and thus must be a major area of concern for construction firms.

A SWOT analysis here reveals strategic implications for maximizing last-mile delivery in construction logistics. The advantages of VRP, GPS, and JIT are cost reduction, enhanced tracking, and enhanced coordination with suppliers, all of which lead to enhanced operational efficiency and project success. Some of the weaknesses like excessive initial implementation costs, training needs, and integration issues are also highlighted in the research. Aside from these challenges, however, are opportunities in AI-based predictive analytics, government support, and autonomous delivery systems like drones that could further maximize last-mile logistics efficiency. Overall, this research illustrates how the integration of VRP, GPS tracking, and JIT delivery systems creates a substantial boost in last-mile logistics efficiency in construction projects. Despite cost, labor adaptation, and regulatory barriers associated with integration, the advantages of minimizing project delays, cost streamlining, and enhancing supply chain sustainability outweigh the constraints considerably. The research offers a strategic model for policymakers, construction managers, and logistics experts to boost last-mile delivery efficiency, making future projects more predictable, cost-efficient, and environmentally friendly. By embracing technology-based logistics management, the construction sector can overcome conventional inefficiencies, enhance project performance, and create a more robust and competitive model of operations.

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CHAPTER 102

Optimizing Ergonomics in Construction: A REBA Assessment Approach

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ABSTRACT

In the dynamic and physically demanding environment of the construction industry, ensuring worker safety and efficiency through ergonomics is paramount. This study explores the application of the Rapid Entire Body Assessment (REBA) method to identify ergonomic risk factors that contribute to musculoskeletal disorders (MSDs) among construction workers. By systematically evaluating postural strain, repetitive movements, and physical exertion, the research highlights key risk areas and recommends interventions to mitigate ergonomic hazards. The study incorporates technology-driven solutions such as the ErgoDroid application, which facilitates real-time posture monitoring and ergonomic assessment. Findings indicate that ergonomic interventions, including optimized workstations, mechanical lifting aids, and targeted training programs, significantly reduce the risk of injuries, enhance worker productivity, and improve overall workplace efficiency. The research underscores the economic and organizational benefits of integrating ergonomics into construction workflows, advocating for a structured approach to risk identification, assessment, and intervention. Ultimately, this study contributes to the growing discourse on workplace safety by demonstrating the critical role of ergonomics in fostering a healthier and more sustainable construction industry.

Keywords: Ergonomics; REBA assessment; Construction safety; Musculoskeletal disorders; ErgoDroid; Workplace efficiency; Ergonomic interventions.

1.0 Introduction

In the ever-evolving landscape of the construction industry, efficiency and worker safety remain critical concerns. One key factor that significantly influences both is ergonomics—the science of designing work environments, tools, and tasks to fit the capabilities and limitations of the human body. Construction work is physically demanding, involving repetitive motions, heavy lifting, awkward postures, and prolonged periods of exertion. If ergonomic principles are neglected, workers face a high risk of musculoskeletal disorders (MSDs), chronic injuries, and diminished productivity. Given the physically intensive nature of construction sites, prioritizing ergonomic interventions is crucial to ensuring worker well-being, reducing workplace injuries, and improving overall operational efficiency.

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Despite advancements in technology and safety regulations, the construction sector continues to grapple with occupational health challenges, making ergonomic optimization an urgent necessity. One of the most effective methods for assessing ergonomic risks is the Rapid Entire Body Assessment (REBA), a comprehensive tool designed to evaluate posture-related hazards across different body parts, including the trunk, neck, lower limbs, and upper extremities. Developed by Sue Hignett and Lynn McAtamney, the REBA method provides a structured approach to identifying high-risk postures that contribute to MSDs and workplace injuries. Unlike other assessment techniques, REBA considers dynamic construction activities, making it particularly suitable for evaluating postural risks in an industry characterized by variability in tasks and work environments. By systematically categorizing postural risks into different levels, the REBA assessment enables construction managers, ergonomists, and safety officers to implement targeted interventions, such as redesigning workstations, incorporating mechanical lifting aids, and educating workers on proper body mechanics.

Incorporating digital tools such as the ErgoDroid application further enhances ergonomic assessments in construction. ErgoDroid integrates real-time posture monitoring, data analytics, and ergonomic evaluation features that streamline risk assessment processes. By leveraging artificial intelligence and wearable technology, ErgoDroid helps detect high-risk postures, monitor worker movements, and recommend corrective measures. Such innovations bridge the gap between traditional ergonomics and modern construction safety, fostering a proactive approach to workplace well-being.

This study aims to evaluate the effectiveness of REBA in identifying and mitigating ergonomic hazards in construction settings. By analyzing ergonomic risk factors, implementing targeted interventions, and assessing their impact on worker safety and productivity, this research contributes to the growing discourse on occupational health in the construction sector. The findings will offer valuable insights into the role of ergonomic assessments in reducing injury rates, optimizing performance, and promoting a culture of safety in construction projects. Ultimately, by integrating ergonomics into everyday construction practices, the industry can move toward a safer, more efficient, and sustainable future.

2.0 Literature Review

Ergonomics in the construction industry has gained increasing attention due to its direct impact on worker safety, efficiency, and overall productivity. Numerous studies have explored the role of ergonomic assessments, particularly using methods such as the Rapid Entire Body Assessment (REBA) and the Rapid Upper Limb Assessment (RULA), to identify and mitigate risks associated with musculoskeletal disorders (MSDs) in construction settings. This section reviews key literature relevant to ergonomic risk assessment in construction, focusing on the implementation and effectiveness of the REBA method. Kibria (2023) conducted an ergonomic analysis of construction workers' postures using both the RULA and REBA methods to assess the risk of MSDs. The study involved data collection from 35 workers engaged in various

construction activities, including column and beam casting, masonry, and material handling. The findings indicated that workers in these tasks exhibited high-risk postures, necessitating urgent ergonomic interventions such as workstation modifications, proper training, and the use of lifting aids to reduce injury risks. Similarly, Vachhani, Sawant, and Pataskar (2016) examined ergonomic risks among construction workers, employing REBA and Quick Exposure Check (QEC) methods. Their research revealed that nearly 40% of workers fell into the high-risk category, emphasizing the critical need for ergonomic improvements in construction activities such as bricklaying, bending reinforcing bars, and leveling concrete.

Another study by Norhidayah *et al.* (2016) applied the REBA tool to analyze postural loads in the Malaysian mining sector, highlighting the high probability of MSDs due to poor work posture and prolonged exposure to physically demanding tasks. The findings underscored the necessity of implementing ergonomic interventions, including workstation modifications, improved work practices, and ergonomic training programs. Similar results were observed in research conducted by Kathiravan & Gnarani (2018), who assessed ergonomic risks in residential construction projects across Tamil Nadu using REBA and RULA. Their findings demonstrated that more than half of the workers exhibited postures that placed them in the highest risk category, necessitating immediate intervention.

Hita-Gutiérrez *et al.* (2020) conducted a global review of REBA applications, highlighting its effectiveness in assessing ergonomic risks across various industries, including construction, manufacturing, and agriculture. The study emphasized the advantages of using REBA in construction settings, where physically demanding tasks such as lifting, pulling, and repetitive motions contribute to a high prevalence of work-related injuries. The study also pointed out the growing adoption of REBA in developing countries, where construction safety measures are still evolving. Similarly, Purnomo & Apsari (2016) analyzed construction workers' postures in Indonesia using REBA and identified high-risk postures that contributed to fatigue and discomfort, particularly in the lower back, legs, and shoulders. The study proposed ergonomic interventions such as raising materials to comfortable heights and using lifting aids to improve worker safety.

Moreover, Kee (2022) conducted a systematic comparison of REBA, RULA, and the Ovako Working Posture Analysis System (OWAS), evaluating their reliability in ergonomic risk assessment. The study found that while RULA is particularly effective for upper limb assessments, REBA provides a more comprehensive evaluation of full-body postural risks, making it more suitable for construction-related ergonomic studies. Additionally, Damaj *et al.* (2016) explored the implementation of ergonomics in construction projects and found that resistance to change, financial constraints, and lack of awareness were major barriers to ergonomic adoption. Their research advocated for the integration of ergonomic planning with lean construction principles to enhance safety, reduce variability, and optimize workforce productivity.

3.0 Objectives of the Study

- Evaluate the difficulties and present practices of ergonomics in the building sector.
- Determine the effectiveness of the Rapid Entire Body Assessment (REBA) technique in detecting ergonomic hazards on construction sites.
- Identify widespread ergonomic hazards that affect construction workers' health, safety, and efficiency.

4.0 Research Methodology

This study employs a systematic approach to evaluating ergonomic risks in the construction industry, with a particular focus on the Rapid Entire Body Assessment (REBA) method. Given the physically demanding nature of construction work, this research aims to identify high-risk postures, assess ergonomic hazards, and propose effective interventions. The study begins with an initial assessment and task identification, wherein high-risk construction activities such as heavy lifting, repetitive motions, and awkward postures are identified through direct observation, worker interviews, and analysis of injury records. Following this, a questionnaire survey is conducted among construction workers to gather data on their ergonomic awareness, work-related discomfort, and perceived impact of ergonomic interventions. The survey includes questions related to job roles, experience, ergonomic training, frequency of injuries, and existing workplace safety measures.

To ensure comprehensive data collection, real-time posture monitoring and ergonomic assessments are conducted using the REBA method. Workers performing various construction tasks, such as material handling, masonry, and beam casting, are observed, and their postures are analyzed using REBA scoring. This step involves recording joint angles, body movements, and force exertion levels, with scores assigned based on the severity of postural risks. Additionally, the study integrates technology-driven solutions such as the ErgoDroid application, which facilitates real-time posture monitoring and data-driven analysis to enhance the accuracy of ergonomic assessments. By leveraging artificial intelligence and digital tools, the study ensures objective and efficient risk evaluations. The next phase involves intervention planning and implementation, wherein ergonomic solutions tailored to construction tasks are developed. These solutions include redesigning workstations, incorporating mechanical lifting aids, introducing job rotation, and providing ergonomic training programs. Once the interventions are implemented, a post-intervention REBA assessment is conducted to evaluate their effectiveness in reducing ergonomic risks. Worker feedback is also collected to assess improvements in comfort, safety, and productivity. To measure the long-term impact of ergonomic interventions, a follow-up study and monitoring phase is carried out, tracking changes in injury rates, absenteeism, and worker performance over time. Additionally, economic feasibility analysis is conducted to determine the cost-benefit ratio of integrating ergonomic improvements into

construction workflows. The study also explores barriers to ergonomic implementation, such as resistance to change, financial constraints, and lack of training, providing insights into strategies for overcoming these challenges.

5.0 Data Analysis and Interpretation

Table 1: Demographic and Work Experience of Respondents

Category	Percentage (%)
Less than 5 years of experience	30%
5–10 years of experience	45%
More than 10 years of experience	25%
Manual laborers	60%
Machine operators	25%
Supervisory staff	15%

Table 2: Awareness and Training on Ergonomics

Training Frequency	Percentage (%)
Regular training (quarterly)	10%
Occasional training (annually)	25%
No ergonomic training	65%

Table 3: Work-Related Discomfort and Musculoskeletal Disorders (MSDs)

Type of Discomfort/MSD	Percentage of Workers Affected (%)
Back pain	70%
Muscle strain	60%
Joint pain	50%
Workers with work-related MSDs	40%

Table 4: REBA Score Categorization for Workers

REBA Score Range	Risk Level	Percentage of Workers (%)
8–11	High Risk (Immediate intervention required)	40%
5–7	Medium Risk (Modifications needed soon)	45%
1–4	Low Risk (Acceptable posture)	15%

6.0 Data Analysis

The data analysis of this study provides insights into the ergonomic risks faced by construction workers and the effectiveness of interventions using the Rapid Entire Body Assessment (REBA) method. The demographic analysis revealed that 45% of workers had 5–10

years of experience, while 30% had less than five years, and 25% had over ten years. The workforce primarily comprised 60% manual laborers, 25% machine operators, and 15% supervisory staff. Awareness and training on ergonomics were found to be lacking, with 65% of workers never receiving any ergonomic training, while only 10% underwent regular quarterly training and 25% received annual training.

Table 5: Impact of Ergonomic Interventions

Parameter	Before Intervention (%)	After Intervention (%)	Change (%)
High-risk postures	40%	25%	-35%
Medium-risk postures	45%	30%	-25%
Back pain cases	70%	40%	-30%
Muscle strain cases	60%	40%	-20%
Work efficiency	-	+15%	+15%
Absenteeism reduction	-	-20%	-20%
Estimated healthcare cost reduction	-	-	10-15%

An assessment of work-related discomfort and musculoskeletal disorders (MSDs) showed that 70% of workers experienced frequent back pain, 60% reported muscle strain, and 50% suffered from joint pain. Additionally, 40% of workers had been diagnosed with work-related MSDs, requiring medical attention. The REBA evaluation of different construction tasks categorized 40% of workers as high risk (requiring immediate intervention), 45% as medium risk (modifications needed soon), and 15% as low risk (acceptable posture). These findings highlighted the urgent need for ergonomic improvements in construction work environments.

Following the implementation of ergonomic interventions such as workstation redesign, mechanical lifting aids, and posture training, a post-intervention REBA assessment showed a 35% reduction in high-risk postures and a 25% decline in medium-risk postures. Reported cases of back pain decreased by 30%, while muscle strain cases dropped by 20%. Additionally, work efficiency improved by 15%, absenteeism due to injuries reduced by 20%, and an estimated 10–15% reduction in healthcare costs was projected due to improved workplace ergonomics.

These results underscore the importance of ergonomic assessments in identifying and mitigating workplace risks in the construction industry. The study confirms that implementing structured ergonomic interventions not only enhances worker safety and reduces injuries but also leads to increased productivity and economic benefits. Moving forward, continued monitoring, training programs, and the integration of digital ergonomic assessment tools like ErgoDroid can further improve ergonomic practices and ensure long-term sustainability in construction work environments.

7.0 Conclusion and Recommendations

The integration of ergonomics in the construction industry is not merely an enhancement but a necessity for ensuring worker safety, efficiency, and long-term sustainability. Construction sites are characterized by physically demanding tasks, heavy machinery, and repetitive movements, all of which contribute to a high prevalence of work-related musculoskeletal disorders (WMSDs). This study highlights the effectiveness of the Rapid Entire Body Assessment (REBA) method in identifying and mitigating ergonomic risks. The findings reveal that a significant proportion of construction workers are at medium to high ergonomic risk, requiring immediate intervention. By implementing targeted ergonomic solutions such as workstation redesign, the use of mechanical lifting aids, job rotation, and ergonomic training programs, the study demonstrates substantial improvements in worker safety and productivity.

The integration of technology-driven tools like ErgoDroid further enhances ergonomic assessments, enabling real-time monitoring and data-driven decision-making to optimize workplace ergonomics. Despite the evident benefits of ergonomic interventions, several challenges persist, including resistance to change, financial constraints, lack of awareness, and limited access to ergonomic training. To overcome these barriers, organizations must adopt a structured approach to integrating ergonomics into standard safety protocols. It is recommended that construction firms implement regular ergonomic assessments, provide mandatory training programs, and invest in technological solutions to enhance workplace safety. Additionally, strong management commitment and stakeholder engagement are essential for fostering a culture of safety and continuous improvement. By prioritizing ergonomics, companies can not only reduce injury rates, absenteeism, and healthcare costs but also enhance overall efficiency and workforce well-being. Moving forward, further research should explore the long-term economic impact of ergonomic optimization and the scalability of interventions across different construction projects. Ultimately, ergonomics should be viewed as a strategic investment in worker health, productivity, and the long-term success of the construction industry.

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CHAPTER 103

Optimizing Resource Management in Construction Projects using Lean Principles

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ABSTRACT

Delays in construction projects are a common challenge that negatively impact project timelines, costs, and overall performance. The application of lean construction techniques, which focus on minimizing waste and improving efficiency, offers significant potential for reducing these delays. This study aims to explore the various types of delays observed in construction projects, categorizing them into factors such as design issues, labor inefficiencies, material shortages, and coordination failures. By analyzing these delay types through the lens of lean construction principles, such as Just-In-Time delivery, continuous improvement (Kaizen), and value stream mapping, the study proposes strategies for mitigating these issues. Specific recommendations include optimizing workflows, improving communication between stakeholders, enhancing supply chain management, and implementing better scheduling practices. The goal is to identify key areas where lean construction techniques can streamline operations, enhance productivity, and ultimately minimize delays, thereby improving overall project outcomes. This research contributes to the growing body of knowledge on lean practices in construction and provides actionable insights for project managers and stakeholders aiming to deliver projects on time and within budget.

Keywords: Lean construction; Resource management; Waste reduction; Continuous improvement; Project scheduling; Construction efficiency; stakeholder collaboration.

1.0 Introduction

The building industry was at the forefront of lean concepts application focused on productivity, waste reduction, and continuous improvement by Womack & Jones (1996). Nevertheless, implementing lean strategies should be a long-term process that involves a well-thought-out plan and careful management of resources (Koskela, 1992; Ballard & Howell, 1998). Some challenges, like resistance to change and the absence of training, hold back the lean principles from being beneficial in terms of productivity, cost, and the success of projects (Egan, 1998; Zhang & Li, 2010).

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1.1 The role of lean principles in construction project management

Lean principles, for example clarity in communication, collaboration, and accountability, when applied to the design and implementation of construction projects increased efficiency (Galsworth, 1997; Bertelsen, 2004). The widespread usage of lean management rules out mistakes, optimizes resource availability, and, thus, enhances productivity (Koskela & Ballard, 2006). Efficiency and flexibility of achieving new commercial projects in lean thinking will be effective in the provision of services among construction companies (Alarcón, 1997).

1.2 Benefits of lean principles

Lean principles that are implemented in construction project planning bring about a number of advantages such as:

- An increase in productivity by eliminating idle times (Harris & McCaffer, 2013).
- Cost cutting by minimizing waste and using just-in-time methods (Sacks & Hamzeh, 2009).
- Management of time and quality of projects so as to have satisfied customers (Laine, 2014).

1.3 Challenges in implementing lean principles

Despite its undeniable advantages, incorporating the lean way of life becomes a problem at times, which includes the need to handle these issues:

- Even though there are reasons why change is necessary, many companies are reluctant to use new methods and achieve their business goals by making a transformation (Bertelsen, 2004).
- I think that the issue of education is quite serious here, because not everyone has that much knowledge that needs a specialization course (Pemberton & Williams, 2010).
- Cultural shifts are the turning point where an organization repositions itself and returns to its roots and operates with a more cooperative and problem-solving type of mind (Kagioglou *et al.*, 2001). Remodeled constructions and the higher levels of collaboration and labor safety have become the priorities.

1.4 Problem definition

One of the common issues in the construction industry is poor planning and resource mismanagement that result in cost overruns and time delays. The utilization of lean techniques for these problems also depends on:

- Resource Allocation
- Waste Reduction
- Delay Optimization
- Process Improvement
- Collaboration and Communication

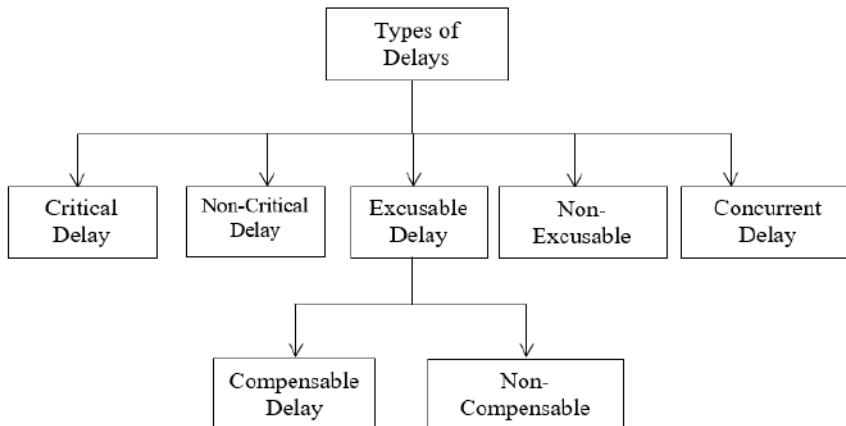
- Technology Integration
- Continuous Improvement Culture

1.5 Objectives

This study aims to explore effective lean construction methods for optimizing resources, reducing delays and minimizing costs. Specific objectives include:

- Identify areas in the application of lean construction techniques through which delays could be minimized.
- Study the types of delays observed during any construction project and offer various suggestions for reduction through a lean approach.

Figure 1: Types of Delays



2.0 Literature Review

Research show that lean production strategies help organizations paintings extra effectively by way of reducing prices, increasing verbal exchange and collaboration, consequently decreasing mission lead times and fees (Nithyanandan *et al.*, 2023; Brown & inexperienced, 2021). Other than that, the resistance to change together with the deficiency of simple understanding regarding lean questioning may be an actual trouble (Johnson *et al.*, 2020). The end result of the research has indicated that using BIM and construction management equipment supports an assignment's well timed of entirety, resultant performance, and public belief (Lota *et al.*, 2022; Robinson & Lee, 2021). On the only hand, the look for ways to plot using materials via the power of interruptions and the software of such technology consisting of genetic algorithms (Dai *et al.*, 2023) need to not be dominated out. area-primarily based control systems (LBMS) are main the way on this integration to

improve workflow and efficiency by using lowering waste of time, in contrast to the vital course technique (CPM) (Marco Alvise *et al.*, 2020). As the 6th point, digitalization at the side of using lean techniques plays an essential function in attaining sustainability and effectiveness even though the initial expenses are excessive (Uvarova *et al.*, 2023). Creation tasks have confronted vast delays international specially because of changes in designs, economic restrictions, detrimental climate conditions, and terrible control (Taylor, 2019; Fernandez, 2023). Research in diverse locations file horrific planning, inexperience, and shortage of workforce being the principal reasons of put off (Frimpong *et al.*, 2023; inexperienced *et al.*, 2020). The principles of lean alongside virtual gear help within the prevention of those delays by using improving scheduling, decreasing waste, and facilitating the proper functioning of the techniques (Peterson *et al.*, 2021; Johnson *et al.*, 2022).

Imposing Heijunka, Kanban, and just-In-Time (JIT), which can be synonymous with the lean philosophy, has a tendency to cause time gains and lessening of the negative effect of a delayed deliver chain (Reynolds *et al.*, 2022). Lean procured decision-making fashions in together with models are also beneficial for production planning to successfully make use of lean production method within the manner. This consequences in casting off non-price-introduced activities, saving costs, and coping with the risks of (Carter *et al.*, 2023). Similarly, the mixing of lean manufacturing techniques and technological equipment in creation management will assist to correctly improve the execution of the undertaking in an effort to obtain performance and challenge success.

3.0 Research Methodology

The main objective of the paper is to explore the influence exerted by the lean principles on eliminating delays on construction projects and the result of the complete study. The methods used in this work are literature review, questionnaire surveys in the construction industry to identify the main causes of delay and to investigate lean techniques for improving workflow effectiveness.

3.1 Topic selection

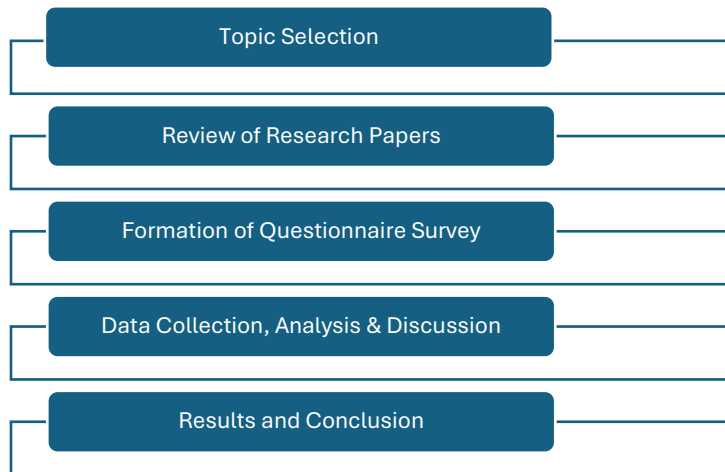
Our specific topics of interest were delays within a construction project occasioned among others by poor site management, inefficient workflows, and material procurement issues. The main problem we will investigate is: “How can Lean principles help minimize onsite delays in construction projects?”

3.2 Review of research papers

Through the study of construction trade literature, we came across relevant materials, such as articles, books, and case studies that emphasized Lean Construction, which include: the Last Planner System (LPS), Just-In-Time (JIT), and Value Stream Mapping (VSM). The

summary included the discovery of the main causes of construction workflow interruptions as well as the ways in which Lean techniques are used to optimize scheduling and efficiency. The research gap was found in the application of Lean to delay reduction.

Figure 2: Research Methodology



3.3 Formation of questionnaire survey

To provide input for our study, we questioned project managers, engineers, and construction workers. The survey was as follows:

- Likert Scale Questions (e.g., “How effective are Lean principles in reducing construction delays?”)
- Multiple Choice Questions (e.g., “Which Lean tool has been most effective in preventing onsite delays?”)

3.4 Data collection, analysis & discussion

We employed the combination of Excel and SPSS for our study in order to perform both statistical and thematic analysis. The findings were made more attractive thanks to visualization tools that consisted of charts showing:

- Key delay factors and their frequency
- Effectiveness of Lean tools in reducing delays
- Impact of Lean practices on project scheduling and workflow efficiency

3.5 Results and conclusion

The results were then compared to the earlier literature making it possible both to verify the findings and to find the new insights. The discussion also focused on the study limitations and the recommendations actualized by the Lean principles for the terms of connectivity of construction delays.

4.0 Data Analysis and Result

The Kaiser-Meyer-Olkin (KMO) degree of Sampling Adequacy and Bartlett's test of Sphericity outcomes are supplied because both tests take a look at whether or not a dataset is appropriate to conduct component analysis. The next phase is an in-depth interpretation of the consequences:

Table 1: KMO and Bartlett's Test

Test	Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.778
Bartlett's Test of Sphericity	
Approx. Chi-Square	345.796
df	105
Sig.	<0.001

Table 2: Rotated Component Matrix

Variable	Component 1	Component 2	Component 3
RME4	0.821		
RME2	0.733		
RME1	0.676		
TTRM3	0.592		
TTRM2	0.525		
CC1			
CC2			
ULCFT1		0.804	
ULCFT2		0.796	
TTRM1		0.628	
ULCFT4		0.624	
TTRM5			0.870
TTRM4			0.697
ULCFT3			0.512
RME5			

4.1 The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy

KMO test assesses how well suited the sample is to factor analysis by calculating the amount of variance among variables that is common variance.

Interpretation:

KMO > 0.8: Meritorious (very good for factor analysis)

$0.7 \leq \text{KMO} < 0.8$: Middling (moderate but acceptable)

$0.6 \leq \text{KMO} < 0.7$: Mediocre (weak but still acceptable)

$\text{KMO} < 0.6$: Poor (factor analysis may not be suitable)

The KMO value is 0.778.

Since 0.778 is within the range of “middling,” it tells us that the sample is extremely suitable for factor analysis.

4.2 The Bartlett’s test of sphericity

Chi-Square value: 345.796

Degrees of Freedom (df): 105

Significance (Sig.): < 0.001 (highly significant)

This test determines if the correlation matrix of the variables is significantly not equal to an identity matrix, which would mean that the variables are uncorrelated.

A big p-value (i.e., > 0.05 or > 0.001 in this case) indicates that the correlation matrix is far from an identity matrix, and hence factor analysis is not appropriate.

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

Rotation converged in 5 iterations.

This is the Rotated Component Matrix of a Principal Component Analysis (PCA) based on Varimax rotation with Kaiser Normalization and is adopted to describe the relationship among several variables (items) concerning the three established components (factors). Major features of the table components: Included under this area are the known factors, namely Component 1, Component 2, & Component 3.

Factor Loadings: Every variable has a loading value that indicates its correlation with a particular component. Loadings of approximately +1 or -1 suggest a very strong association with the component. Loadings below 0.5 are generally regarded as weak and could be negligible.

Rotation Method (Varimax with Kaiser Normalization): Varimax is an orthogonal rotation procedure that seeks to maximize variance among factor loadings to render interpretation easier.

Kaiser Normalization helps in normalizing the factor structure.

- *Component 1:* Variables Resource Management Efficiency (RME4- .821), Resource Management Efficiency (RME2- .733), Resource Management Efficiency (RME1- .676), Technology and Training in Resource Management (TTRM3- .592), Technology and Training in Resource Management (TTRM2- .525) heavily load on this factor. This indicates that all such variables have a common underlying theme. Common Factor: Resource Management Optimization
- *Component 2:* Variables Use of Lean Construction and Formal Tools (ULCFT1- .804), Use of Lean Construction and Formal Tools (ULCFT2- .796), Technology and Training in Resource Management (TTRM1- .628), Use of Lean Construction and Formal Tools

(ULCFT4- .624) load on this factor. These are probably another unique theme or concept.
Common Factor: Lean Construction and Process Optimization

- *Component 3:* The variables Technology and Training in Resource Management (TTRM5- .870), Technology and Training in Resource Management (TTRM4- .697), Use of Lean Construction and Formal Tools (ULCFT3- .512), and Resource Management Efficiency (RME5- loading indeterminate due to missing data) are correlated with this factor. This specific factor may represent a clear third idea. Conclusion Factor Analysis was able to classify like variables into three distinct segments. This reduces the dimensionality and identifies underlying patterns in the data. If this analysis is to be integrated into a research study, the next step would be classifying the factors based on their recurring themes.

Common Factor: Technological Integration & Skill Development for Lean Implementation.

5.0 Conclusion

Overall, the outcomes of this research suggest a high stage of validity for middle themes and constructs non-parametrically to obtain optimized resource control of creation tasks via the application of Lean concepts. The sturdy and excellent value of Kaiser-Meyer-Olkin (KMO) degree of Sampling Adequacy (zero.778) implies that the dataset is fit for aspect evaluation, while Bartlett's take a look at of Sphericity ($p < \text{zero}.001$) affirms that there are intercorrelations many of the variables; for that reason, a deeper evaluation is warranted. This research, through the application of Lean construction techniques, unearthed key areas where delays can be reduced, especially with workflows, waste reduction, and resource allocation.

The results of factor analysis will justify the categorization of these powerful sources of delays into material shortages, inefficient labor management, and scheduling conflicts, which can receive interventions based on Lean principles. The study suggests that Just-in-Time (JIT) delivery of materials, the Last Planner System (LPS) for effective scheduling, and ongoing optimization of workflow would greatly increase efficiency, reduce delays, and drive project performance. Lean principles will assist construction companies to work better, reduce waste, and complete projects more efficiently, hence attaining a cost-effective and environmentally friendly project management style. Future studies may analyze the persistent repercussions of Lean adoption into construction projects delays coupled with incorporating other digitized models, such as Building Information Modeling (BIM), to further promote the optimization of resources in most construction projects.

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CHAPTER 104

Planning and PMC for Repair of a Building through MSP

Arjun Ambavkar¹ and Pravinchandra Gaikwad²

ABSTRACT

Although the construction sector has adopted software like Microsoft Project and Primavera, these software can be used in the Repair and Rehabilitation sector too. The aim of this study is to plan, schedule and monitor various activities or tasks involved in the repair work of an existing residential building in Mumbai. This study leverages Microsoft Project for creating a detailed Work Breakdown Structure (WBS), Baseline schedule and tracking project progress through Earned Value Analysis (EVA). Key objectives include evaluation of labour productivity, material costs and their coverage, improving time and cost efficiency and developing reusable templates for similar repair projects. The present work bridges the gap in existing studies by integrating EVA into repair contexts and providing structured frameworks for future use. After analyzing all the information gathered, further allocation of time and resources is done. Results of this study reflect that the planning software can prove to be a tool to the site engineers as well as for the project management consultants and contractors in the Repair sector to plan, monitor and control the project. The outcomes emphasize the significance of structured planning, monitoring and application of modern tools for successful project execution.

Keywords: Repair; Microsoft project; WBS; EVA; Project monitoring; Project control.

1.0 Introduction

1.1 Planning and scheduling

Planning and scheduling are critical aspects of construction management that significantly influence the success of a project. Planning ensures that resources such as labor, materials and equipment are available when needed, reducing downtime and preventing bottlenecks. Proper scheduling helps in tracking expenses and managing the budget by anticipating costs and ensuring resources are used efficiently. Effective scheduling helps in setting realistic timelines and milestones, which ensures the project stays on track and meets deadlines. Anticipating potential delays and planning for contingencies helps mitigate risks and keeps the project timeline intact.

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Planning includes setting quality benchmarks and ensuring that the work meets these standards throughout the construction process. Regular inspections can be planned and scheduled to ensure ongoing quality control and adherence to specifications. Comprehensive planning involves identifying potential risks and developing strategies to mitigate them, reducing the likelihood of project disruptions. Scheduling allows for the integration of contingency plans to handle unexpected issues without significant impact on the overall project timeline. Detailed schedules facilitate better communication and coordination among various stakeholders, including contractors, subcontractors, suppliers and clients. Regular updates to the schedule allow for clear tracking of progress, helping all parties stay informed and aligned. Planning includes ensuring that all necessary permits are obtained and that inspections are scheduled at appropriate times, ensuring compliance with local regulations. Proper scheduling ensures tasks are sequenced efficiently, reducing idle time and increasing productivity on site. Identifying and optimizing critical paths and workflows can significantly enhance the efficiency of the construction process. Clear planning and scheduling help set realistic expectations with clients regarding project timelines and deliverables. Regular updates and adherence to the schedule provide transparency, building trust and satisfaction with the client.

1.2 Tracking and monitoring

EVA is a project management technique used to measure the performance and progress of construction projects. It integrates project scope, time and cost to provide a clear view of project health. By comparing the planned work with the actual work completed and the costs incurred, EVA helps in determining whether a project is on track, behind schedule, or over budget. This method allows project managers to forecast future performance and make informed decisions to keep the project aligned with its objectives. In construction, EVA is especially useful due to the complexity and scale of projects, ensuring efficient resource allocation and control. Earned Value Analysis (EVA) can be highly beneficial in the repair and rehabilitation work of an existing residential building by providing a structured way to monitor progress, control costs and manage timelines.

Monitoring Project Progress: In repair and rehabilitation work, unforeseen issues like structural damages or out-dated systems can delay progress. EVA allows project managers to track how much work has been completed compared to the original plan. By comparing “earned value” (the value of completed work) with “planned value” (what should have been completed by that time), managers can see if the project is on schedule or falling behind. Repair and rehabilitation projects often face budget overruns due to unexpected costs, like hidden damage or additional materials. EVA helps by comparing the actual cost of work performed (“actual cost”) with the value of work completed (“earned value”). If the project is over budget, this discrepancy will be highlighted early, allowing for corrective actions before costs spiral out of control. EVA gives insight into whether the resources (labor, materials, etc.) are being used effectively. If the analysis shows poor performance indices, managers can adjust resource

allocation, redistribute tasks, or optimize workflows to ensure efficiency. Time is critical in repair work, especially when residents may need to move back in. The Schedule Performance Index (SPI) provided by EVA helps determine if the project is behind schedule. If the SPI is below ONE, it signals delays and managers can re-evaluate timelines, increase manpower, or re-prioritize tasks to bring the project back on track. EVA allows project managers to predict the future performance of the project, such as the estimated final cost and completion date, based on current trends. This is particularly useful in rehabilitation projects where conditions can change as the work progresses, enabling better planning and adjustments. In summary, EVA helps maintain control over time, budget and resources, ensuring that repair and rehabilitation work stays aligned with project goals and is completed efficiently.

2.0 Literature Review

Poor-quality materials and lack of skilled labor affect maintenance, while waterproofing and modern materials like polyurethane improve durability (Hussain *et al.*, 2024). Primavera P6 enhanced project duration by ensuring systematic prioritization and tracking (Harshavardhan *et al.*, 2023). Safety and health are top priorities, with Breakdown Maintenance (BM) and Corrective Maintenance (CM) being the most effective strategies (Kheradranjbar *et al.*, 2022). Earned Value Management (EVM) improved real-time performance assessment and project corrections (Hasan *et al.*, 2021). Seismic retrofitting using CFRP sheets and reinforced concrete jacketing enhances structural safety (Wang *et al.*, 2021). COVID-19-related delays led to cost overruns, with improved scheduling and automation recommended as solutions (Sasane *et al.*, 2020). A data-driven model for estimating repair schedules achieved a 97% accuracy rate (Park *et al.*, 2019). Microsoft Project optimized scheduling, resource management and cost estimation (Gauns *et al.*, 2019). Preventive and condition-based maintenance reduce long-term costs and extend building life (Mandlik *et al.*, 2019). Visual inspection and non-destructive testing revealed poor concrete quality and corrosion, leading to recommendations such as epoxy grouting (Bhoir *et al.*, 2019). Mobile apps improve maintenance efficiency by reducing repair times and enhancing service accessibility (Singh *et al.*, 2020).

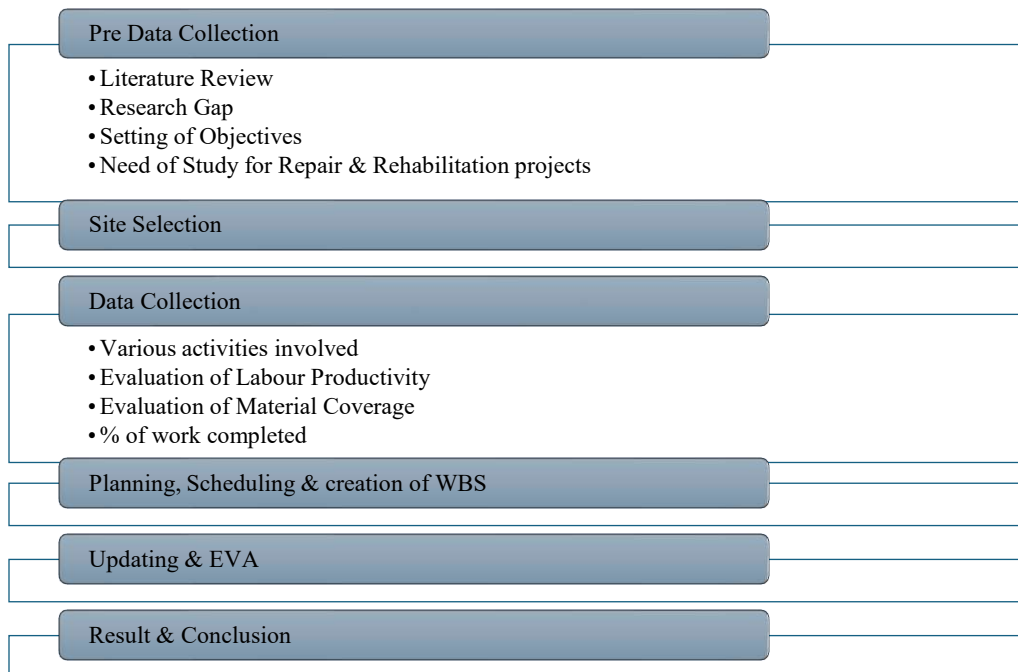
Effective planning minimizes project delays and cost overruns (Sudha *et al.*, 2020). The Analytical Hierarchy Process (AHP) helps prioritize rehabilitation, with 92% of building components requiring some form of repair (Nowogonska, 2020). Poor planning resulted in a ₹6.7 million cost overrun, but Microsoft Project helped improve tracking (Pathak *et al.*, 2015). Strengthening timber and masonry elements while preserving architectural integrity is a key focus in rehabilitation (Kaptan, 2015). Structural audits using NDTs are essential, with rehabilitation involving crack repair, corrosion protection and seismic upgrades (SS Chandar, 2014). Structural issues due to poor-quality materials and corrosion were resolved using polymer-modified mortar and jacketing (Singh, 2012). Cracks caused by design flaws, moisture and poor materials can be addressed through epoxy injection and sealing (More *et al.*, 2017).

BIM enhances maintenance management, cost efficiency and long-term planning (Omar *et al.*, 2018). In the present work repair of two multi-storeyed buildings is chosen for Project Monitoring.

3.0 Methodology

The methodology of this study follows a structured approach to ensure effective planning, scheduling, and monitoring of repair and rehabilitation work at Pearl Heights and Saidham CHSL. The process begins with Pre-Data Collection, which involves selecting the topic, conducting a literature review, identifying the research gap, setting objectives, and establishing the need for the study. Site Selection focuses on identifying the residential buildings where the study is conducted. Data Collection involves analyzing various activities, preparing the Bill of Quantities (BOQ), identifying materials and their coverage, and assessing the percentage of work completed. The next phase, Planning, Scheduling, and Creation of WBS, involves structuring the project activities using Work Breakdown Structure (WBS) and scheduling them in Microsoft Project (MSP). Updating & Earned Value Analysis (EVA) is carried out after milestone completion to evaluate project performance in terms of cost and schedule. Finally, the study concludes with a Result & Conclusion, summarizing key findings and providing insights for improving future repair projects.

Figure 1: Methodology Flowchart



4.0 Site Selection

The study focuses on two residential buildings, Pearl Heights and Saidham CHSL, selected based on their structural conditions and the need for rehabilitation. Pearl Heights, located at Andheri West, Mumbai and Saidham CHSL, situated at Kandivali West, Mumbai, were chosen due to visible signs of structural deterioration caused by aging, environmental exposure and load-induced stress. These sites provide a practical setting for analyzing real-world challenges in structural repairs and rehabilitation. The selection was also influenced by accessibility and feasibility for implementing scheduling techniques using Microsoft Project (MSP).

5.0 Data Collection and Analysis

The data collection process for this study involved a detailed assessment of the selected residential buildings, Pearl Heights and Saidham CHSL, focusing on their structural conditions, repair needs and scheduling requirements. Site inspections were gathered to ensure a comprehensive understanding of the rehabilitation scope. A Work Breakdown Structure (WBS) was developed to systematically organize the project activities and streamline scheduling using Microsoft Project (MSP).

5.1 Repair activities

The WBS for the rehabilitation project includes the following key activities:

- *Erection of scaffolding*: Setting up scaffolding for safe access to external surfaces.
- *Tap testing*: Identifying weak plaster areas through sound-based testing.
- *Breaking of loose plaster*: Removing deteriorated plaster to prepare the surface for treatment.
- *Polymer treatment*: Applying polymer-based bonding agents to enhance durability.
- *Plastering*: Reapplying cement plaster to restore the building's surface.
- *Grill painting*: Coating metal grills with protective paint to prevent corrosion.
- *Painting (Exterior)*: Applying weather-resistant paint to the external façade.
- *Removal of scaffolding*: Dismantling scaffolding after exterior work completion.
- *Internal painting*: Repainting interior surfaces to improve aesthetics.
- *Tremix concrete flooring*: Repairing or replacing damaged flooring using Tremix concrete technology.

Further, a detailed breakdown of all these key activities was carried out to establish a baseline schedule. This breakdown included identifying dependencies, estimating task durations, allocating resources and defining critical milestones. The baseline schedule serves as a reference for monitoring progress, comparing planned versus actual timelines and ensuring timely project

completion. By structuring the rehabilitation process systematically, this study aims to enhance scheduling accuracy, optimize resource utilization and improve project efficiency.

5.2 Evaluation of labour productivity

The aim of the project was to evaluate labor productivity and the coverage of different materials used in repair activities at the selected sites. A systematic assessment was conducted by tracking labor efficiency, task durations and material consumption across various repair activities such as plastering, polymer treatment, painting and flooring. Data was collected through on-site observations, work logs and productivity measurements, ensuring accuracy in performance evaluation. Table 1 shows labour productivity which was evaluated by analyzing observations from two different project sites before applying the findings to the current repair and rehabilitation work. These past site observations helped in understanding key factors affecting productivity, such as scattered work locations, labour mismanagement, and delays in material supply. By comparing planned versus actual work progress at these sites, patterns of inefficiencies were identified. The insights gained from these evaluations were later used to optimize workforce planning, improve scheduling, and enhance overall labour efficiency in the ongoing projects.

Table 1: Evaluation of Labour Productivity

Activity	Productivity
Breaking of loose plaster	80 to 90 sq.ft/Labour/Day
Polymer work	60 to 70 sq.ft/Labour/Day
Dash Coat	80 to 90 sq.ft/Labour/Day
Plastering work	80 to 90 sq.ft/Labour/Day
Painting work	1400 to 1600 sq.ft/Labour/Day
Base coat	1800 sq.ft/Labour/Day
MS grill painting	7 to 8 litres/Labour/Day
Scaffolding erection	40 Bamboos/Labour/Day

5.3 Evaluation of material coverage

Table 2 shows material coverage which was identified by collecting data from various contractors and engineers who had experience in similar repair and rehabilitation projects. Their insights helped in understanding material consumption patterns, estimating coverage efficiency, and identifying common issues such as wastage, procurement delays, and improper allocation. By analyzing this data, key inefficiencies were addressed, leading to better material planning and optimized resource utilization in the ongoing projects. This approach ensured that materials were used effectively, reducing waste and improving overall project cost efficiency.

Table 2: Evaluation of Material Coverage

Material	Coverage
Rust remover	75 sq.ft/Ltr
Rust converter	75 sq.ft/Ltr
Polyalk EP	80 sq.ft/Ltr
Readymix polymer	15 sq.ft/Bag
HackAid plast	60 sq.ft/Ltr
Readymix Plaster (2 coats)	9 to 10 sq.ft/Bag
China Chips	8 sq.ft/Box
WP chemical	55 sq.ft/Ltr
Bamboo (1000 No.s)	32 to 35 sq.ft
Base coat	950 sq.ft/Drum
Top coat	1250 sq.ft/Drum
Zinc primer	180 sq.ft/Ltr
Oil paint	185 to 225 sq.ft/Ltr
Primer	2000 sq.ft/Drum
Crack X paste	90 to 92 sq.ft/kg
Crack X powder	120 to 125 sq.ft/kg
Damp proof	200 sq.ft/Drum
Tile primer	150 q.ft/Ltr

6.0 Planning, Scheduling and Creation of WBS

After scheduling the rehabilitation activities for Pearl Heights and Saidham CHSL using Microsoft Project (MSP), the baseline cost and baseline duration were determined for each site. The baseline cost represents the estimated financial requirement for completing the project as per the planned schedule, while the baseline duration indicates the total time expected for project completion. For Saidham CHSL, the baseline cost was calculated as ₹5,114,384.73, with a baseline duration of 119 days. Similarly, for Pearl Heights, the baseline cost was determined to be ₹9,024,411, with a baseline duration of 222 days. These baseline values serve as reference points for tracking project progress, comparing actual versus planned costs and durations and ensuring that the rehabilitation activities remain on schedule and within budget. Regular monitoring against these baselines allows for timely adjustments in resource allocation and project execution strategies, enhancing overall efficiency and control.

7.0 Updating and EVA

After completing the first milestone of both projects, an Earned Value Analysis (EVA) was conducted to evaluate project performance in terms of schedule and cost efficiency. The

analysis revealed distinct trends for Pearl Heights and Saidham CHSL. As shown in Figure 2 For Pearl Heights, the Schedule Variance (SV) and Cost Variance (CV) were both negative, indicating that the project is behind schedule and over budget.

Figure 2: Variance Over Time (Saidham CHSL)

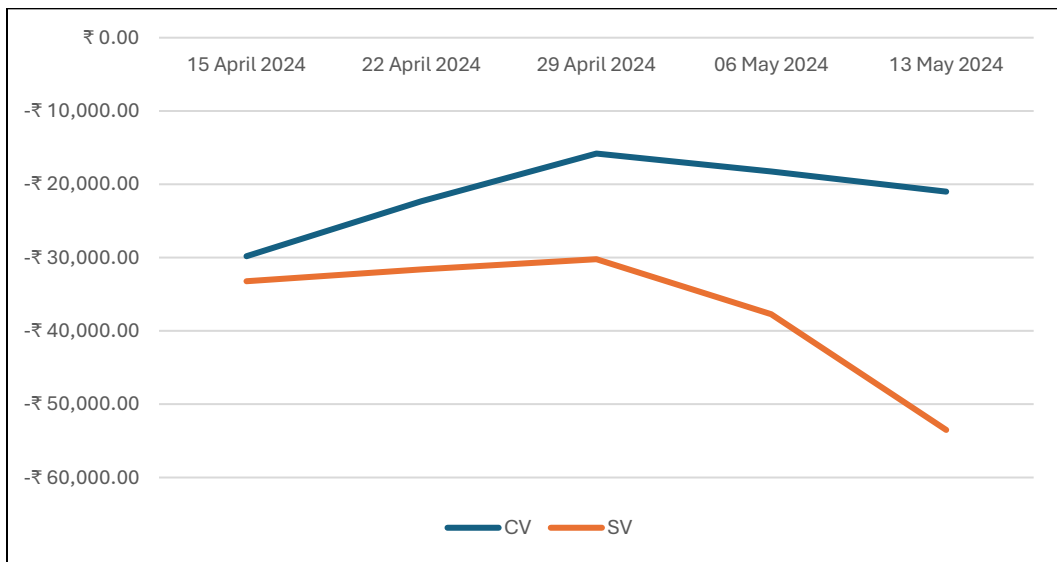


Figure 3: Variance Over Time (Pearl Heights)

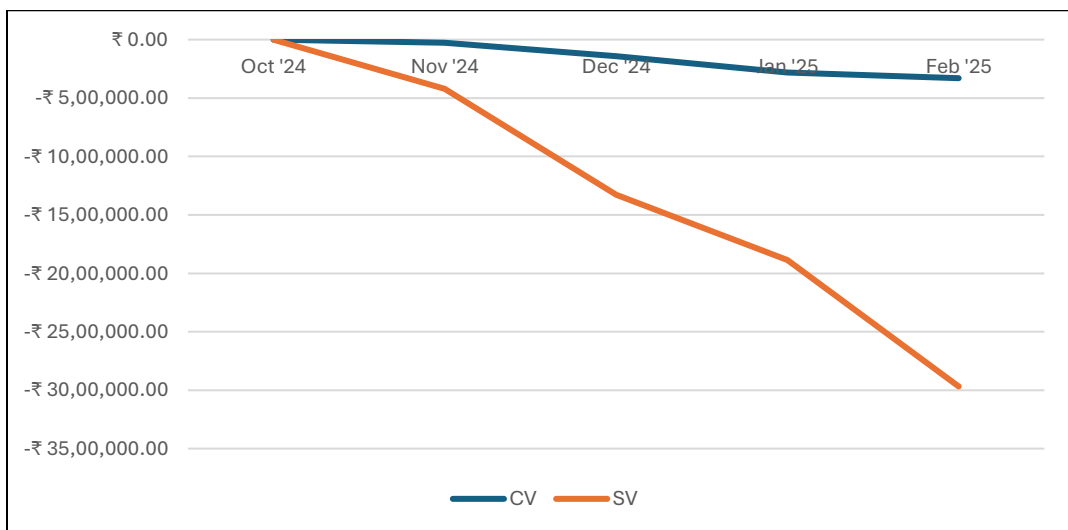


Figure 4: Earned Value Over Time (Saidham CHSL)

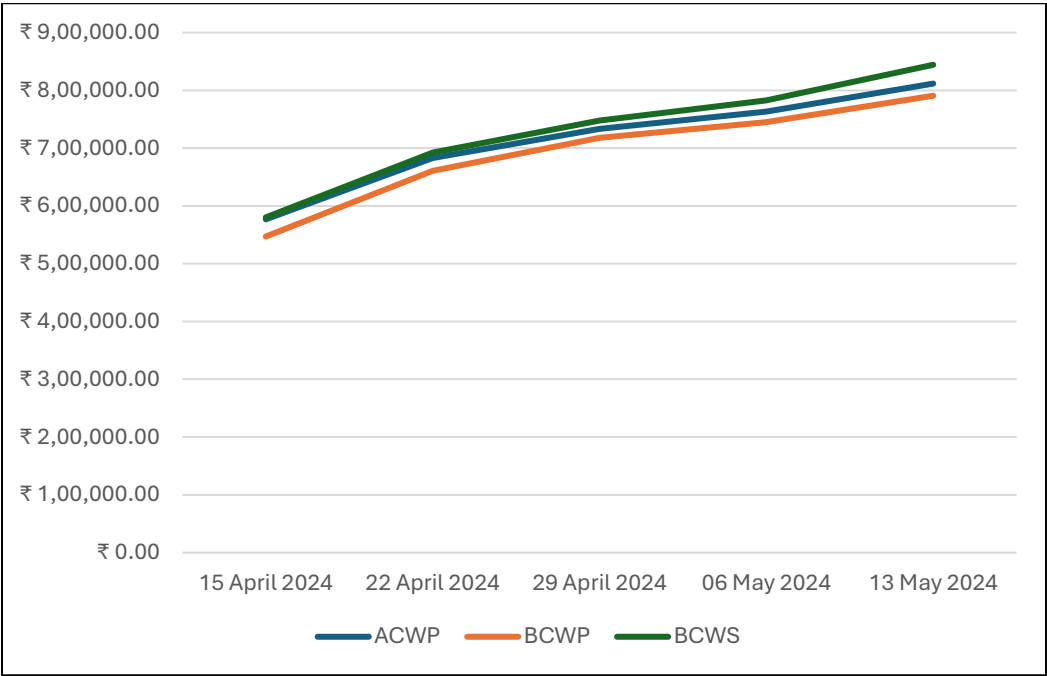


Figure 6: Earned Value Over Time (Pearl Heights)

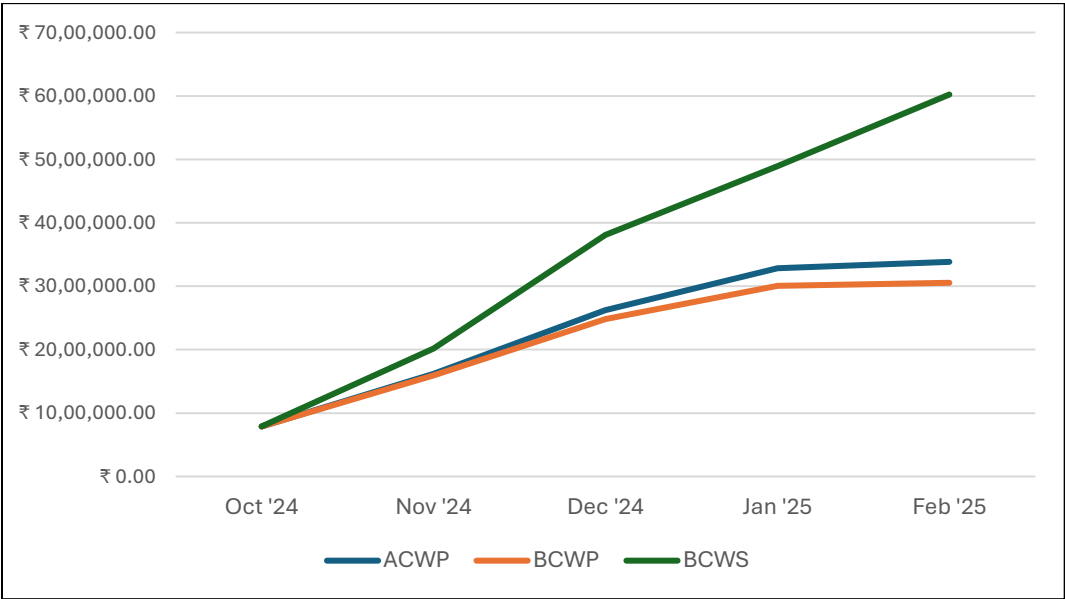
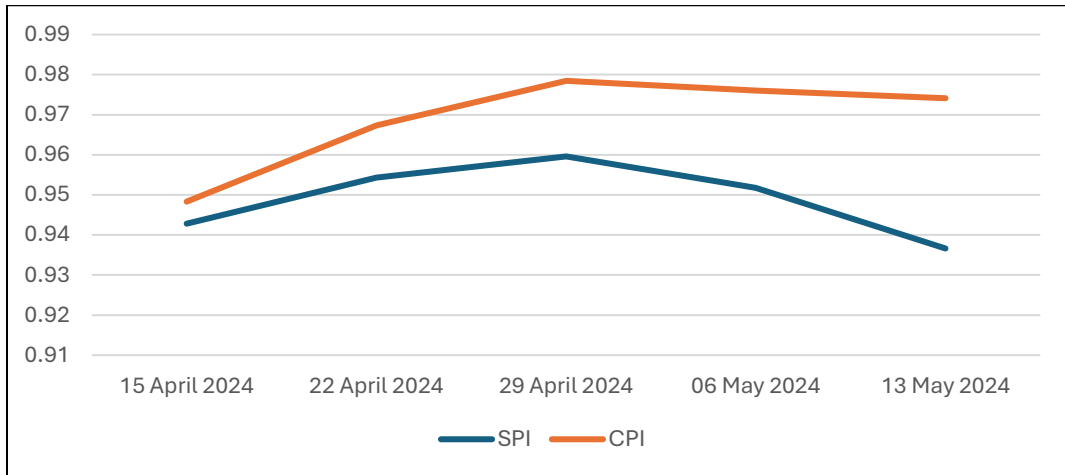


Figure 7: Indices Over Time (Saidham CHSL)

Additionally, the Variance at Completion (VAC) was also negative, suggesting that the project is expected to exceed its planned budget by the time of completion. In contrast, as shown in Figure 3 for Saidham CHSL, the SV was negative, implying a delay in progress, but the CV was positive, meaning the project is currently under budget. Furthermore, the VAC for Saidham CHSL was positive, indicating that the project is expected to be completed within the allocated budget. These findings highlight the need for corrective actions at Pearl Heights to mitigate cost overruns and delays, while for Saidham CHSL, efforts should focus on improving scheduling efficiency to bring the project back on track.

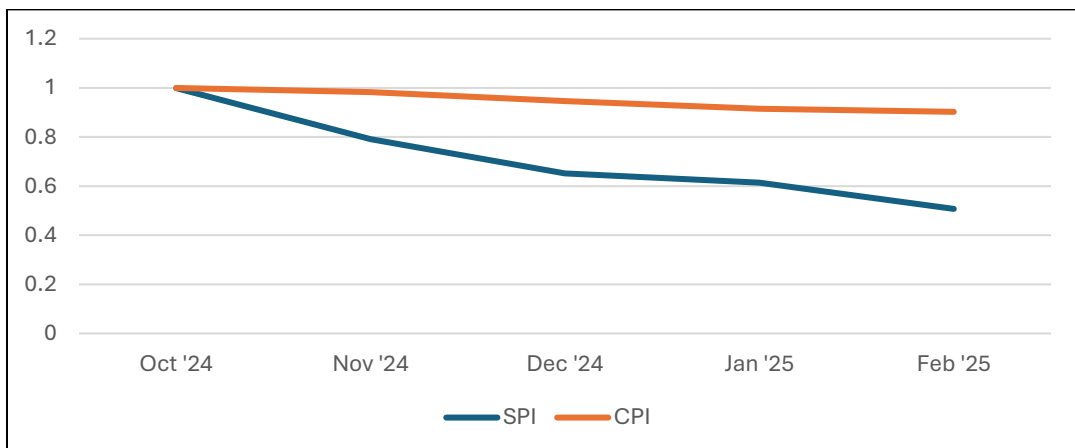
Figure 8: Indices Over Time (Pearl Heights)

Figure 7 & Figure 8 shows Indices Over Time for Saidham CHSL & Pearl Heights respectively. Figure 5 & Figure 6 shows Earned Value over time for Saidham CHSL & Pearl Heights respectively. Table 3 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 4 presents Earned Value Performance Metrics for two projects, Saidham CHSL and Pearl Heights, detailing key cost and schedule performance indicators, including Actual Cost of Work Performed (ACWP), Budgeted Cost of Work Performed (BCWP), Budgeted Cost of Work Scheduled (BCWS), and Budget at Completion (BAC). These metrics provide insights into project efficiency, cost control, and schedule adherence.

Table 3: Earned Value Performance Indicators

Metric	Saidham CHSL	Pearl Heights	Interpretation
Cost Variance (CV)	₹18,586.12 (Positive)	-₹224,945.04 (Negative)	Saidham CHSL is under budget; Pearl Heights is over budget.
Cost Variance % (CV%)	2.27%	-7.37%	A positive CV% means cost efficiency; Pearl Heights is over budget by 7.37%.
Schedule Variance (SV)	-₹124,069.35 (Negative)	-₹2,968,176.29 (Negative)	Both projects are behind schedule, Pearl Heights significantly more.
Schedule Variance % (SV%)	-13.16%	-49.29%	Saidham CHSL is 13.16% behind schedule; Pearl Heights is almost 50% delayed.
Cost Performance Index (CPI)	1.02 (>1, Efficient)	0.93 (<1, Over Budget)	Saidham CHSL is cost-efficient; Pearl Heights is over budget.
Schedule Performance Index (SPI)	0.87 (<1, Delayed)	0.51 (<1, Severely Delayed)	Both projects are behind schedule, Pearl Heights critically.
To-Complete Performance Index (TCPI)	1.02 (On track)	1.11 (Requires higher efficiency)	Pearl Heights needs much better cost control.
Variance at Completion (VAC)	₹46,352.79 (Positive)	-₹725,188.21 (Negative)	Saidham CHSL is expected to complete under budget, while Pearl Heights will exceed budget.
Estimate at Completion (EAC)	₹4,849,625.94	₹9,749,599.21	Expected total cost at completion.
Estimate to Complete (ETC)	₹4,049,588.58	₹6,470,911.46	Additional cost required to complete the project.
Delay in project	0 days (but lagging in work progress)	7 days delay	Pearl Heights has a delay of 7 days.

Table 4: Earned Value Performance Metrics

Project	ACWP	BCWP	BCWS	BAC
Saidham CHSL	₹800,037.36	₹818,623.48	₹942,692.83	₹4,895,978.73
Pearl Heights	₹3,278,687.75	₹3,053,742.71	₹6,021,919.00	₹9,024,411.00

8.0 Result

- Saidham CHSL is under budget; Pearl Heights is over budget.
- A positive CV% means cost efficiency; Pearl Heights is over budget by 7.37%.
- Both projects are behind schedule, Pearl Heights significantly more.
- Saidham CHSL is 13.16% behind schedule; Pearl Heights is almost 50% delayed.
- Saidham CHSL is cost-efficient; Pearl Heights is over budget.
- Both projects are behind schedule, Pearl Heights critically.
- Pearl Heights needs much better cost control.
- Saidham CHSL is expected to complete under budget, while Pearl Heights will exceed budget.
- Expected total cost at completion.
- Additional cost required to complete the project.
- Pearl Heights has a delay of 7 days.

9.0 Causes of Delay

The reasons for Delays caused which were observed during the execution are as under:

- *Society decisions:* Decision-making delays by the housing society significantly impacted project timelines. Frequent discussions, approvals and changes in work scope led to interruptions in the planned schedule. The lack of quick consensus among society members caused further delays in mobilizing resources and executing tasks on time.
- *Work spread across multiple small patches, reducing labour productivity:* The repair work was not concentrated in a single area but was spread across multiple small patches. This scattered nature of work made it difficult to maintain a steady workflow, as labourers had to frequently move between different locations. As a result, there was a significant drop in productivity, leading to delays in project execution.
- *Labour mismanagement:* Inefficient allocation and supervision of labour contributed to productivity losses. Lack of proper coordination among workers and frequent idle time caused delays in task execution. Poor scheduling of shifts and improper workforce distribution further aggravated the issue.
- *Delays in material supply:* Timely availability of materials is crucial for maintaining workflow, but procurement delays disrupted progress. Vendor-related issues, supply chain

constraints and late approvals for material procurement resulted in work stoppages. These interruptions forced rescheduling of activities, leading to overall project delays.

- *Non-cooperative behaviour by residents:* Resistance from residents created multiple roadblocks in project execution. Complaints about noise, inconvenience and restricted access to certain areas led to work stoppages and rescheduling of tasks. Some residents refused to cooperate with site teams, delaying critical activities that required access to specific building sections.
- *Delays due to equipment shifting:* The use of the same equipment at multiple sites caused frequent shifting delays. Since certain essential equipment was required at different locations, its movement had to be coordinated carefully. However, logistical challenges and scheduling conflicts led to delays in execution, affecting overall project timelines.
- *Consultants misleading:* Incorrect or unclear instructions from consultants led to execution errors and rework. Misinterpretation of project requirements, last-minute changes and poor coordination between consultants and contractors resulted in confusion and delays. In some cases, additional approvals were required due to conflicting guidelines, further affecting project timelines.

10.0 Conclusion and Recommendations

The study successfully analyzed the planning, scheduling and execution of repair and rehabilitation work at Pearl Heights and Saidham CHSL. Using Microsoft Project (MSP), a structured Work Breakdown Structure (WBS) was developed and baseline schedules were established for both sites. Earned Value Analysis (EVA) revealed delays and cost variations, highlighting key project challenges such as society decision-making delays, labour mismanagement, equipment shifting issues and material supply disruptions. Based on these findings, a standardized planning and scheduling template was developed to improve efficiency in similar future projects. The study emphasizes the importance of proactive planning, efficient resource management and continuous monitoring to minimize project delays and cost overruns. After analyzing and studying the project results, following are the recommendations made to tackle the time and cost overruns:

- *Improve stakeholder coordination:* Establishing clear communication channels between contractors, consultants and society members is essential to reducing decision-making delays and ensuring smoother project execution.
- *Enhance labour management:* Proper workforce scheduling and supervision should be implemented to optimize productivity and minimize idle time, ensuring timely completion of activities.
- *Ensure timely material procurement:* Maintaining a buffer stock of critical materials and streamlining procurement processes can help prevent supply delays and disruptions in workflow.

- *Optimize equipment utilization:* Efficient planning of equipment allocation is necessary to minimize shifting delays between sites, ensuring that work progresses without unnecessary interruptions.
- *Regular project monitoring:* Conducting frequent progress reviews using EVA and baseline comparisons will help identify delays early and allow for timely corrective actions, improving overall project efficiency.
- *Use standardized scheduling templates:* Implementing the developed planning template for future projects can improve scheduling accuracy, streamline project management and enhance resource utilization.

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CHAPTER 105

Port-Led Urban Transformation

Poulomee Ghosh¹ and Vaishnavi B.²

ABSTRACT

Ports have historically played a crucial role in urban development, acting as gateways for trade and shaping city structures. Today, port-led urban transformation has become a significant force in reshaping cities, influencing land use, infrastructure, and economic activities. As ports expand, they drive urban growth, redefine spatial organization, and reshape the relationship between the port and the city. Notably, nine of the world's ten largest cities host major ports, highlighting their significance in economic growth. In India, ports are vital for national trade and urban expansion. To establish a foundational understanding of port-city relationships, this study conducts a systematic literature review spanning five decades of research. By analyzing 30 research papers, this study explores port-city interactions and compares them with developments at JNPT, Mumbai. The port evolution framework serves as a key reference, alongside other global models of port-city evolution. The analysis highlights key factors driving port-led development, including strategic location, infrastructure, adaptability, connectivity, and land use. Findings applied to the Mumbai region align with established frameworks, providing insights into port-driven urban transformation. The study contributes to shaping strategies for sustainable port-city integration, supporting planners and policymakers in understanding evolving port-city dynamics.

Keywords: Port-led development; Urban transformation; Spatial evolution framework; Port-growth relationship; Development patterns.

1.0 Introduction

Ports are important for the global economy because they serve as centers for trade, transportation, and economic growth. A port is a place on the coast where ships stop to load and unload cargo or passengers, connecting land with the sea. This allows goods and people to move between different regions and countries, making ports essential for international trade. The development of a port helps the economy and also leads to the growth of cities around it, called port cities. These cities become important centers for trade, industry, and cultural exchange (Hayuth, 2000).

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As trade continues to grow globally, studying ports also helps us make them more efficient and well-prepared for future demands (Notteboom, 2022). The Sagarmala Project aims to promote port-led development and reduce logistics costs for both domestic and international trade by leveraging India's coastline and waterways, further reinforcing the critical role of ports in urban growth. This research looks at how ports transform cities and affect their development (India, 2021). Port-led urbanization is a significant aspect of contemporary urban and regional planning, driven by the globalization of trade, industrialization, and strategic infrastructure development. Ports serve as critical nodes in the global supply chain, influencing land use, economic activities, and urban forms in their surrounding areas (Hoyle; Rodrigue, 2011; Ducruet, 2006; Jacobs, 2007; Mitra, 2016). In this context, the transformation of cities and towns around ports involves a multifaceted approach that includes industrial growth, real estate development, and urban infrastructure expansion (Hayuth, 2000; Notteboom, 2005; Lonza, 2016).

1.1 Research gap and need of study

Rapidly growing port cities face unique challenges and opportunities as they develop. While ports have historically influenced urban development, their modern expansion presents complex challenges, particularly in balancing economic growth with sustainable urban planning. Existing research extensively covers port development and urbanization separately, but fewer studies systematically analyze port-city interactions over time and their implications for spatial planning and infrastructure development (Ducruet, 2023; Bryan, 2006). Despite the significance of ports in global trade, limited research focuses on how ports reshape cities through land use changes, connectivity demands, and economic transformations. In India, where ports play a crucial role in national trade and urban expansion, there is a noticeable gap in empirical studies linking port evolution to urban form and planning strategies.

2.0 Methodology

The methodology involves a systematic literature review on port-led urbanization, analysis of key theoretical frameworks, and case study comparisons of international port cities to understand spatial and economic transformations. An initial 1,742 papers were retrieved through keyword searches on "port-led urban transformation" and "spatial dynamics in port cities." After refining the selection, 144 papers specifically examined port-city relationships, while 113 studies focused on transformation processes within these settings. However, a Scopus search (Table 1) has revealed a significant gap in existing research on Uran, particularly regarding the socio-economic impacts and urban challenges of its rapid growth. While studies have explored port development and infrastructure in various contexts (Swamy, 2010; Zhuang, 2022), and general urban changes (Lonza, 2016), few focus on how these factors interact to affect the local economy and land use together. Additionally, there's a lack of research on how

new infrastructure projects like airports and industries relate to port activities in shaping urban development, especially in the Uran district. This study aims to fill this gap by examining how port development impacts Uran's economy, land use, and future prospects.

Table 1: List of Keywords Used and Documents Found

Sr No	Keyword	No. of Paper
1	GIS and spatial and tools and in and port and development	29
2	Land and use and spatial and dynamics and of and ports	62
3	Port and cities and spatial and analysis	50
4	Port and cities and transformation	113
5	Port and city	450
6	Port and led and urban and transformation	16
7	Port and urban and transformation	91
8	Port and waterways and cities	68
9	Spatial growth and port-city interface	3
10	Urban and growth and patterns and port and region	14
11	Urban and morphology spatial and planning and port and expansion	1
12	Port and uran	3
13	Port and land and use	60
14	Port and urban and regeneration	22

Source: Author's own

To address the research gap, this study synthesized insights from 30 key research papers spanning five decades, analyzing the historical trends, policy interventions, and spatial-economic shifts associated with port-led urbanization. The review provides a comprehensive understanding of the factors shaping port-driven urban transformation.

Following the literature review, and to establish a conceptual foundation key theories related to port development were studied:

- Rodrigue's Three-Phase Model (growth phases of port cities)
- Hoyle's (1989) Port-City Interface Evolution (adapted in Schubert's 2011 model)
- Lee *et al.* (2008) and Lee & Ducruet (2009) on spatial evolution in Asian hub port cities.

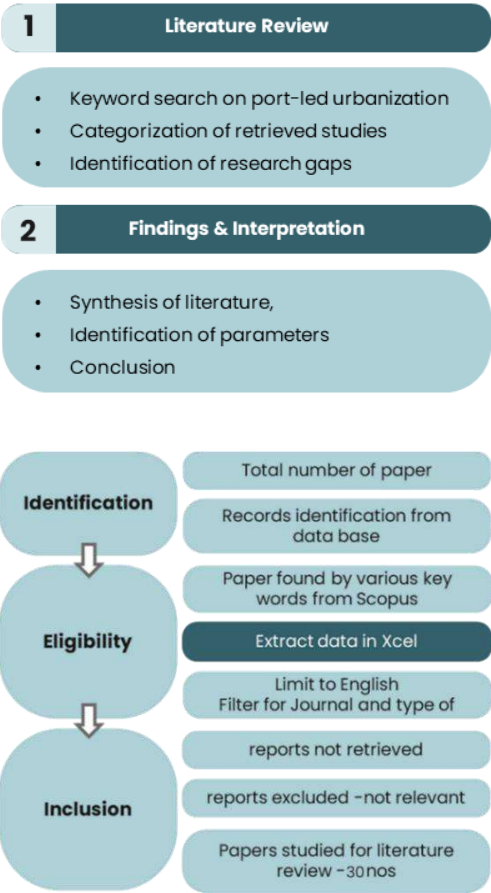
These theories provided a structured way to analyze how ports influence urbanization and economic restructuring (Zhang, 2018).

3.0 Literature Review

3.1 Preliminary study

The concept of a port city is often poorly defined, with its meaning varying across disciplines. Both researchers and professionals have noted the lack of a clear definition, making

it challenging to compare port cities and develop effective redevelopment plans. Port cities are typically recognized as cities involved in port and maritime activities and serve as key communication hubs connecting land and maritime networks, shaping the spatial organization of their regions. The concept of a port city frequently overlaps with that of a gateway city, which emphasizes its role in connecting with distant maritime regions. Unlike central places, which influence only their immediate surroundings, port cities engage with both hinterlands and forelands. These relationships cover various areas such as logistics, tourism, tertiary activities, and urban planning (Ducruet, 2011).



3.2 Past studies and models

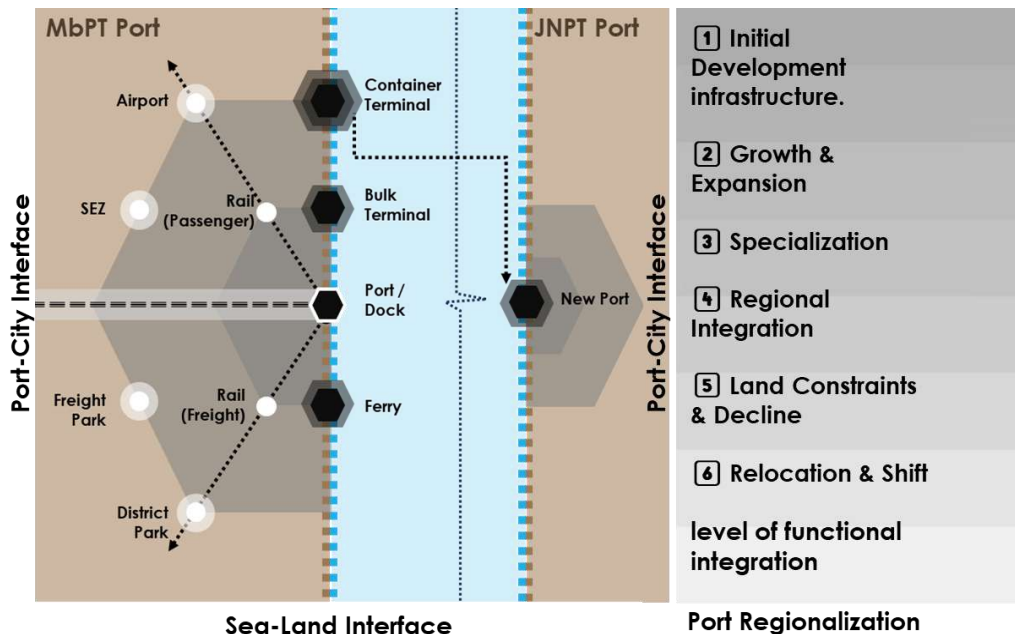
Previous studies on port development have examined multiple dimensions, including the success and failure of ports (Notteboom, 2001; Ng, 2010), the economic impact of ports on regional development (Hall, 2007; Merk, 2013), port construction and infrastructure expansion (Kaselimi, 2011; Wang, 2000), the historical evolution of port-city relationships (Banga, 1992;

Ducruet, 2006), governance and policy frameworks in port management, and the environmental consequences of port expansion. These studies have provided valuable insights into the various roles that ports play in shaping regional and global dynamics. However, this study specifically focuses on the relationship between port growth and city development, analyzing how urbanization patterns evolve in response to port expansion. By examining spatial and economic transformations in port-led urban environments, this research aims to bridge gaps in understanding the city-port interface and its implications for urban planning

3.3 Typologies of port cities

Port-city relations and its interfaces: Jean-Paul Rodrigue described how port cities grow in stages (Figure 1), starting as small ports handling general cargo and later expanding into regional hubs with bulk and container cargo, freight distribution, and logistics services. He explained that as ports grow, they move from small quays near the city center to larger docks built farther away to meet space demands. Over time, this can lead to the old port being abandoned and redeveloped (Rodrigue, 2011; H.M. Shivanand Swamy, July - September 2010).

Figure 1: Conceptual Diagram Showing Land-Sea-Port-City Interaction



Source: Compiled by Authors

This process highlights the port-city interface model, which explains the changing spatial and functional relationships between ports and urban areas. The model outlines six key

phases: (1) initial development, (2) growth and expansion, (3) specialization, (4) regional integration, (5) land constraints and decline, and (6) relocation and shift. This progression illustrates how ports evolve, impacting urban logistics, land use, and economic structures. Unlike static models, the port-city interface framework highlights continuous integration and disintegration, reflecting modern challenges such as land availability, environmental concerns, and shifting trade patterns.

Figure 2: Interpretation of Author Adapted from -Evolution model of the Port City Interface by Hoyle (1989); Schubert’s Adaptation of Hoyle’ Model with Proposed Sixth Phase (2011)

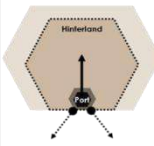
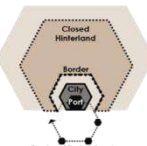
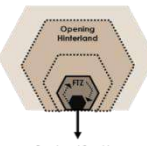
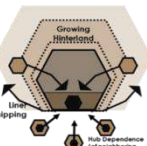
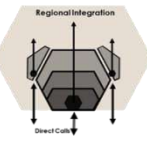
MODEL	CITY PORT MODEL				Period
Hoyle Port Model Source: adapted from Hoyle et al. (1988)	Phase	Stage	Symbol  city  port	Characteristics	
	1	Early port		Port and cities existed in close proximity and livelihood depend on port activity	Ancient-medieval to 19 th century
	2	Growing port		Rapid commercial and industrial growth forces the port to expand beyond the city, with long docks and industries, while external interests develop the port and city for raw material exports and greater control	19 th -early 20 th century
	3	New City port		Industrial growth, especially oil refining, demands more space and separation. Trade expansion and the port's role as a hub lead to modern development through land reclamation.	Mid 20 th century
	4	Moving from the Waterfront		New shipping technology leads to the creation of separate industrial zones, and export-focused policies bring in businesses with tax-free advantages.	1960-1980s
	5	Improving the Waterfront		Modern ports use a lot of land and water, which leads to renewing the old city center. The port's hub role increases productivity and puts pressure on space.	1970-1990s
Schubert's adaptation proposed 6 phase (2011)	6	Connecting Port and City		Changes in trade and transportation alter how ports and cities connect. Urban redevelopment helps them work better together. Rising costs in the hub lead to continued port activities and new construction, as well as growth into nearby areas.	1980-2000+

In contrast, (Figure 2) Hoyle’s Port Model (1988) provides a historical perspective on the evolution of port-city relationships. It describes how ports were initially deeply integrated into city centers but gradually moved outward due to urban expansion, land constraints, and modernization. Schubert’s adaptation (2011) refines this model by adding a phase that considers the reintegration of former port areas into urban planning, reflecting contemporary trends in waterfront redevelopment and mixed-use spaces. This theory provide an overview of the concepts associated with ports and port cities reveals a dynamic interplay among factors bearing upon their evolution. The relationship between ports and cities can be conceived through a series of models, represented in (Figure 2) to illustrate the cyclical nature of port-city development. The key concepts underpinning this evolution include the size of the port, its proximity to urban

centers, and the surrounding environmental factors. As ports expand and modernize, the transformation also affects their urban landscape, resulting in increased demands for infrastructure and services in adjacent areas. However, this is not done linearly because it shows fluctuations where ports can enter a decline phase due to different challenges such as competition with other ports, degradation of the environment, and changes in trade routes (Yueyue ZHANG, 2018; Carola Hein, 2019).

Both models provide valuable insights into the evolution of port-city relationships. Hoyle’s framework outlines a timeline of transformation, illustrating how ports shift over time due to urban expansion and modernization. On the other hand, Rodrigue’s port-city interface model emphasizes the functional integration of ports within their urban and regional contexts, focusing on modern logistical structures and connectivity. Together, these perspectives offer a comprehensive understanding of port-city dynamics, aiding in the development of sustainable urban and port policies that balance economic growth, efficient connectivity, and urban development challenges.

Figure 3: Spatial Evolution of the Hub Port City

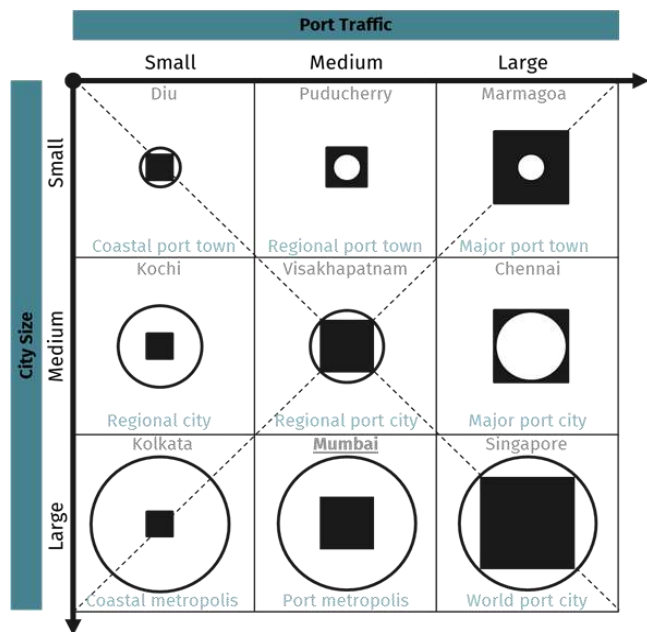
Time	Fishing coastal village	Colonial gateway	Entrepot city port	Free trade port city	Hub port city	Multi-hub gateway region
Global Factor	Settlement	Conquest, resource exploitation, export	Cargo consolidation, geopolitical control	Export-led policy, tax-free procedures, low labor cost, containerization.	Industrial shift to less-developed countries, financial and business hub, spatial division of labour	Increased globalization, port selection, supply chain strategies of shippers/carriers vertical & horizontal integration
Port City						
Local Factor	Small community of native practice self-sufficient trade	Rural exodus, harbour development, Western quarters	Trade increase, port expansion, demographic growth, industrialization	Modern port development through sea reclamation, manufacturing growth, suburbanization	Tertiarization, traffic concentration and congestion, transit trade from adjacent hinterland, waterside redevelopment	Port competition and cooperation, technological shift, cross-border cooperation, logistics development territorial pressure at CBD
Interface						

Source: Author’s interpretation compiled from literature

Figure 3 presents a synthesis of the key mechanisms influencing the port-city interface across different stages of development. As a zone where port and urban growth intersect—both spatially and functionally—the interface undergoes continuous transformation. These changes are not only physical and aesthetic but also impact the functional dynamics of the area, reflecting shifts such as tertiarization and evolving economic activities.

It shows the spatial development from small fishing villages to complex multi-hub gateway regions driven by global trade interactions at various levels and local factors. The initial role of ports was toward regional, self-sustaining communities, which then became gateways for resource extraction and export as part of colonialism, thus linking the hinterland with the colonizing metropole. Cities expanded industrially and ports turned into entrepôts, and regional trading networks morphed to become free-trade zones focused on export-led growth and containerization. Hub ports ultimately emerged as the global trade centres wherever-growing hinterlands merged with the shipping routes of the developing economies. Finally, with the gradual process of globalization, various multi-hub gateway regions emerged, characterized by regional integration, competition, and technological advancements linked into global supply chains and logistics networks (Lee, 2009). A synthesis proposed by Ducruet & Lee (2006) (Figure 4) illustrates that there are different types of port cities, varying based on port size and city size, ranging from coastal port towns to global port cities. which explains the relationship between ports and cities, building on the ideas of Fleming and Hayuth (1994). This matrix helps understand how ports and cities interact. It focuses on two key concepts: centrality, which refers to the city’s importance and functions, and intermediacy, which describes the port’s role in maritime trade and connections.

Figure 4: Matrix of Port-city Relations



Source: adapted from C. Ducruet (2003) “The Trans-Scalar Development of Transportation Hubs: A Quantitative Comparison of European and East Asian Container Port Cities in the 1990s”.

As shown in Table 3 Ports and cities evolve in different ways, leading to varied economic and spatial dynamics. The relationship between port size and urban growth shapes the development patterns of a region, influencing trade, infrastructure, and employment. This classification highlights how different cities function within their maritime context, ranging from small coastal towns to major metropolitan hubs.

Table 3: Types of Port Cities: Based on Size of Port and Town.

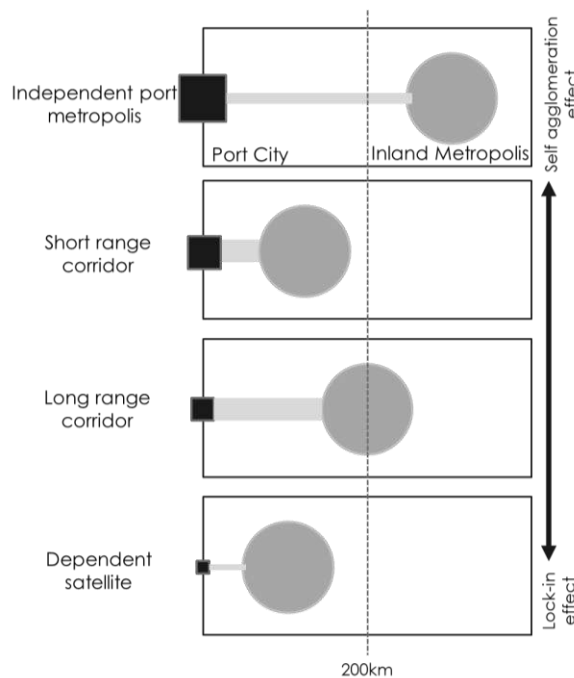
Type of Port-City	Description
Coastal Port Town	Small towns with ports serving local economies.
Regional Port Town	Medium-sized towns with ports serving a broader regional trade network.
Major Port Town	Larger towns where the port plays a significant role in the local economy.
Regional City	Cities with diverse economic activities but smaller or no port functions.
Regional Port City	Cities where ports serve a regional trade network, but urban activities dominate.
Major Port City	Cities where the port is larger than the urban area and crucial for trade.
Coastal Metropolis	Large cities with secondary port functions, often focused on other industries.
Port Metropolis	Cities where urban activities are prominent, but ports remain significant.
World Port City	Global cities with large ports playing a major role in international trade.

Small cities and their ports: Small cities with small ports typically rely on fishing and local tourism. These towns have a limited population and economic activity, with ports mainly serving local needs. An example of this is Diu, a coastal island town where the port primarily supports fishing and tourism. However, in cases where a small city has a medium-sized port, the economic activity extends beyond local needs, facilitating small-scale trade. Puducherry represents such a case, where the port accommodates fishing activities along with some cargo transportation. In contrast, some small cities may have disproportionately large ports, making them significant trade hubs despite their limited urban population. Marmagao in Goa exemplifies this scenario, as it is a small town with a large port focused on iron ore exports.

Medium-sized cities and their port dynamics: Medium-sized cities exhibit more economic activity and infrastructure development, leading to a diverse range of port sizes. In cases where a medium city has a small port, the port primarily serves regional needs such as fishing, tourism, and small-scale trade. Kochi, for instance, has a small port that supports local fishing and coastal tourism but does not handle large cargo operations. When a medium city has a port that is proportionate in size, the port functions as an essential trade center for regional industries. Visakhapatnam, with its medium-sized port, plays a crucial role in cargo transportation and industrial trade. However, when a medium-sized city possesses a large port, it significantly influences economic development by facilitating major import and export activities. Chennai is an example of such a city, where its large port serves as one of the busiest maritime trade hubs in India.

Large cities and their port roles: Larger cities with small ports often experience constraints due to geography or shifts in economic priorities. Despite having a significant urban population, these cities may not rely on their ports as primary economic drivers. Kolkata, for example, is a large city with a relatively small port, primarily handling riverine transport and inland cargo movement. When a large city has a medium-sized port, it plays an important role in regional and international trade but does not dominate global maritime logistics. Mumbai, one of India's largest cities, has a port that is crucial for trade yet not among the world's largest. Finally, in the case of a large city with a large port, both the urban and maritime sectors thrive, making the city a global economic powerhouse. While an Indian example is not as prominent, Singapore illustrates this category perfectly, where the port is central to the city's economy and global trade network.

Figure 5: Port-Town Relationships w.r.t. Distance



Sorce: Merk et al. 2011

While in international context: World port cities are large cities with major ports, such as New York, Hong Kong and Singapore. In port metropolises, the city is large, while the port, though significant, is smaller examples include Cape Town and Buenos Aires. When the port is even smaller within a large city, it is called a coastal metropolis, like Stockholm and Tunis. On the other hand, some cities have ports that are larger in comparison to their urban area. These are

known as major port cities, such as Rotterdam and Genoa. Smaller cities with relatively large ports are called major port towns, like Freeport and Laem Chabang. This study focuses on port cities where either the city, the port, or both are significantly large or small (Merk, 2013). As the literature above explains the relationship between a port and its surrounding area, some cities may not have a port. In such cases, the concept discussed in the following paragraph becomes relevant.

Port-city relations based on distance: Even though some big cities don't have a port, they still rely on how well they are connected to one. Smaller ports that are closer to a major city often become part of that city's network. In such cases, they can act as dependent hubs or be linked through short or long transport routes (Figure 5).

The relationships between cities and ports can be categorized based on their functional and spatial linkages, forming different typologies of port-metropolis interactions.

Table 4: Cities with their Dependent Port Typology

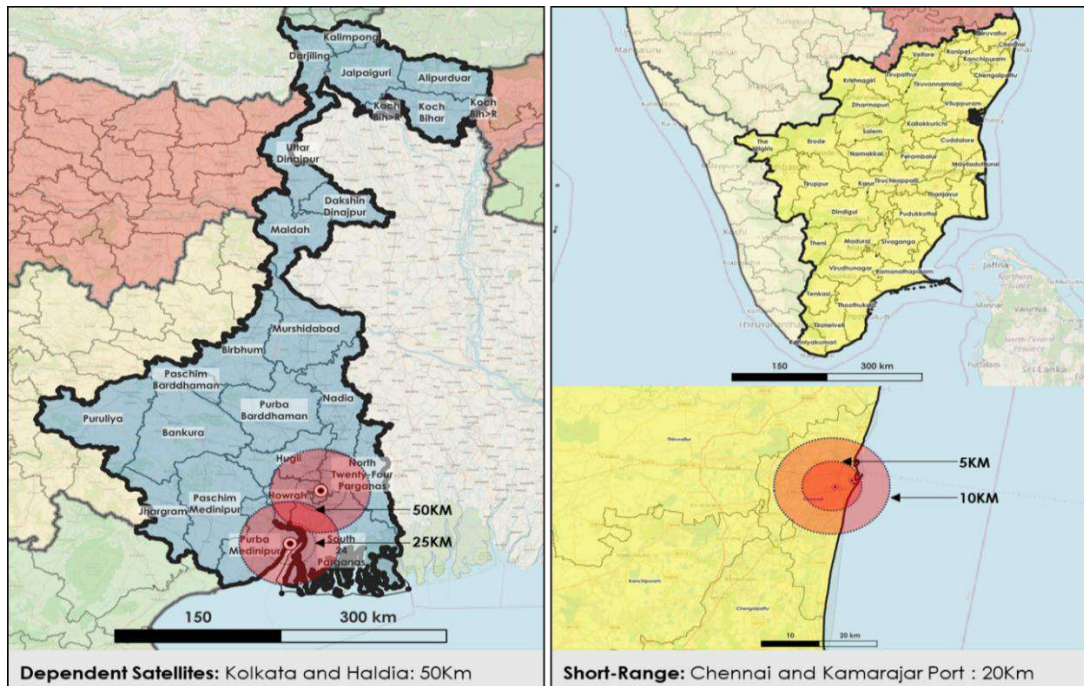
Typology	Town	Port	Distance (Approx.) km
Dependent Satellites	Kolkata	Haldia	50
	Visakhapatnam	Duvvada	15
Short-Range Corridor Relationships	Mumbai	Jawaharlal Nehru Port	25
	Chennai	Kamarajar Port	24
Long-Range Corridor Relationships	Delhi	Mundra Port	1,100
	Bhopal	Kandla Port	900
Independent Metropolises	Kolkata	Paradip Port	400
	Hyderabad	Visakhapatnam	600
Landlocked Regions and Their Port Dependencies	Madhya Pradesh	Kandla/Mundra	900–1,200
	Rajasthan	Kandla/Mundra	700–1,100

Dependent satellites: Some metropolitan areas rely on smaller satellite ports that support their trade and shipping activities. These satellite ports reduce congestion at primary ports while ensuring smooth logistical operations. A prime example of this relationship is Kolkata and Haldia (Figure 1). Located approximately 50 kilometers from Kolkata, Haldia acts as a critical auxiliary port, handling a significant share of cargo traffic. By complementing Kolkata's extensive trade network, Haldia ensures that Kolkata's economic activities remain uninterrupted despite limitations at the city's primary port. Internationally, example could be Civitavecchia in its relation to Rome, and San Antonio in relation to Santiago.

Short-range corridor relationships: In some cases, major metropolitan, example closely linked to ports through well-developed transport corridors. These corridors enable efficient trade flows between cities and their primary maritime gateways. For instance, Mumbai and Jawaharlal Nehru Port (Nhava Sheva) form a highly integrated port-city system. Similarly, Chennai and

Kamarajar Port (Figure 6) exhibit a short-range corridor relationship. Internationally Santos-Sao Paulo, Port Klang-Kuala Lumpur and Incheon-Seoul shows similar relation.

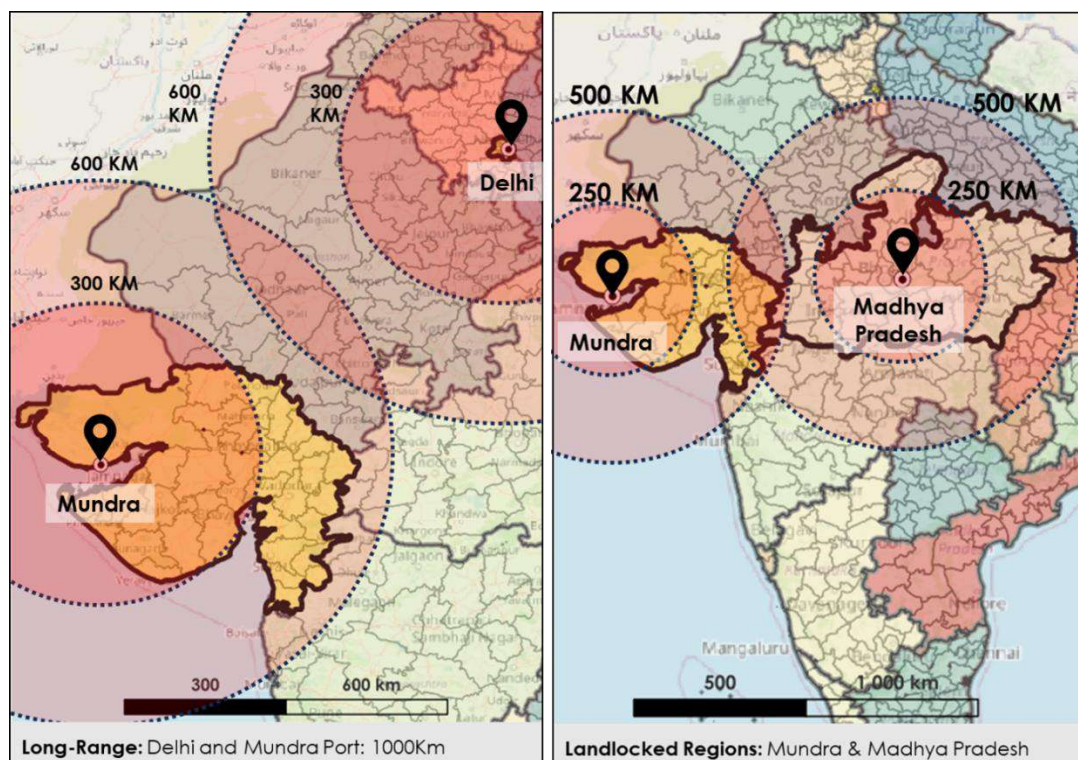
**Figure 6: Map Showing Various Corridor Relation w.r.t Port and City
(Dependent Satellite and Short Range)**



Long-Range Corridor Relationships: One of the most notable examples is Delhi and Mundra Port (Figure 7). Despite being over 1,000 kilometers apart, Mundra Port in Gujarat functions as Delhi's primary maritime outlet. The extensive road and rail network linking the two regions allows Delhi's industries to engage in international trade with efficiency. Similarly, Le Havre-Paris, Port Said-Cairo and Constantza-Budapest exemplify a long-range corridor relationship.

Landlocked regions and their port dependencies: Regions that lack direct coastal access must rely on multiple ports for their trade needs. Efficient transport networks ensure that these regions remain well-integrated with global supply chains. For example, Madhya Pradesh (Figure 7), a completely landlocked state, depends on ports in Gujarat, such as Kandla and Mundra, to facilitate trade. Rail and road connections play a crucial role in ensuring the smooth movement of goods to and from these ports.

**Figure 7: Map Showing Various Eorridor Relation w.r.t Port and City
(Long Rand and Landlocked Region)**



Independent metropolises: These cities develop their own economic bases while utilizing ports for external trade rather than direct dependency. A case in point is Kolkata and Paradip Port. Despite being the primary port for eastern India, Paradip functions independently from Kolkata, catering to industrial belts in Odisha and Jharkhand. This independence allows both Kolkata and Paradip to thrive without excessive reliance on each other.

4.0 Application of Port Development Models

It is observed that ports transform over time, a process that can be observed in India's maritime development. Derived from the framework of: Spatial evolution of the hub port city, India's ports have progressed from fishing villages (Kochi, Mumbai) to colonial gateways (Kolkata, Chennai), serving as trade hubs under British rule. As trade expanded, ports like Mumbai became entrepôt cities, managing regional commerce within closed hinterlands. Post-liberalization, JNPT and Mundra evolved into free trade port cities, integrating with global markets (JNPA, 2023). Today, ports like JNPT, Mundra, and Kandla are transitioning into a

multi-hub gateway system, enhancing regional and international trade networks (Ducruet, 2006). Based on the various development models, examples of this pattern in India are highlighted in the table below.

Town	Port	Typology based on distance	Port Category (Based on Size & City Size)	Distance (Approx.) km
Kolkata	Haldia	Dependent Satellites	Regional Port City	50
Visakhapatnam	Duvvada		Regional Port Town	15
Mumbai	Jawaharlal Nehru Port	Short-Range Corridor Relationships	Port Metropolis	25
Chennai	Kamarajar Port		Major Port City	24
Delhi	Mundra Port	Long-Range Corridor Relationships	Major Port Town	1,100
Bhopal	Kandla Port		Major Port Town	900
Kolkata	Paradip Port	Independent Metropolises	Major Port Town	400
Hyderabad	Visakhapatnam		Major Port City	600
Madhya Pradesh	Kandla/Mundra	Landlocked Regions and Their Port Dependencies	Major Port Town	900–1,200
Rajasthan	Kandla/Mundra		Major Port Town	700–1,100

Application to Uran - JNPT port and surrounding: Uran has been taken as case to further understand in detail. Mumbai's history pertaining to the port goes back to ancient times as it was an important trade center because it has been located on the western coast of India. The British East India Company seized this opportunity during the 17th century that led to the development of substantial infrastructure in the city. The Bombay Port Trust was established during the year 1873 (jnport, 2024). This expansion ensured the position of Mumbai as India's premier port, based on volumes that handle a large share of the country's cargo traffic.

However, with containerization picking up in the 1980s, the Mumbai Port could not cope, leading to extreme congestion and inefficiencies that spelt the need for more capacity. In response to such an event, JNPT, more popularly known as Nhava Sheva, was established in 1989 with the objective of decongesting Mumbai Port and also catering to increasing container volumes. Strategically situated near the Greater Mumbai Area, JNPT has emerged as India's largest container port and currently handled nearly 5.1 million TEUs during the period of 2020-2021, this we can relate with: Typologies of port cities. Additionally, Vadhvan Port is being developed as a satellite port to support Jawaharlal Nehru Port (JNPT).

The port supported connectivity through major road and rail networks and greatly contributed to the country economy as it created about 100,000 jobs while enabling exports and imports. Observations at JNPT port reflect the theory of: Spatial Evolution of the Hub Port City by Lee & Ducruet (2009), which examines the relationship between port development and urban growth. At present, JNPT deals with about 33 percent of all container traffic in India, thus underlining its importance to the trade and economic development of the growth (AECOM, 2016; Aman Rathi, December 2020).

Figure 8: Map of Uran

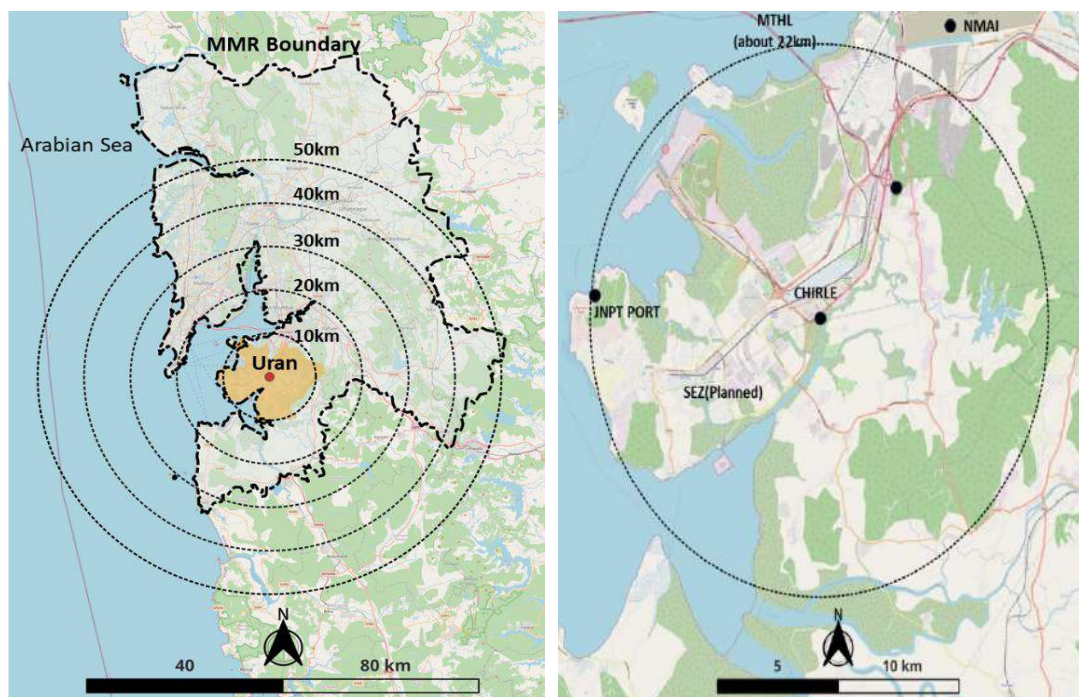
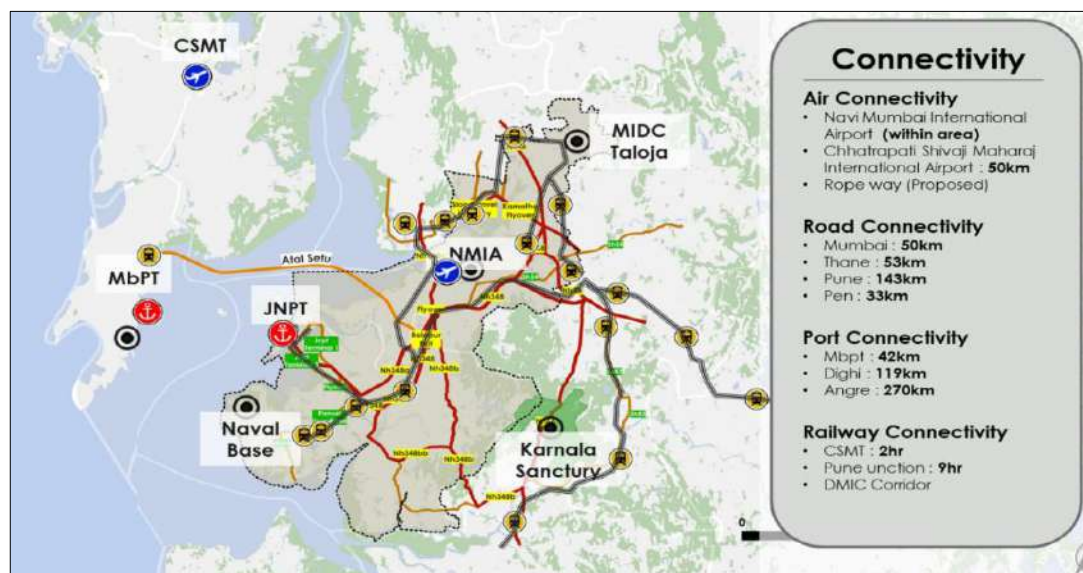


Figure 9: Map with Connectivity and Major Projects around of Uran



5.0 Conclusion

In conclusion, several key parameters drive port-led development, leading to the evolution of ports over time. Amongst them are strategic location, connectivity to transport networks, and land: port: city relation start to evolve with changed land use patterns. There is no single way in which port-city relationships evolve. The patterns of port-city separation seen in European port cities apply in many cases worldwide, but not all. Some highly developed port cities have experienced a decline in port activity, but many have successfully adapted through good planning and strategic location advantages. However, creating a new model for port-city relationships is challenging because each city's growth is shaped by a mix of local and regional factors influenced by globalization. Observations in Uran reveal that something similar is happening there too; the closeness to Mumbai and the necessity of upgrading the port facilities reflects a huge scope for port-led development. By capitalizing on its strategic location through infrastructure enhancement, land-use optimization, and fostering institutional cooperation, Uran has all the potential to turn into a vital maritime hub. These factors will consider the historical context, environmental quality, urban growth and activity concentration, and stakeholder interests-similarly essential not only for supporting regional economic activities but also in service of India's overall trade objectives.

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CHAPTER 106

Process Mapping to Identify and Minimize Wastes in Formwork Operations

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ABSTRACT

Low productivity in construction processes is a major concern which significantly impacts project outcomes and reduces their overall value. Process mapping is an important tool in the Lean construction approach which involves breaking down a workflow into clearly defined, visual steps to enhance understanding. It establishes a common framework for analyzing the process and identifying opportunities for improvement. Formwork is one of the significant expenses in reinforced concrete structures. However, formwork operations often involve non-value-adding activities, leading to inefficiencies and waste. Addressing these issues is crucial for improving productivity and reducing costs. Process mapping helps identify inefficiencies in formwork operations, optimize workflows, and reduce waste, leading to better project outcomes. The findings in this study demonstrated that the implementation of process mapping can minimize waste in formwork operations while enhancing the overall value of construction. This approach offers a fresh perspective on improving efficiency in formwork processes.

Keywords: Lean construction; Process mapping; Formwork; Process waste.

1.0 Introduction

1.1 Background

The construction sector is a vital part of the global economy and contributes substantially to infrastructure, development and growth (Adinyira & Agyekum, 2021). Within this vast sector, concrete construction and formwork activities stand out as fundamental components. Formwork is a temporary structure used to hold concrete in place while it sets and hardens. The process includes setting up the formwork, pouring the concrete, and then removing the formwork once the concrete has fully cured (Mantri, 2023). Formwork operations are complex and labour-intensive, involving multiple activities such as material procurement, preparation, assembly, erection, and dismantling. Inefficiencies in these operations often lead to excessive material wastage, increased labor costs, and extended project timelines. Thus, the identification and minimization of wastes in formwork processes have emerged as critical imperatives within the construction industry (KO & KUO, 2015).

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The construction industry struggles with low productivity (McKinsey, 2017). By identifying and removing wasteful activities that don't add value for the final product can significantly improve productivity (Unnikrishnan & Sudhakumar, 2024). Therefore, it becomes paramount to optimize the practices associated with these integral construction phases. Thus, the aim of the study is to take a closer look at the step-by-step processes involved in formwork operations and identify where resources are not being used appropriately.

1.2 Process mapping

It is a visual technique used to outline and analyse the tasks and decisions which are generally involved in a specific process. It helps organizations understand how workflows from start to finish, identifying inefficiencies, redundancies, and opportunities for improvement (LCI, 2025). By visually representing each phase of the formwork process from material procurement and assembly to inspection and dismantling project teams can pinpoint bottlenecks, streamline workflows, and improve coordination among workers (Ko *et al.*, 2011). Various types of maps like flowchart, value stream and swim lane diagram can be employed depending on the complexity and focus of the process (Aslam *et al.*, 2022). For example, value stream mapping, often used in lean construction, helps differentiate between value added and non-value-added activities, enabling more efficient resource utilization (Espinoza *et al.*, 2021). In formwork construction, this could involve visualizing the workflow from receiving design plans and procuring materials to assembling different formwork elements, concreting, and eventually dismantling of different structures (Pothen & Ramalingam, 2018). By using process mapping, construction teams can reduce material wastage, improve labour efficiency, and ensure timely project completion, making it a vital tool in adopting lean construction practice (Ramani & Lingan, 2022).

1.3 Current state map

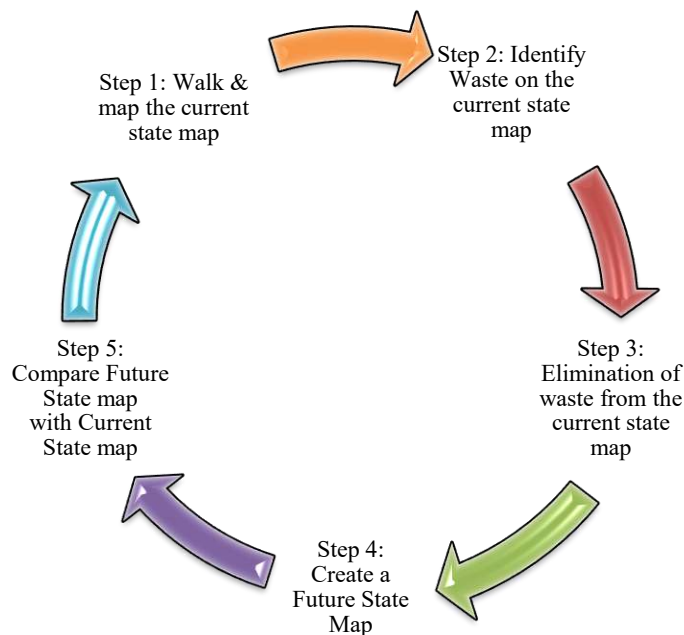
This map is a visual tool that illustrates how a process currently functions, detailing all existing steps, activities, and workflows. It highlights both essential tasks that add value and those that do not add any value, providing a clear and complete view of material movements, information flow, time demands, and resource use (Espinoza *et al.*, 2021). In construction, particularly in formwork operations, a current state map is instrumental in identifying inefficiencies such as material delivery delays, redundant labor activities, and bottlenecks in the assembly or dismantling phases (Pothen & Ramalingam, 2018). By thoroughly documenting the present process, stakeholders can pinpoint sources of waste, including overproduction, idle time, unnecessary transportation, or surplus inventory (Wu & Feng, 2014).

1.4 Future state map

The Future State envisions how a workflow should function after targeted improvements are put in place. It focuses on designing an optimized workflow that eliminates

waste, reduces inefficiencies, and enhances overall productivity (Ramani & Lingan, 2022). The future state map redefines the process to minimize delays, streamline material handling, and improve team coordination. Strategies may include timely material deliveries, eliminating unnecessary movements, standardizing procedures, or integrating automation where feasible (Unnikrishnan & Sudhakumar, 2024). The primary objective is to create a lean, efficient process that maximizes value while minimizing waste (Aslam *et al.*, 2022). When there is comparison between the current and future state maps it helps us identify strategies to bridge the gap between existing practices and the ideal, streamlined workflow, resulting in more efficient and cost-effective project execution (Ramani & Lingan, 2022).

Figure 1: Steps of Process Mapping



1.5 Classification of activities

In process mapping, activities within a workflow are typically categorized into three groups: value added (VA), non-value added (NVA), and non-value added but necessary (NVAN) (Ramani & Lingan, 2022). Knowing these categories is crucial for spotting inefficiencies and streamlining procedures, especially in sectors like construction where time and resource management are crucial. Value-Added activities are tasks or processes that directly contribute to meeting customer requirements or enhance the final product or service. As they give the result physical or perceived value, these actions turn materials, information, or components into something the client is willing to pay for (Pothen & Ramalingam, 2018).

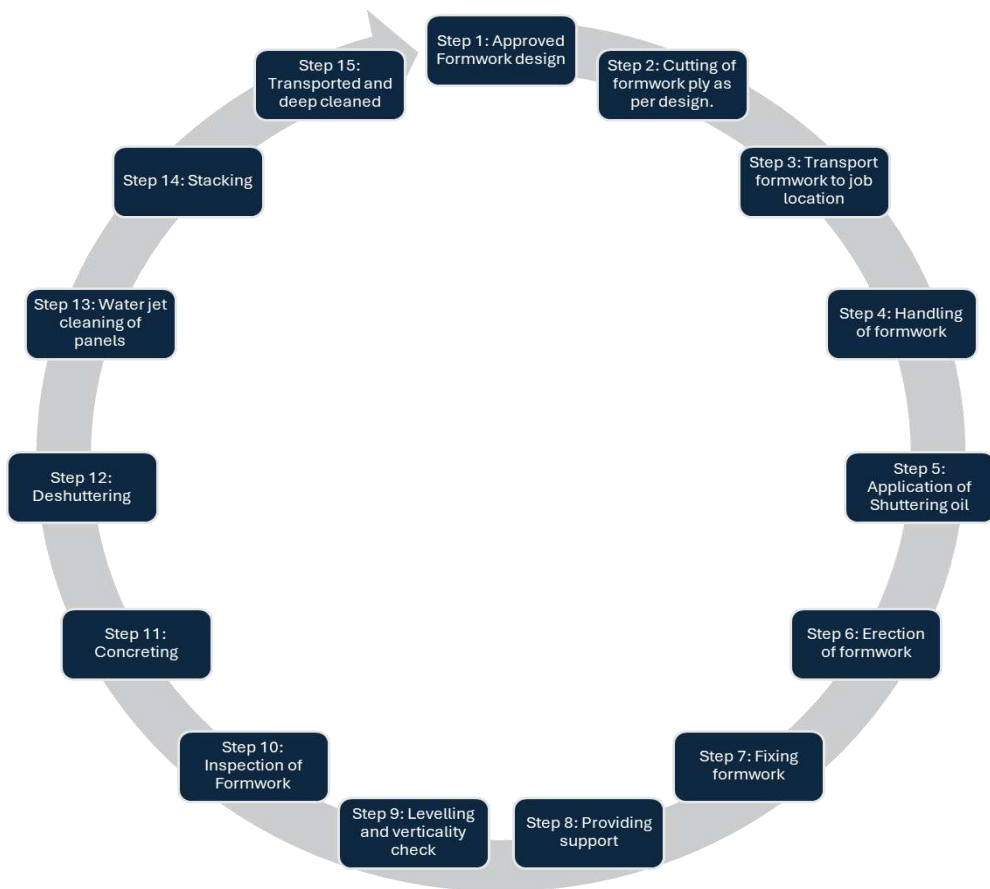
Activities that directly contribute to the construction or improvement of a structure, including pouring concrete, setting up formwork, or finishing surfaces, are considered value-adding in the construction industry. Activities that take up time, money, or effort but don't go towards the finished good or service are known as non-value-adding activities. These procedures are frequently regarded as waste because they don't alter the final product in a way that the consumer finds desirable (Han *et al.*, 2007).

One of the fundamental ideas of lean construction and lean techniques is the removal of non-value-adding activities. NVA activities include unnecessary movements, waiting times, overproduction, rework, and excess transportation (Ramani & Lingan, 2022). These activities inflate project timelines and costs without enhancing the quality or functionality of the final structure (KO & KUO, 2015). Identifying and eliminating NVA activities is essential to streamline processes (Han *et al.*, 2007). However, completely eradicating them may not always be possible due to practical constraints on-site. Activities that are necessary for the process to run smoothly or to satisfy legal requirements but do not directly contribute to the finished product are known as non-value adding but necessary activities. These tasks are required for safety, compliance, coordination, or other operational requirements even when they don't bring value from the standpoint of the client (Pothen & Ramalingam, 2018). NVAN activities occupy a unique space in process mapping, as they cannot be classified purely as waste but still do not enhance the product's intrinsic value. While these activities may not directly advance construction progress, they are crucial for ensuring project safety, meeting industry standards, and avoiding costly legal or operational setbacks (Ramani & Lingan, 2022). Lean principles recognize that while NVAN activities should be minimized where possible, they often represent unavoidable aspects of responsible and compliant construction management (Han *et al.*, 2012).

2.0 Methodology

Formwork operations are a critical component of construction projects, affecting cost, time, and overall efficiency. To achieve a comprehensive understanding of formwork operations and to identify potential inefficiencies and wastes, a detailed observational study was conducted on active construction site. The methodology combined direct observation with data collection techniques based on Lean Construction principles, facilitating the development of accurate process maps to highlight value-adding and non-value-adding activities. The method in Lean where participants are observed without their knowledge is called "shadowing" or "unobtrusive observation". This approach is often used to gather insights about how processes are carried out in real-life settings without influencing behavior due to the observer's presence. By avoiding direct interference, you can obtain a more accurate and unbiased understanding of inefficiencies, wastes, or deviations in the workflow. The project involved a 13-story building on area of approximately 1400 square meters. The foundation of the building is an open pit foundation and constructed in traditional way upto plinth level.

Figure 2: Steps in Formwork Operations



Upon completion of the plinth level, precast elements including columns, slabs were used for the construction of all 13 floors. The focus of this study is on the formwork construction carried out in foundation. The formwork for the foundation was completed using a combination of Timber and Steel Formwork. The study focused on capturing detailed information on time consumption, labor movements, material handling, and the sequence of tasks. Time-motion studies were conducted using video recordings to capture the duration of specific tasks and the transitions between them. This allowed for precise measurement of time spent on each activity, facilitating the identification of bottlenecks or delays in the workflow. The observational data collected was analyzed through the lens of Lean Construction principles to identify various forms of waste inherent in the formwork process. The observation process was structured around a fifteen-step formwork operation flowchart, which served as the backbone for monitoring activities on-site.

3.0 Findings and Data Analysis

For our research, we extracted time-based data from multiple video recordings to analyze task durations and optimize workflow efficiency. The methodology involved segmenting each video into distinct operational activities, such as assembling formworks, material searching, and waiting periods. Each activity was categorized into motion types (e.g., walking, searching, waiting) to understand how time was distributed across different tasks. Using video playback we recorded the duration of each activity and calculated the percentage contribution of each action to the total recorded time.

Table 1: Analysis of Labor Working on Formwork Operations

Activities	Total No. of Labors	Value Added (VA)	Non-Value Added (NVA)	Non-Value Added but Necessary (NVAN)
1.Drilling	3 Labors	1	2	-
2.Curing	1 Labor	1	-	-
3.Unwinding Wire	4 (2 Supervisor+2 Labors)	3	-	1
4.Formwork Measurements	3 (1Supervisor+2 Labor)	2	1	-
5. Concreting for Tower Crane Foundation	10	5 labor	-	5 (4 labor, 1 supervisor/engineer)
6.PCC for Footing	13	4 labor	5 labor	4 (1 labor, 1 surveyor, 2 supervisor/engineer)
7.Formwork for Footing	4	1 labor	1 labor	2 labor

The collected data was systematically compiled into an Excel sheet, with columns detailing the motion type, description and time taken. This structured approach enabled us to compare time utilization across different operational scenarios, providing insights into inefficiencies and potential areas for process improvement.

Table 2: Formwork Operation Analysis

Operation	Motion	Description	Time (in seconds)	Time(in %)
Assemble & machine formworks	Walk	Walk to the formwork storage area	30	5.43
	Search	Search for appropriate materials	127	23.01
	Wait	Wait while an assistant looks for materials	40	7.25
	Measure	Measure the size of the required formwork	63	11.41
	Machine	Cut materials	65	11.78
Transport molds	Pass	Pass formwork to worker	15	2.72
	Move	Move the stripped molds to the next area	57	10.33
Erecting	Fix	Position & Fix formwork	95	17.21
	Fix	Final Positioning and Verticality	60	10.87
Total			552	100.00

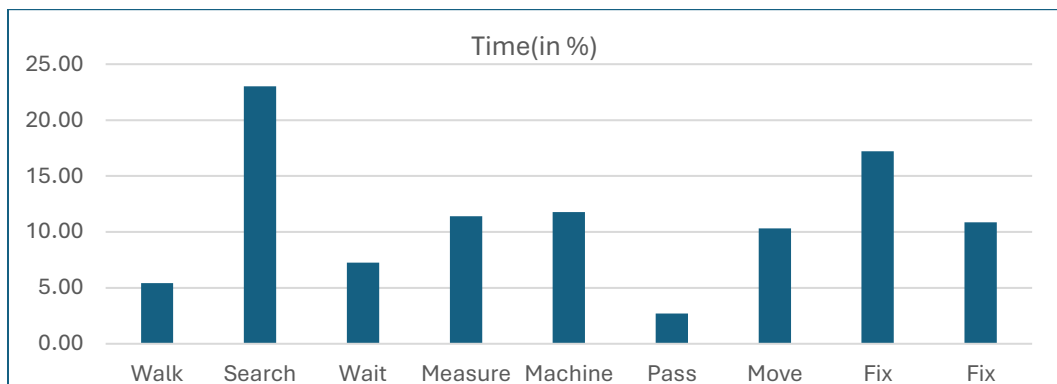


Figure 3: Graphical Representation of Time taken by each Formwork Operation



Improper stacking of formwork has resulted in workers searching for the required size of board



Workers are waiting for the cleaning task to be completed.



Some workers are cleaning and preparing the surface of formwork while others are standing idle.



Formwork boards are improperly stored in workplace instead of dedicated storage area.



A lot of formwork boards are stored near the working area making it difficult for the workers to move.



During concreting operation some workers are engaged in the task while some are sitting idle waiting for their turn.

Table 3: Current State Map

Sr. No	Pre Construction	Symbol	PM Metric	During Construction	Symbol	PM Metric	Post Construction	Symbol	PM Metric
1	Material Selection		VA	Concrete Pouring		VA	Formwork Removal (Stripping)		VA
2	Formwork Fabrication		VA	Rework Due to Concrete Spillage or Formwork Failure (Defects)		NVA	Formwork Storage and Maintenance.		VA
3	Formwork Setup and Installation		VA	Regular Inspection and Monitoring		NVAN	Excessive Delays in Formwork Removal (Waiting)		NVA
4	Material Handling & Movement		NVAN				Unnecessary Double Handling of Formwork (Motion)		NVA
5	Unnecessary Adjustments and Rework (Excess Processing)		NVA				Formwork Cleaning and Repair		VA
6	Site Preparation and Leveling		VA						
7	Inspection and Quality Checks		NVAN						
8	Safety Measures (Scaffolding, PPE, etc.)		NVAN						

This map establishes a baseline for process improvement, serving as a reference point to measure the effectiveness of future improvements. It categorizes activities into Value Addition (VA), Non-Value Addition but Necessary (NVAN), and Non-Value Addition (NVA) across pre-construction, construction, and post-construction. Issues include rework due to defects, excessive handling, waiting times, and unnecessary adjustments. Solutions focus on optimizing material selection, reducing delays, improving inspection, and minimizing excess movement. Addressing these inefficiencies enhances productivity, reduces waste, and improves workflow standardization. Implementing Lean Construction techniques will lead to cost savings, reduced timelines, and sustainable resource management.

Table 4: Future State Map

Sr · No	Pre- Construction	Symbol	PM Metric	During Constructi on	Symbol	PM Me tric	Post Constructio n	Symbol	PM Metr ic
1	Material Selection		VA	Concrete Pouring		VA	Formwork Removal (Stripping)		VA
2	Formwork Fabrication		VA	Regular Inspection and Monitoring		NV AN	Formwork Storage and Maintenance		VA
3	Formwork Setup and Installation		VA				Formwork Cleaning and Repair		VA
4	Material Handling & Movement		NVAN						
5	Site Preparation and Leveling		VA						
6	Inspection and Quality Checks		NVAN						
7	Safety Measures (Scaffolding, PPE, etc.)		NVAN						

This Map outlines an optimized workflow for formwork operations. Key improvements include better material selection, structured fabrication, efficient setup, and streamlined movement. Waste reduction is achieved by minimizing waiting times, unnecessary movement, and rework. The strategy enhances workflow efficiency through clear process standardization,

improved logistics, and stakeholder coordination. Ultimately, these optimizations contribute to cost savings, reduced project timelines, and sustainable construction practices.

Table 5 Current Vs Future State Map Savings Analysis

Symbol	Process	Original (CSM)	Improvement (FSM)	Savings
	Storage	1	1	0
	Transportation	2	1	1
	Operation	7	6	1
	Delay	2	0	2
	Inspection	4	4	0
	Total	16	12	4

By analysing the differences between the Current State and the Future State, the research uncovered potential areas for improvement.

- Storage: Steps reduced from 1 to 0, eliminating unnecessary material stockpiling.
- Transportation: Steps reduced from 2 to 1, minimizing excess movement of materials.
- Operations: Optimized from 7 to 6, reducing over-processing waste.
- Delays: Reduced from 2 to 0, eliminating unnecessary waiting times.
- Inspection: Maintained at 4, ensuring that quality remains uncompromised.
- Overall Process Waste Reduction: The total number of steps reduced from 16 to 12, indicating a 25% improvement in efficiency.

4.0 Conclusion

This research set out to analyse the various processes involved in formwork operations through process mapping, aiming to identify and minimize different types of waste. By employing Lean Construction principles and techniques such as Process Mapping (PM), the study provides an in-depth assessment of existing inefficiencies and proposes a structured approach to optimizing formwork workflows. Through a detailed classification of activities into productive (VA), unproductive (NVA), and essential but non-value adding (NVAN) tasks, the research identified key problem areas such as excessive transportation of materials, waiting time due to poor coordination, frequent rework due to improper assembly, and inefficient labor distribution. The study also revealed that unstructured workflows and a lack of standardized procedures led to unnecessary movement and delays, further reducing operational efficiency. To address these inefficiencies, the research developed a Future State Map, envisioning an optimized process flow that reduces waste and improves productivity. The proposed lean-based improvements are:

- *Minimization of waiting times:* Establishing clear coordination protocols for timely material supply and workflow scheduling.
- *Reduction of excessive movement:* Optimizing site layouts to ensure that materials and tools are stored closer to workstations, reducing unnecessary transportation.
- *Process standardization:* Implementing structured guidelines for formwork erection, dismantling, and reassembly to minimize errors and rework.
- *Improved resource utilization:* Ensuring that labor is effectively assigned to critical tasks, avoiding underutilization or workforce congestion at specific process points.

The limitation of the research is that it primarily investigates formwork operations and does not extend to other critical construction processes such as reinforcement, concreting, and finishing works. Since construction activities are highly interdependent, optimizing formwork alone may not yield maximum efficiency gains without addressing related processes. Further, the study focuses on process identification and optimization but does not include real-time implementation and performance evaluation of the proposed improvements. Future research could focus on piloting the recommended solutions in active construction projects, tracking their impact over extended project timelines. The effectiveness of Lean Construction techniques depends heavily on workforce skills, training, and adaptability. Since different sites have varying levels of expertise among laborers and supervisors, the implementation of lean strategies may not be uniform or equally effective across all projects. Many construction firms and project managers are unfamiliar with Lean Construction principles or are reluctant to modify traditional work practices. The lack of awareness, towards new methodologies, and minimal exposure to lean training programs may hinder successful implementation.

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CHAPTER 107

Quality Improvement using Six Sigma Methodology for Pre-Cast Structures

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ABSTRACT

The construction industry, characterized by its complexity and project-specific challenges, often struggles with maintaining consistent quality, adhering to strict deadlines, and controlling costs. Precast concrete production, a crucial aspect of modern construction, frequently encounters issues such as defects, material waste, and production delays, which can negatively impact overall project efficiency and budget management. Addressing these challenges requires a structured approach to quality improvement, and Six Sigma methodology, particularly the DMAIC (Define, Measure, Analyze, Improve, Control) framework, provides a systematic solution. This study examines the application of Six Sigma in precast concrete production to identify and reduce defects, streamline workflows, minimize resource wastage, and enhance operational efficiency. By integrating data-driven decision-making and a continuous improvement approach, this research highlights how Six Sigma principles can improve the quality and durability of precast structures. Through an in-depth analysis of common defects, including dimensional variations, surface imperfections, and reinforcement misplacement, the study offers practical recommendations for optimizing production processes. The findings suggest that the implementation of Six Sigma can lead to significant improvements in product quality, process efficiency, and cost-effectiveness, making construction projects more sustainable and reliable. Additionally, by reducing rework and material waste, the adoption of Six Sigma supports environmentally friendly construction practices while enhancing compliance with industry standards. The insights from this study can help construction firms and precast manufacturers achieve higher customer satisfaction, greater competitiveness, and long-term operational excellence.

Keywords: Six Sigma; Precast concrete components; DMAIC methodology; Quality improvement; Process optimization; Operational efficiency; Construction management.

1.0 Introduction

To remain competitive in today's construction industry, companies must consistently deliver high-quality work and add value to the clients.

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It is crucial to move beyond the traditional adversarial approach to construction management and instead foster stronger, more direct relationships with clients. Encouraging teamwork on job sites and focusing on producing superior quality work are essential steps in this direction. Achieving these objectives requires the implementation of a continuous improvement (CI) strategy to enhance quality management. One of the effective approach for continues improvement is Six Sigma. Six Sigma provides a structured set of techniques and tools designed to enhance process efficiency and minimize defects.

In this methodology, every task is viewed as a process, and specific steps must be followed to define and refine it. Since a process consists of various actions, changes, and functions, proper planning is crucial to ensure optimal results. This methodology is versatile and can be applied across industries, professions, and even in daily life. Initially, Six Sigma was perceived as a purely statistical method, but over time, it has evolved into a broader discipline aimed at reducing errors and maximizing value. While its adoption may require organizations to navigate the challenges of change, the benefits—such as enhanced performance, reduced costs, increased customer satisfaction, and greater overall success—far outweigh the initial difficulties.

In today's construction industry, precast structures are used for projects completion as it helps in reducing project execution time. Non-adherence of quality norms while creating precast structures may lead to quality issues which ultimately can increase project duration. Quality improvement in precast concrete structures is crucial for ensuring durability, efficiency, and cost-effectiveness in construction projects. The application of Six Sigma methodologies in this area can help reduce defects, minimize waste, and enhance overall structural performance. Precast construction, while offering advantages such as faster project completion and better resource utilization, also faces significant challenges related to material inconsistencies, dimensional inaccuracies, reinforcement misalignment, and surface defects. These quality issues can lead to increased project costs, rework, and delays, ultimately affecting customer satisfaction and safety. The primary objective of any construction project is to ensure that structures are safe and long-lasting.

To enhance structural integrity and safety, precast components are used in today's construction industry. Quality issues in precast components, like improper curing, reinforcement misplacement, or cracks, can significantly impact the structural integrity of buildings. By adopting a systematic quality improvement approach, precast manufacturers can enhance quality of the structures. Ensuring high-quality precast components may result in buildings that are more resilient to environment, load-bearing stresses, and reduce the risk of failures. Defects in precast components often result in excessive material wastage, leading to higher production costs. Manufacturing errors such as dimensional inaccuracies or surface imperfections necessitate rework or replacements, which increase resource consumption and extend project timelines.

Implementing Six Sigma DMAIC methodology may allow companies to identify the root causes of defects, optimize workflows, and minimize material waste. This not only reduces project cost but also promotes sustainability by decreasing the environmental impact of

construction activities. Arjunbhai (2023) analyzed the role of Six Sigma in enhancing efficiency within construction projects. The research utilized statistical analysis and process optimization techniques to identify primary causes of project delays, defects, and resource wastage. The study highlights the significance of data-driven decision-making and continuous improvement strategies in improving project quality, minimizing costs, and ensuring timely project completion. Efficient production processes are key to the success of precast manufacturing. Variability in concrete composition, improper handling, and inefficient curing processes can slow down production and lead to inconsistent quality. A structured quality improvement approach ensures that production lines operate smoothly, with fewer interruptions due to defective units. Tools such as Statistical Process Control (SPC) and Fishbone Diagrams help analyze production inefficiencies and implement corrective measures, leading to streamlined operations and improved productivity.

Construction projects must adhere to strict regulatory guidelines and quality standards, such as ISO 9001 and ASTM specifications. Poor quality in precast structures can lead to non-compliance issues, resulting in legal penalties, project delays, and reputational damage. By integrating Six Sigma principles, companies can establish a robust quality control system that ensures every precast component meets industry regulations. This proactive approach minimizes the risks associated with non-compliance and strengthens the credibility of construction firms. Also, client expectations for quality and reliability are higher than ever in the construction industry. Defective precast components can lead to customer dissatisfaction, disputes, and loss of business opportunities.

By adopting Six Sigma-driven quality improvement strategies, manufacturers can deliver products that meet or exceed customer expectations. Consistently high-quality precast elements contribute to faster project completion, reduced maintenance costs, and increased client trust, enhancing the overall success of construction projects. Quality improvement initiatives in precast manufacturing help lower emissions by minimizing material waste, reducing energy consumption, and enhancing production efficiency. By incorporating Lean Six Sigma practices, companies can implement eco-friendly processes that align with global sustainability goals while maintaining high-quality output.

1.1 Problem statement

The production of precast concrete elements in the construction industry faces persistent quality challenges, leading to structural defects, increased rework, and cost overruns. Common issues include dimensional inaccuracies, surface defects, reinforcement misalignment, and variations in concrete strength. These defects compromise structural integrity, delay project timelines, and reduce overall efficiency. Addressing these recurring defects requires a systematic approach to quality improvement. Implementing Six Sigma methodologies, particularly the DMAIC framework, can help identify root causes, optimize processes, and enhance the overall quality of precast concrete components.

1.2 Purpose of study

The primary aim of this study is to explore and apply Six Sigma methodologies, particularly the DMAIC framework, to address inefficiencies and quality challenges in precast concrete production. By systematically identifying and mitigating defects, and enhancing operational efficiency, this study seeks to improve the overall quality and sustainability of precast construction processes.

1.3 Objectives

Considering the above discussion, the primary aim of this study is to explore and apply Six Sigma DMAIC framework to address quality issues in precast concrete production. By systematically identifying and mitigating defects, and enhancing operational efficiency, this study seeks to improve the overall quality and sustainability of precast construction processes. The specific objectives set for this study are given below.

- Use of DMAIC framework to identify recurring defects in precast concrete production process such as dimensional mismatches, surface imperfections, and reinforcement placement errors.
- To systematically investigate and categorize the primary causes of identified defects, focusing on factors such as materials, methods, manpower, and machinery.
- Develop targeted improvement strategies during the Improve phase to address the identified root causes, ensuring practical solutions that are both effective and feasible.

2.0 Literature review

Lean Six Sigma (LSS) is widely regarded as an improvement methodology. Different Parties have Integrated the Lean Six Sigma approaches in their management and production processes in order to improve the product/service characteristics, reduce the costs, improve the capital profitability, and customer's satisfaction. Alexandra and Luis in year 2013 worked out a model for the improvement of project management within LSS using the method of DMAIC. This model is developed through an instrumental case study in a Portuguese Telecom company with sample of 33 completed projects from 2006 to 2010. The LSS model which integrates the DMAIC cycle, and the statistical tools is capable of diagnosing project management deficiencies, determining their causes, and providing corrective action toward improved project management and the project management processes. In construction of St Pancras raised railway station in London, UK, Stewart and others (2005) applied Six Sigma in the concrete longitudinal beams. The Process Improvement Plan (PIP) of the Six-Sigma process improvement project led to improved productivity, better teamwork, and reduced delays to the project.

LSS is the latest generation of improvement methodologies that came about during the end of 1990's and early 2000's. Burawat (2019) aimed to improve productivity in the highway engineering industry using Lean Six Sigma, Total Productive Maintenance (TPM), Eliminate Combine Rearrange and Simplify (ECRS), and 5S methodologies. The research identified issues

in the asphalt production process. The issue was solved through Cause-and-Effect Diagram along with the Pareto chart. These methodologies are relevant and can contribute to enhancement in productivity in highway engineering as well as any industry that has a manufacturing and service component. Chiarini & Kumar (2020) synthesized LSS tools and principles with technologies of Industry 4.0 to formulate a new model of Operational Excellence. New technologies or the industry 4.0, as defined by Kolberg *et al.*, (2017), integrate a wide variety of new or emerging technologies for automation and digitization of supply chains and productivity enhancement. For collecting the data, the Italian managers of manufacturing were interviewed at ten case organizations and their procedures associated with Industry 4.0 were directly watched. LSS successful integration required reinvented mapping tools, Horizontal integration (“Autonomous Process Synchronization”), vertical integration (“ERP modules”). Nicoletti (2012) aimed to apply the “Lean and digitize” methodology to procurement processes. The LSS principles, combined with a strategic approach to digitization, can significantly improve procurement processes. By mapping processes, eliminating non-value-added activities, and redesigning processes, organizations can avoid digitizing errors and waste.

Ottou *et al.* (2020) used Six Sigma by DMAIC methodology which gives the primary advantage of time benefit and secondary advantages in customer service, communication, quality, processes, manpower, finance, and decision making. The tendering process for construction company also contributed towards time effectiveness, especially in quantity surveying and procurement. Oguz *et al.* (2012) used LSS methodologies to enhance the production of concrete panels for multi-story housing complex project.

The construction project involved the production of precast concrete panels for 405 villas was running 25 percent behind the schedule. By integrating Lean tools with the DMAIC approach, the project was able to identify and address critical factors affecting production rates, eliminate waste, and achieve in efficiency and schedule adherence. Ke *et al.* (2025) explored the application of LSS as a tool for risk management in engineering projects. It investigates the effectiveness of LSS in identifying, assessing, and mitigating project risks. Statistical analysis (using tools like SPSS or R) is applied to survey data, and thematic analysis (using software like NVivo or MAXQDA) is used for qualitative data.

Morales *et al.*, (2016) described the application of Six Sigma methodologies to improve production operations within a concrete block manufacturing company. The project utilized the DMAIC process and various statistical tools such Pareto graphs, cause-effect diagrams (fishbone diagrams), box plots, scatter diagrams, and response surface methodology (RSM) to identify problems, reduce defects, eliminate downtime and increase overall efficiency and customer service. Husin (2021) Implemented Lean Six Sigma to improve cost and time efficiency in high-rise building projects, specifically focusing on basement construction activities like bored pile, secant pile, and excavation work. This was found that implementing LSS by using DMAIV methodology resulted in a cost efficiency of 6.85% and a time efficiency of 9.60% in the case study project. Panchal *et al.* (2025) investigated the adoption of LSS for remote project

management during crises, particularly in the Nigeria, adapted LSS framework to improve project outcomes, reduces costs, and enhances team collaboration.

Jowwad *et al.* (2017) used LSS methodology along with DMAIC approach to improve quality and reduce waste in road construction projects. It uses a quantitative approach, employing questionnaire surveys and the Relative Importance Index (RII) method (analyzed with SPSS) to identify critical factors affecting quality and waste in road construction. It Identified root causes using tools like cause-and-effect diagrams and Failure Mode and Effect Analysis (FMEA). Bechtel used Six Sigma methodologies to enhance performance at the Ivanpah Solar Electric Generating System in California. By employing Six Sigma tools, the team optimized material logistics, redesigned the Heliostat Assembly Building for increased efficiency, and streamlined assembly processes. Sakinah and Wahyudi Sutopo (2021) investigated quality improvement in precast concrete production at PT. XYZ, focusing on reducing defects through DMAIC and FMEA.

Primary objective is to identify major defects, analyze their causes, and propose corrective actions. Shuang Wu, Hong Tang (2024) examined the role of Six Sigma in the service industry, analyzed its impact on operational efficiency and customer satisfaction. The study finds that Six Sigma significantly improved service quality, reduces customer wait times, and enhances employee training. However, the methodology relies on structured data, making it less effective for industries with high variability in customer demands. Liang *et al.*, (2005) focused on the structural behavior of steel-concrete composite beams under bending and shear forces. Used Six sigma to improve load-bearing capacity while minimizing material consumption. Lingard *et al.*, (2000) examined the effectiveness of waste management systems in Australian construction companies using Lean Six Sigma (LSS). Love & Li, (2000) quantified the financial and operational impact of rework in construction projects. Using Six Sigma and statistical analysis, the study identifies common causes such as design errors and communication failures. Navon & Goldschmidt, (2010) investigated worker tracking methods to improve labour efficiency in construction. The methodology includes RFID tracking and data analytics.

The objective is to enhance workforce productivity and safety. Pheng & Hui, (2004) implemented Six Sigma in construction project management. It involves statistical defect analysis to enhance quality control and reduce errors. Polat, (2010) compared precast concrete adoption in various economies using Six Sigma. Schroeder *et al.*, (2008) focused on Six Sigma for the development of quality management practices in production operation. Soham *et al.*, (2018) used six sigma in construction industry for improving project quality, reducing defects, and enhancing customer satisfaction. Sarathkumar (2016) used DMAIC methodology and statistical analysis (SPSS software) for a process improvement method in construction, particularly in painting, tile work, and brickwork.

Lade *et al.* (2015) evaluated the performance quality of Ready mix Concrete plants in Mumbai using Six Sigma, which involves collecting information and analyzing data statistically through process sigma levels. Beary *et al.*, (2005) developed a framework based on Lean Six

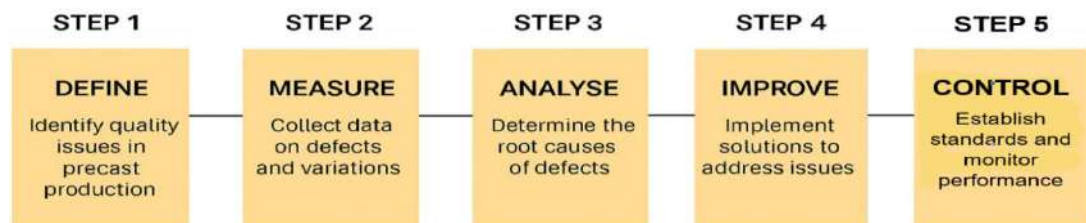
Sigma for enhancing production planning within the homebuilding industry, which integrates the Lean concept of minimizing wastes with Six Sigma's approach of minimizing errors. Zhang *et al.* (2016) applied LSS to logistics to achieve lower costs, reduced inventory, and shorten process cycle time, and improved delivery performance/customer satisfaction, smoother workflow, and higher productivity from employees. Dellifrairie *et al.* (2010) made use of the Six Sigma and Lean Systems (SS/L) as quality improvement tools towards providing an opportunity for better health care management from a quality perspective by applying DMAIC & PDCA. Mostafa, (2025) used Six sigma to enhance time efficiency and quality in Nepal construction sector with the implementation of DMAIC approach.

Fashina *et al.* (2020), explores how project management practices influence the performance of small and medium-sized construction firms in Hargeisa. Through a questionnaire-based survey, the study evaluates 16 critical factors, such as market expansion, risk mitigation, project success rates, and quality improvements. The results indicate that integrating Six Sigma and project management methodologies enhances competitiveness, optimizes resource utilization, and boosts customer satisfaction. This research offers valuable guidance for SMEs and policymakers seeking to improve efficiency through structured project management strategies.

3.0 Methodology

The DMAIC methodology, which stands for Define, Measure, Analyze, Improve, and Control, forms the foundation of this study. This systematic and continuous improvement approach is widely used to identify problems, improve product quality, and minimize defects across production systems. Its application in this research focuses on reducing the defects in precast concrete factories to achieve higher levels of quality and align with Six Sigma standards. The methodology is given in Figure 1.

Figure 1: DMAIC Process



3.1 Define

The first stage of the methodology involves identifying key production challenges faced by precast factories, such as mapping production activities to pinpoint defect causes. This

process includes setting project scope, defining desired outcomes, and ensuring the availability of equipment and resources. Additionally, the Critical to Quality (CTQ) characteristics of the production system are identified to understand internal company requirements and the specific defects impacting the quality of precast concrete.

3.2 Measure

In this stage, data is collected on the number of defects in production, enabling the calculation of Defects Per Million Opportunities (DPMO) to evaluate process performance. The DPMO is calculated using the following formula:

$$DPMO = \frac{\text{Number of defects}}{\text{Total Units} \times \text{Opportunities per Unit}} \times 10^6 \quad \dots 1$$

Using the DPMO value, for calculating the sigma level of process to its benchmark performance. The formula for calculating the sigma level is as follows:

$$\text{Sigma } (\sigma) = \text{NORMSINV} \left[1 - \frac{DPMO}{10^6} \right] + 1.5 \quad \dots 2$$

Here, NORMSINV represents the inverse normal distribution function.

3.3 Analyse

In analysis phase, where tools such as cause- and-effect diagram, statistical analysis etc. are used to find the root causes of production defects. The point is to pinpoint what affects defects the most and target it for fixing efforts.

3.4 Improve

Improvement efforts utilize the various quality improvement tools such as FMEA to assess and mitigate risks associated with identified defects. The Risk Priority Number (RPN) is calculated to determine the severity, occurrence, and detection likelihood of potential failures. Actions are then implemented to address high-priority risks, ensuring process stability and quality improvement.

3.5 Control

The final stage involves establishing control measures to sustain improvements. This includes documenting quality standards, implementing best practices, and developing a monitoring system to maintain process performance and prevent future defects.

4.0 Case Analysis

To enhance the quality of precast concrete structures, the DMAIC methodology, was applied at Indo Global Precast System LLP, to identify and address defects and inefficiencies in the manufacturing process of precast structures.

Figure 2: Pre-Cast component



Source: Author generated

During the assessment, several recurring defects were observed, including surface cracks, honeycombing, dimensional inaccuracies, and curing-related issues. These defects not only contributed to product rejection and material waste but also led to higher production costs and delays in project completion. The company frequently encountered quality-related setbacks, resulting in rework and inefficiencies that affected overall productivity. Some of the pictures of the site are given below as Figure 2, 3 4 and 5.

Figure 3: IN-Site Casting Yard for Precast



Source: Author generated

Figure 4: Pre-Cast elements



Source: Author generated

Figure 5: Precast Slab from Site Visit



To determine the underlying causes of these defects, an extensive data collection and analysis process was conducted. This involved reviewing past production records, examining defect patterns, and carrying out on-site inspections. The findings revealed that surface cracks and inadequate curing were the most prevalent defects, impacting nearly 55% of all precast

elements. Additionally, discussions with factory personnel and quality control teams provided further insights into process inconsistencies that contributed to these quality issues. Further investigation pinpointed the primary root causes behind these defects, including inconsistencies in material mixing, improper vibration techniques during casting, and ineffective curing methods. Variations in the water-cement ratio and aggregate blending led to structural weaknesses, while incorrect vibration application resulted in honeycombing and void formations. Additionally, inadequate moisture and temperature control during curing compromised concrete strength and durability. Addressing these challenges required a structured approach to process optimization, quality control, and defect prevention, ensuring a more efficient and reliable precast production system.

The data collection methods included direct observation, interviews with company employees, and a review of relevant literature. The data gathered consisted of the monthly production volume, the number of defective units produced each month, and the various types of defects identified. These details are presented in Table 1.

Table 1: Monthly Total Production Defects in Years

Period	Total production (unit)	Total production defect (unit)
Jan-24	60	4
Feb-24	28	5
Mar-24	14	2
Apr-24	39	11
May-24	98	20
Jun-24	90	18
Jul-24	48	11
Aug-24	14	2
Sep-24	10	2
Oct-24	97	19
Nov-24	45	13
Dec-24	47	11
Total	590	118

5.0 Results and Discussion

Through data analysis and statistical tools, the study identified the key factors affecting quality of precast concrete components as:

- *Void & Honeycombing (49 cases)*: Improper concrete compaction led to gaps or air pockets in the structure, reducing strength and durability.
- *Outer Surface Damage (30 cases)*: Handling and transportation issues caused chipping, breakage, and uneven surfaces.

- *Concrete Cracks (26 cases)*: Shrinkage, temperature variations, and improper curing resulted in cracks, reducing structural integrity.
- *Broken Concrete (13 cases)*: Incorrect demolding or excessive force applied during production caused sections of the concrete to break.

These defects contributed to production inefficiencies, rework, and increased material waste, underscoring the need for process improvements. Using the DMAIC methodology, the research quantified the defect levels and identified their root causes. DPMO and Sigma Levels were calculated for each month as given in Table 2. The average sigma level was found to be 3.10 i.e. below the industry benchmark of 6, indicating room for improvement. The study found that high defect rates were primarily caused by:

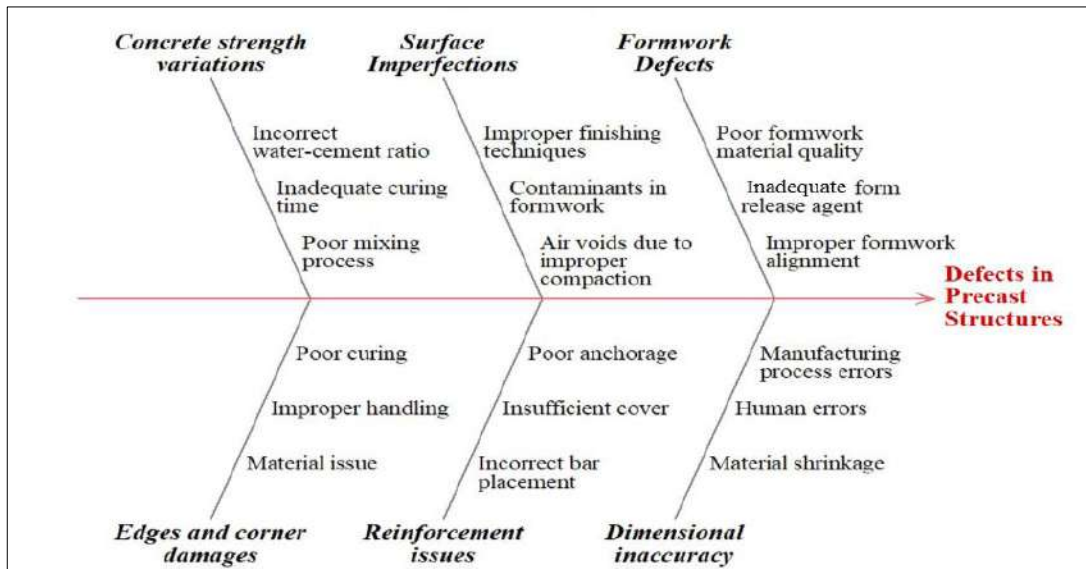
- Material-related issues, such as improper concrete mix or contamination.
- Process inefficiencies, including inadequate curing and poor compaction.
- Human factors, such as inconsistent workmanship and inadequate training.

Table 2: DMPO and Six Sigma Level in Each Month

Month	Production Units	Defective Units	DPMO	Sigma Level
January	60	4	16,666.67	3.53
February	28	5	44,642.68	3.08
March	14	2	35,714.29	3.17
April	39	11	70,512.82	2.99
May	98	20	51,020.41	3.06
June	90	18	50,000.00	3.07
July	48	11	57,291.67	3.02
August	14	2	35,714.29	3.17
October	97	19	48,969.07	3.08
November	45	13	72,222.22	2.98
December	47	11	58,510.64	3.02

Cause and Effect diagram for the major causes of defects is given in Figure 6 below. The research confirms that Six Sigma is an effective quality management tool for precast concrete production. By systematically identifying and eliminating defects, companies can enhance operational efficiency, minimize waste, and improve customer satisfaction. However, the findings also highlight challenges in achieving a higher sigma level. While defect rates declined, the process still shows inconsistencies. Factors such as workforce training, real-time monitoring, and advanced statistical analysis are critical for achieving sustained improvements.

Figure 6: Cause and Effect diagram for Defects and their Causes



6.0 Conclusion and Further Research

This study demonstrates how Six Sigma methodology can effectively improve the quality and efficiency of precast concrete production. By systematically identifying and addressing recurring issues—such as dimensional inaccuracies, surface defects, reinforcement misplacements, and inconsistencies in concrete strength—this research highlights how Six Sigma helps reduce waste, enhance productivity, and optimize construction workflows. The findings confirm that implementing Six Sigma tools results in measurable quality improvements and a reduction in defects. An increase in calculated sigma levels reflects improved control over production processes and emphasizes the significance of continuous improvement. The research also underscores the value of data-driven decision-making in boosting operational efficiency, reducing rework, and improving client satisfaction in the construction industry.

Although Six Sigma offers clear advantages in precast production, broader adoption in the construction sector faces several challenges. Successful implementation requires refining current methodologies, embracing technological advancements, and following a structured process improvement approach. Companies that adopt these strategies are more likely to achieve higher quality, cost-effective, and sustainable outcomes. Six Sigma adoption can lead to increased productivity and long-term industry growth. Despite these benefits, the study does have limitations. Primarily, it focuses only on precast concrete and does not explore Six Sigma's application in other construction methods like cast-in-place concrete, steel framing, or modular

systems. Each construction technique presents its own unique set of challenges, and further research is needed to evaluate Six Sigma's adaptability to these alternatives.

Another limitation is the lack of financial analysis. While the study discusses defect reduction, it does not assess the cost-effectiveness of implementing Six Sigma. A detailed cost-benefit analysis would help firms evaluate the economic feasibility of investing in quality improvement initiatives. Additionally, the study relies mainly on historical production data and does not incorporate real-time quality monitoring. Integrating real-time systems could improve defect detection and enable timely corrective actions before production completion. This would result in more dynamic and responsive quality control processes. Human factors also present significant challenges. Resistance to change among staff and management can hinder progress. The absence of comprehensive training programs further limits the effective adoption of Six Sigma principles. Overcoming this requires investing in structured training and behavioral strategies to encourage employee involvement in quality improvement efforts.

Moreover, the study does not use advanced analytics like regression models, machine learning, or predictive tools. These techniques could help uncover hidden patterns in defect data and reveal root causes of inefficiencies. Employing such methods would enhance the overall effectiveness of Six Sigma applications in construction. To broaden Six Sigma's scope in construction, future studies should explore its use in various building systems, including cast-in-place concrete, steel structures, and modular buildings. Comparative studies could determine whether similar benefits can be achieved across different materials and production environments. Additionally, the integration of advanced data analytics—such as time-series forecasting, machine learning algorithms, and regression analysis—can provide deeper insights into defect trends and support predictive maintenance strategies. This shift from reactive to proactive quality control would represent a major improvement in construction practices.

Another important direction for future research is the long-term evaluation of Six Sigma's impact. While this study focuses on short-term outcomes, longitudinal research would reveal whether Six Sigma helps sustain high quality over time and across different projects. Since implementing Six Sigma often requires investment in tools, training, and technology, understanding its return on investment (ROI) is crucial. Quantifying savings from defect reduction and process improvements can help companies make better decisions about adopting it as a long-term strategy. The integration of smart technologies such as Internet of Things (IoT) devices, AI-driven analytics, and real-time monitoring systems can significantly strengthen Six Sigma's effectiveness. These technologies allow for instant defect identification and real-time corrections, making quality management more efficient. Future studies should investigate the synergy between Six Sigma and emerging technologies to improve defect detection, process control, and overall construction quality. Finally, overcoming resistance to change is essential for the successful implementation of Six Sigma. Developing behavior-based strategies, offering regular training, and creating incentive systems can help foster employee engagement. Since workforce support is a key factor in quality improvement, understanding and addressing human

behavior in organizational change is crucial. In summary, this study confirms that Six Sigma has the potential to transform quality management in the construction sector. By refining processes, incorporating technology, considering financial feasibility, and addressing human factors, Six Sigma can lead to more efficient, cost-effective, and high-quality construction outcomes.

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CHAPTER 108

Quantitative Risk Assessment and Safety Optimization in Construction Workflows

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ABSTRACT

In the realm of construction safety management, ensuring the well-being of workers and the seamless execution of projects is paramount. This comprehensive study investigates the Indian construction sector, elucidating the critical roles played by both leading and lagging safety indicators. The research meticulously examines 75 incidents spanning the period 2009-2024, utilizing data from diverse sources such as newspaper reports and expert opinions from site personnel to prioritize the most common hazards leading to accidents. Methodologically, the study employs case-based evaluations and survey responses to scrutinize safety hazards prevalent in key construction activities, including working at heights, soil excavation, electrical work and more. Employing sophisticated data visualization techniques such as heat maps and risk prioritization matrices, the research identifies critical risk areas and proffers actionable insights.

Keywords: Construction safety; Risk mitigation; Hazard prioritization; Safety indicators; Quantitative evaluation

1.0 Introduction

Safety has always been a critical yet overlooked factor in the construction industry, which operated under inherently hazardous and dynamic conditions. Construction work is characterized by adverse weather, frequent team rotations, a significant proportion of unskilled or temporary workers and shifting topographies that pose challenges to safety management (Bobick, 2004). The importance of safety has grown substantially in the modern competitive era, particularly considering alarming global statistics. For example, Europe reported about 9.5 fatalities per 1,00,000 construction site workers in 2006 (Zhou, 2012) with similar figures observed in the United States in 2007 (Baxendale, 2000). Such fatal incidents underscore the urgency of prioritizing safety across the construction sector worldwide. Efforts to improve safety standards have been bolstered by documenting the cause of accidents and implementing corrective measures.

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Government bodies have also played a significant role in reducing site accidents by addressing critical safety issues and promoting health and safety initiatives (Zhou, 2013). This study aims to achieve objectives, To analyze the role of leading and lagging safety indicators in the Indian construction industry by conducting a systematically designed literature review and evaluating by conducting a systematically designed literature review and evaluating key hazard trends and to propose a novel safety prioritization matrix that integrates quantitative risk assessment with industry-specific safety performance indicators and mitigation solutions for high-risk construction activities.

2.0 Literature Review

Safety and its methods have been a focal point of the construction sector, with protective gear such as helmets, hard hats and modern personal protective equipment (PPE) gaining attention over the years (Akinlolu, 2022). (Teizer, 2015). Despite advancements in technology, planning and execution, achieving effective safety results remains a challenge. Safety should be considered a precondition rather than a priority. Real-time monitoring of construction health and safety can be achieved using sensor-based technologies (Zhang, 2017). These findings highlight the need for integrated safety strategies that combine advanced technologies with behavioral interventions to foster a safer construction environment.

3.0 Research Methodology

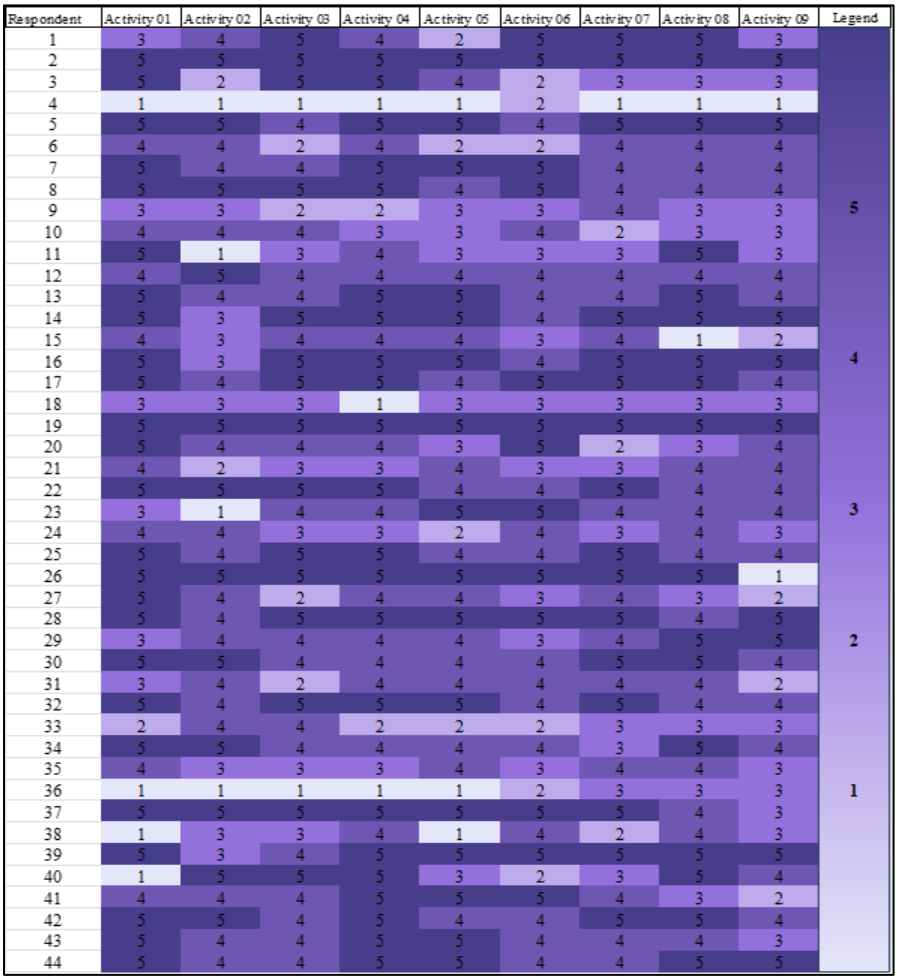
The research methodology is developed based on case-based data evaluation; a comprehensive survey questionnaire was floated to collect responses from experienced professionals. The questionnaire focused on the rating-based questions to generate the results. This study uses a numerical scale from 1 to 5 where 1 = lowest and 5 = highest rating for the available questions. Authors believe that this scale is compatible for evaluating various safety hazards and discrepancies associated with the chosen construction activities. The questionnaire also consists of additional section where the respondents can provide their suggestions, additional information and comments about any specific procedure, safety evaluation parameter etc.

4.0 Respondent Data Interpretation

The survey questionnaire consisted of four sections, 1. “Severity rating” section, 2. “Frequency rating” section, 3. “Problems and suggested safety solutions” section and 4. “Safety precautions implemented at your sites” section. For the severity rating section, the researchers calculated mean severity rating, where the highest severity = 4.05 was seen for working at height. Lifting operation = 4.11, writes down a major concern about falling objects, materials,

tools, spares etc. and questions the equipment stability while working. The lowest severity rating was seen for Soil excavation = 3.73, indicating a lower but still noteworthy risk level. Considering other activities like, working around moving equipment & machinery, Hot work applications and Demolition shows consistent severity ratings = 3.95, emphasizing a need for consistent safety measures.

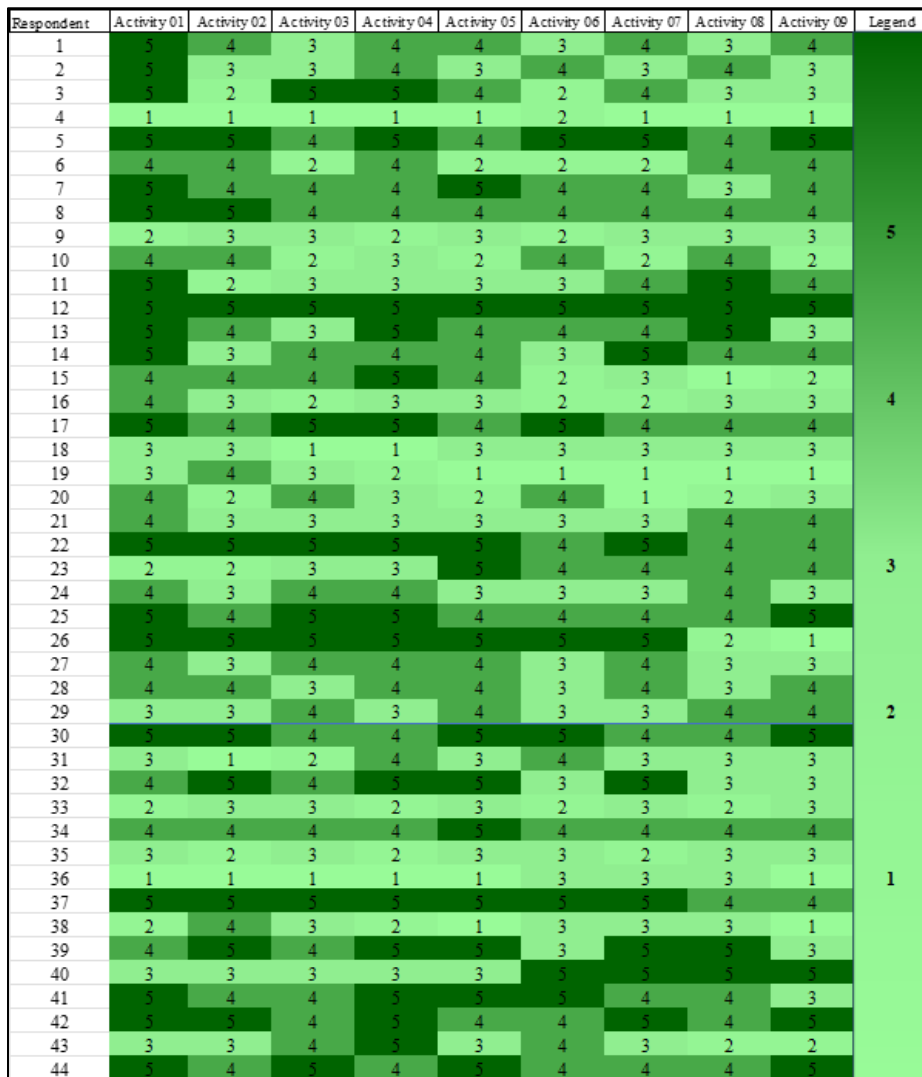
Figure 1: Heat Map for Severity Rating, where 1= low risk & 5= high risk



Source: Compiled by authors

Authors developed a heat map, Figure 1, to provide immediate visual representation of data patterns and trends for the respondent data. A heatmap representing data pattern for frequency rating is also shown in Figure 2.

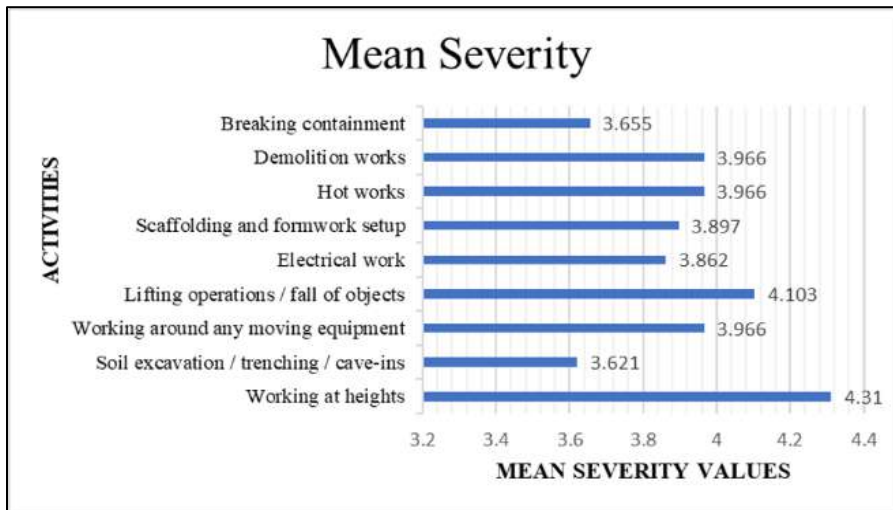
Figure 2: Heat Map for Frequency Rating, where 1= low risk & 5= high risk



Source: Compiled by authors

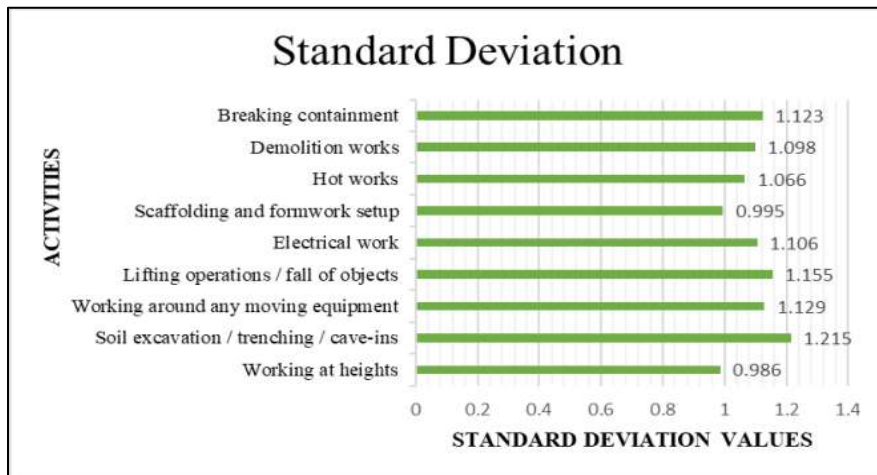
The bar graph makes it clearer for the audience to understand the data pattern for mean severity rating Figure 3 as well as standard deviation Figure 4. Activities like soil excavation and lifting operations show a standard deviation value = 1.19 signifying higher variability responses, suggesting a lack of consensus or differing construction site conditions. With a lower value of 1.01 = Working at height proves relatively lower variation, indicating an agreement on its severity.

Figure 3: Bar Chart for Mean Severity Rating



Source: Compiled by authors

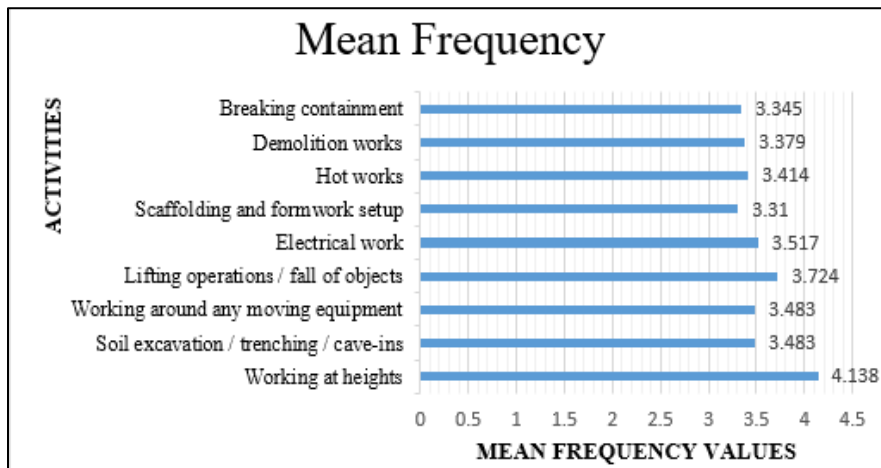
Figure 4: Bar Chart for Standard Deviation of Severity Rating



Source: Compiled by authors

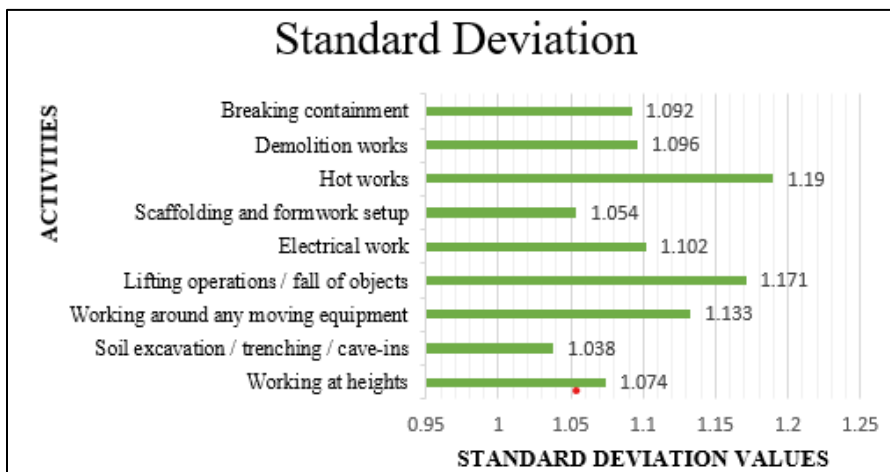
Upon analysis of the data collected from frequency rating section, researchers found out that activities with the highest mean rating are 1. Working at height = 3.52, 2. Lifting Operations and Fall of objects = 3.73 and 3. Soil excavation and Trenching = 3.50. These activities can be perceived as having a higher frequency of risk occurrence, writing down that they are significant areas of concern for safety.

Figure 5: Bar Chart for Mean Frequency Rating



Source: Compiled by authors

Figure 6: Bar Chart for Standard Deviation of Frequency Rating



Source: Compiled by authors

The frequency distribution pattern observed, Figure 5 and Figure 6 clearly portrays that Working at height has high number of ratings ranging in between 4-5 indicating it as a high-risk activity whereas lower frequency rating ranging between 1-2 were attributed to Scaffolding and Formwork setup, indicating relatively less perceived risk construction activities. Based on the risk categorization that we have done using Microsoft Excel is pictured below in Figure 7 and Figure 8.

Figure 7: Risk Categorization for Severity Rating for Enlisted Construction Activities

Sr. No	Activity Names	Mean Severity	Standard Deviation	Quadrant
1	Working at heights	4.31	0.986	Quadrant 2 (High Priority)
2	Soil excavation / trenching / cave-ins	3.621	1.215	Quadrant 3 (Monitor)
3	Working around any moving equipment	3.966	1.129	Quadrant 3 (Monitor)
4	Lifting operations / fall of objects	4.103	1.155	Quadrant 1 (Critical)
5	Electrical work	3.862	1.106	Quadrant 3 (Monitor)
6	Scaffolding and formwork setup	3.897	0.995	Quadrant 4 (Low Priority)
7	Hot works	3.966	1.066	Quadrant 3 (Monitor)
8	Demolition works	3.966	1.098	Quadrant 3 (Monitor)
9	Breaking containment	3.655	1.123	Quadrant 3 (Monitor)

Source: Compiled by authors

**Figure 8: Risk Categorization for Frequency Rating for
Enlisted Construction Activities**

Sr. No	Activity Names	Mean Severity	Standard Deviation	Quadrant
1	Working at heights	4.138	1.074	Quadrant 1 (Critical)
2	Soil excavation / trenching / cave-ins	3.483	1.038	Quadrant 3 (Monitor)
3	Working around any moving equipment	3.483	1.133	Quadrant 3 (Monitor)
4	Lifting operations / fall of objects	3.724	1.171	Quadrant 3 (Monitor)
5	Electrical work	3.517	1.102	Quadrant 3 (Monitor)
6	Scaffolding and formwork setup	3.31	1.054	Quadrant 3 (Monitor)
7	Hot works	3.414	1.19	Quadrant 3 (Monitor)
8	Demolition works	3.379	1.096	Quadrant 3 (Monitor)
9	Breaking containment	3.345	1.092	Quadrant 3 (Monitor)

Source: Compiled by authors

The colour coding in Figure 8, especially signifies different level of severity. Red = critical, Orange = high priority, Yellow = monitor and Green = low priority. Similar conditions were applied to data set of Frequency Rating values, Figure 8, and we developed the quadrants. The next section entailed in the survey form gathered data about the problems and suggested safety solutions we opted for. Researchers used – segmentation analysis to summarize the respondent data. Segmentation analysis allows us to break down specific problems associated with each type of construction activities being listed and then name tailored solutions for them.

5.0 Conclusions

Proactive Risk management with Safety performance indicators: This research underscores the crucial role of leading and lagging safety indicators in Indian construction industry. By meticulously analyzing accident data from 2009-2024, it goes beyond the traditional safety approaches which focus solely on compliance with IS 15883 (Part 1-3): Construction Project Safety Management.

Table 1: Segmentation Analysis of Construction Activities

Construction Activities	Identified problems	Suggested solutions (By respondents)	Specific actions
Working at height	Risk of fall from height especially from edges and scaffoldings	Use of safety belts, harness. Using safety nets. Erecting hard barricades at edges to prevent them from falling.	Using personal protective equipment's along with fall protection equipment like safety harness and jackets. Emphasizing more on stringent protocols for work on height and implementing regular tool-box-talks or safety briefing before initiating working at height.
Soil Excavation / Trenching / Cave-Ins	Danger from soil cave-ins especially in deep excavation zones	Implementing slope excavation. Adhering to strict safety protocols during deep excavation work.	Implementing trench support systems and conducting routine safety inspections can significantly reduce the risk of soil cave-ins.
Working around moving equipment	Risk of collision with heavy machineries.	Designated movement zone along with signal operators, flagger or traffic marshal. Conducting tool-box-talks before initiating heavy civil activities.	Segregation of pedestrians from equipment operations zones. Using barricades and conducting regular training sessions for operators, flagger, signal men and workers.
Lifting operations & Fall of Objects	Risk associated with overloading and fall of objects.	Barricading around lifting and shifting zones, toolbox talks regarding lifting / shifting capacity of machines and ensuring operators are competent.	Conduct pre-lift assessment and strictly adhere to the safe working load capacity of cranes or lifters to reduce the potential risks.
Electrical work	Risk of electrocution due to presence of live wires and inadequate insulation. Leniency in adhering to electrical safety guidelines and precautionary rules.	Use of safety kits, adequate earthing and providing rubber mats.	Ensuring workers are well equipped with insulated gloves, rubber soled boots while working around live / operational electrical systems to nearly 0 the chances of electrocution.

Source: Compiled by authors using enlisted sources

Instead, it introduces an innovative safety prioritization matrix that quantifies risks and proactively pinpoints potential hazards before accidents happen. This novel methodology aligns with BOCW Act, 1996 (The Building and Other Construction Workers (Regulation of Employment and Conditions of Service)) encouraging a shift from reactive to predictive safety management in civil engineering industry, A new safety prioritization matrix for High-risk activities, while existing Indian standards such as IS 13416 (Part1-5): Recommendations for preventing hazards at construction sites categorizes hazards, they lack a quantitative rating

system for dynamically assessing the risk levels. This research presents a data-driven approach using heatmaps and risk categorization matrices to systematically rank construction activities based on severity and frequency ratings. By leveraging survey data and industry insights, it identifies key organizational and behavioral factors influencing safety outcomes. This novel contribution not only enhances compliance with existing regulations but also sets a new benchmark or modern safety management in civil engineering.

Table 2: Statistical Data Summary

Sr. No.	Construction activity	Risk level	Statistical insight
1.	Working at height	3 / High	Working at height is statistically the most critical activity as it aligns with the common safety respondent data. Here fall related incidents are a leading cause of injuries on construction site.
2.	Lifting Operations	3 / High	Lifting operations have high risks due to the potential for falling objects, overloading or counterweight failures. Hence, this contributes to the high number of workplace accidents.
3.	Soil Excavation / trenching	2 / Moderate	This activity poses a moderate, i.e., significant but manageable risk if necessary precautionary measures like shoring and sloping are implemented. Approximately, 25 – 30% of excavation incidents can be prevented through effective and efficient safety practices.
4.	Working around moving equipment	2 / Moderate	Moving equipment's possess moderate risk levels primarily due to collision. Toolbox talks and various awareness sessions can statistically reduce collision risk by 15-20 %.
5.	Electrical work	2 / Moderate	Electric work involves moderate risk primarily related to shock hazard. Adhering to safety protocols, using PPE's and proper insulation statistically reduces the incidents caused due to electrocution by 40%.

Source: Compiled by authors

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CHAPTER 109

Real Estate Asset Classes: Role in Multi-Asset Portfolio Designing

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ABSTRACT

The advent of new investment asset classes has offered opportunities to diversify and optimize the risk-return trade-off to the investors. This paper attempts to design an optimal multi-asset portfolio for investors seeking stable income and capital preservation. The asset classes considered to design this multi-asset portfolio are Physical Real Estate, Infrastructure Bonds, REITs, and Gold. The research objectives are to identify and analyze asset classes suitable for achieving a targeted Rate of Return on Investment, to analyze the correlation between various considered assets, and subsequently design an optimal multi-asset portfolio. This Research Paper builds on various Portfolio Theories such as the Modern Portfolio Theory, the Black-Litterman Model & Post-Modern Portfolio Theory to meet the objectives.

Keywords: Multi-asset portfolio 1; Physical Real estate 2; Infrastructure bonds 3; REITs 4; Modern portfolio theory 5.

1.0 Introduction

1.1 Background

Managing an investment portfolio is crucial for making smart financial choices, influencing wealth growth, risk management, and overall financial health. Various portfolio theories have developed over time to enhance investment strategies, helping investors achieve their financial goals while effectively balancing risk and return. In a financial market that is becoming increasingly intricate, grasping portfolio management techniques and their effectiveness is crucial for both individual and institutional investors. This project focuses on the application and analysis of significant portfolio theories, including the Modern Portfolio Theory, Capital Asset Pricing Model (CAPM), Arbitrage Pricing Theory (APT), and Post-Modern Portfolio Theory (MPT). By critically evaluating these theories, the study seeks to offer insights into their practicality and relevance in the current financial environment.

1.2 Objectives

To investigate different investment portfolio theories and assess their effectiveness in guiding financial decisions.

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- To analyze the risk-return trade-offs associated with portfolio diversification strategies.
- To evaluate how these theories can be utilized in real-world investment situations.
- To identify the strengths & weaknesses of various portfolio management models.
- To provide insights for investors and financial analysts on constructing optimal portfolios.

1.3 Limitation of study

- Dependence on secondary data, which may be subject to biases or inaccuracies.
- Assumptions made in portfolio theories that may not always align with real-world financial markets.
- The impact of external economic factors, market volatility, and investor behavior, which are difficult to predict.
- Limited case studies due to constraints in data availability.

1.4 Scope of study

This research aims to provide valuable insights into investment portfolio management by evaluating different theories and their practical applications. The findings will be beneficial for investors, financial analysts, and academicians seeking a deeper understanding of portfolio optimization techniques. By analyzing historical data and theoretical models, the study contributes to the knowledge of investment strategies and aids in informed decision-making for financial growth and stability.

2.0 Literature Review

Modern Portfolio Theory, introduced by Markowitz (1952), emphasizes risk minimization and return maximization through diversification, particularly by considering asset covariance (Jayeola *et al.*, 2017). The Black- Litterman Model refines asset allocation by incorporating investor views with market equilibrium (Jayeola *et al.*, 2017). Gold remains a significant investment, serving as a hedge against inflation and market downturns, with various investment options such as ETFs, bullion and futures (Nawaz, 2013). Traditional and modern approaches to Weighted Average Cost of Capital (WACC) impact firm valuation, with newer models improving accuracy (Rehman, 2010). Portfolio optimization strategies, including risk-adjusted methods and dynamic asset allocation, enhance investment performance (Groll, 2017). Real estate remains a preferred asset in India, influenced by liquidity, taxation and geographical diversification (Matharu & Manda, 2021). Studies highlight real estate portfolio management, the role of human capital, and the impact of property type and tenant base on returns (Feng *et al.*, 2021). Hotels contribute to diversification in commercial real estate portfolios, improving risk-adjusted returns (Singh, 2003). REITs have shown stronger performance compared to InvITs, while declining real estate sales in India impact REIT attractiveness (Boddu, 2021). Municipal bond ratings influence stock and bond markets, with credit rating agency conflicts

affecting financial decisions (Cornaggia *et al.*, 2014). Government spending impacts local employment through municipal bond recalibrations, influencing economic growth (Adelino *et al.*, 2016). Gold's efficiency as an investment has been demonstrated through Xetra-gold, benefiting Euro and USD portfolios (Demidova *et al.*, 2007).

3.0 Research Methodology

In the study, the Primary aim shall be of building and analyzing a multi-asset portfolio of gold, bonds, real estate (HPI), and REITs optimally to realize a pre-defined targeted rate of return with even risk profiles. The methodology adopted for conducting this study includes the following:

- Collection of historical financial data for the selected asset classes.
- Statistical and descriptive analysis of performance, risk, and correlations in assets.
- Constructing a portfolio based on modern portfolio theory and using mean-variance optimization.
- To assess the optimization portfolio's robustness, back testing and stress testing.
- Comparison with a variety of asset-allocation strategies concerning efficiency toward attaining the target return.

The study works within the boundaries of the positivist paradigm by drawing conclusions based on numerical data, statistical methods, and objective financial theories. To carry out this study, a historical data analysis has been performed where returns and volatilities of assets over an extensive period will be examined. Mathematical optimization will further be applied using algorithms, to derive the best asset allocation. On top of that, risk management techniques will focus on the assessment of market risks through standard deviation, Variance, and Monte Carlo simulations.

4.0 Data Analysis and Findings

4.1 Data sources and variables

Information gathered from Gold Prices, Bond Yields, House Price Index (HPI), and REITs (Mindspace, Brookfield, Embassy, Nexus). Time frame: 2017–2025, analyzed on monthly basis.

4.2 Descriptive statistics

Mean return and standard deviation computed for various asset classes.

$$\text{Monthly Return} = \{\text{Price}(t) - \text{Price}(t-1)\} / \text{Price}(t-1) \quad \dots 1$$

$$\mu = \frac{1}{N} \sum_{i=1}^N R_i \quad \dots 2$$

Standard Deviation (Measure of volatility):

$$\sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (R_i - \mu)^2} \quad \dots 3$$

Correlation analysis: To find the relationships between assets, we use Pearson's Correlation Coefficient

$$r = \frac{\sum (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum (X_i - \bar{X})^2} \cdot \sqrt{\sum (Y_i - \bar{Y})^2}} \quad \dots 4$$

4.3 Portfolio performance analysis

Portfolio Return Analysis

$$R_p = \sum_{i=1}^n w_i R_i \quad \dots 5$$

Portfolio Standard Deviation

$$\sigma_p = \sqrt{\sum_{i=1}^n w_i^2 \sigma_i^2 + \sum_{i=1}^n \sum_{j=1, j \neq i}^n w_i w_j \sigma_i \sigma_j \rho_{ij}} \quad \dots 6$$

Performance Analysis

$$S = \frac{R_p - R_f}{\sigma_p} \quad \dots 7$$

4.4 Data representation

Eight portfolios were developed with varying combinations of asset classes. Portfolio 2 (Gold, Bond, HPI-Hyderabad, REITs-Nexus) was also a top performer, with Sharpe Ratio 2.56 and 10.85% return. Portfolio 6 (Gold, Bond, HPI-Chennai, REITs-Nexus) posted the highest Sharpe Ratio (3.13), thus it was the best in terms of risk-adjusted returns.

4.5 Correlation analysis

Portfolio 6 (i.e., Gold, Bond, HPI-Chennai, REITs-Nexus) is best choice best on correlation analysis.

5.0 Consequences for Indian Real Estate Investment

Gold & Chennai (0.26): Weak link; gold prices provide some clue but are not a good indicator. Nexus & Bonds/Gold (-0.05, 0.03): Not much effect; investors need to look at location-specific information. Chennai & Nexus (0.38): Weak correlation; an investment in either is not particularly strong diversification. Bonds & Real Estate (0.07, 0.03): No significant effect; bond market trends have no influence on Chennai or Nexus real estate.

Diversification Strategy: Investors should search for uncorrelated or negatively correlated assets to manage risk.

Table 1: Portfolio Combinations

	Asset classes	Return	Standard Deviation	Sharpe Ratio	Total Weight	Risk Free ROR
Portfolio 1	Gold, Bond, Pune, Brookfield	7.04%	1.45%	0.21	100%	6.73%
Portfolio 2	Gold, Bond, Hyderabad, Nexus	10.85%	1.61%	2.56	100%	6.73%
Portfolio 3	Gold, Bond, NCR, Embassy	8.17%	2.33%	0.62	100%	6.73%
Portfolio 4	Gold, Bond, Mumbai, Mindspace	5.45%	1.50%	-0.85	100%	6.73%
Portfolio 5	Gold, Bond, Bengaluru, Brookfield	9.10%	1.56%	1.52	100%	6.73%
Portfolio 6	Gold, Bond, Chennai, Nexus	10.93%	1.34%	3.13	100%	6.73%
Portfolio 7	Gold, Bond, Ahmedabad, Embassy	6.94%	2.75%	0.08	100%	6.73%
Portfolio 8	Gold, Bond, Kolkata, Mindspace	6.88%	1.50%	0.10	100%	6.73%

Source: Compiled by authors

Table 2: Correlation of Assets

Correlation Matrix	
GOLD & BOND	-0.05
GOLD & CHENNAI	0.26
GOLD & NEXUS	-0.05
BOND & CHENNAI	0.07
BOND & NEXUS	0.03
CHENNAI & NEXUS	0.38

Source: Compiled by authors

6.0 Conclusion

Through this study, we have provided a comprehensive summary of investment portfolio theories and their practical application in the financial market. While examining different portfolio models such as the Modern Portfolio Theory (MPT), Capital Asset Pricing Model (CAPM), Arbitrage Pricing Theory (APT), and Post-Modern Portfolio Theory (PMPT), we have examined their effectiveness in optimizing returns at minimum risk. Empirical analysis of data supported through the study has demonstrated diversification of assets is necessary to curb risk and raise returns. The correlation analysis focused on how the classes of assets correlate and agreed with balancing risky and not-risky assets for portfolio maximization. Among the portfolios under consideration, Portfolio 6 (Gold, Bond, HPI Chennai, and REITs Nexus) was the best in terms of risk-adjusted returns, as evident from its highest Sharpe Ratio (3.13). This suggests that investors seeking a balance between risk and return would be best

served by this asset combination. For risk-taking investors, Portfolio 2 is also a suitable choice with a strong Sharpe Ratio (2.56) and high returns.

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CHAPTER 110

Real Estate Marketing of Commercial Building in India

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ABSTRACT

The Indian commercial real estate space, which includes office environments, retail spaces, co-working spaces, and industrial properties, has developed significantly in tandem with the trends of urbanization, infrastructural evolution, and changes in business models. This paper discusses the challenges present in the marketing of commercial properties with a focus on an integrated marketing approach involving traditional and digital marketing strategies. Some of the critical factors that impact marketing success are location branding and technology incorporation as well as innovative amenities. The research brought out significant trends through questionnaires and data analysis like content marketing's increased significance paid social media campaigns' effectiveness and green hybrid workspaces' growing attraction. Such findings will produce practical solutions for marketers in real estate so that they can adjust according to changing market conditions to reach an appropriate audience for achieving optimum return on investment which in turn would contribute toward continuous growth of commercial real estate sector in India. The survey was carried out for collecting the data and gathering the valuable insights which came in handy to understand the market and what are the expectations of the consumers who want to invest in the property.

Keywords: Indian commercial real estate; Digital marketing strategies; Integrated marketing approach; Location branding; Consumer insights.

1.0 Introduction

In India, commercial real estate speaks from office complexes to retail facilities, co-working spaces, and industrial establishments, proliferating with urbanization and business models changes. There are opportunities and challenges in this sector, where strategic marketing is needed in order to attract business and investors. Property branding requirements necessitate amalgamating old school and new school media to project properties in the appeared competitive market space. The focus of this research lies in how marketing strategies are conceptualized and implemented. It delves into the issues of location, amenities, price, and technology, while examining trends such as hybrid offices, green buildings, and flexible leases.

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Digital platforms began to revolutionize property marketing; a continued blending of contemporary tools with older techniques will remain pertinent. Though providing some information, the limitations of the research arise from changing market trends and geographic differences. The design of the article is intended to further comprehension of the market dynamics, marketing strategy, challenges, and case studies, ending with recommendations for firms in search of the right buyers to maximize their returns.

1.1 Research objectives

- To analyze real estate marketing plan as a detailed strategy which outlines how a property will be promoted and sold. It should include specific actions, tactics, and resources to attract potential buyers or renters and achieve successful real estate transactions.
- To understand the market, we need to take into account these three major points: product, place, and price.
- To identify key metrics to gauge the success of marketing efforts for commercial buildings.
- To find the influence of specific building features and amenities on tenant attraction and rental rates.

1.2 Research problem

- Effectiveness of integrated offline and online marketing, considering property type and demography, in influencing targeted audience preference for commercial real estate.
- Impact of digital marketing tools on commercial real estate decisions.
- Influence of economic on marketing strategies for commercial real estate.

2.0 Research Methodology

The qualitative interviews and quantitative surveys made use of a two-phase research design to evaluate India's commercial real estate market: statistically relevant insights served to formulate education on office interiors, site selection drivers, and amenities so as to provide, in varied bases, what the market wants. Yet, they could not reveal the deep motivations for such trends by nature. Benefits included insight through discussions with professionals in the industry: brokers, developers, investors, and corporate real estate personnel. The discourse revolved around notions about work models, changing notions of sustainability, and patterns of long-term investment. The answers of structured quantitative survey and qualitative insights completed the connection between observed trends in a market and psychology behind such behavior. This blended method provided an all-encompassing perspective into the behaviors of both investors and tenants, and assisted in drawing marketing strategies that were targeted and effective for commercial real estate in India.

2.1 Data collection methods

The study makes use of both primary and secondary data collection methods in the analysis of India's commercial real estate market. Primary data were collected through surveys

and interviews with property owners, potential buyers, and industry experts, providing first-hand insights and tuning the assumptions on which the study was based and thus ensuring that the study remained accurate and reliable. Secondary sources of data include industry reports, market research, government and other official documentation, and academic journals. Being a cost-effective method, this will give them a quick assessment for a great deal of information, thus speeding up their researching process. The integration of both data sources gives the study a broad view of market trends, stakeholder preferences, and strategic options. This broad understanding will, therefore, enhance the appreciation of the driving forces behind commercial real estate marketing in India.

2.2 Data analysis methods

Both qualitative and quantitative analysis are used in this study to develop a thorough understanding of the Indian commercial real estate market.

- *Qualitative analysis:* It targets non-numerical data such as interviews, observations, and textual sources to investigate customer choice, market trends, and industry issues. Qualitative analysis aids in comprehending subjective factors affecting real estate marketing strategies.
- *Quantitative analysis:* It is the process of reviewing numerical information from surveys, financial statements, and market research to determine patterns, relationships, and trends. As it presents statistical proof, it supplements qualitative insights, providing a data-driven analysis of industry dynamics and marketing effectiveness. Both approaches combined ensure comprehensive and dependable analysis.

3.0 Data Analysis and Findings

Data was gathered using online questionnaires and surveys. A pilot survey with a small sample was used to determine major themes and narrow down research questions. From these findings, a detailed Google Form was created to collect varied and statistically sound responses. The form was then shared via WhatsApp and email to reach a wider and more representative group in the commercial real estate sector.

3.1 Online survey analysis

Data analysis is an important stage in market research, encompassing data collection, cleansing, and modeling to derive meaningful insights. To know market trends, industry experiences, and investor expectations in India's real estate market, a structured questionnaire was created through Google Forms. It was sent to prominent professionals, such as developers, founders, project managers, marketers, financial associates, engineers, and consultants. This survey gave valuable insights into consumers' expectations and market dynamics, which helped in gaining a complete understanding of commercial real estate trends.

3.2 Questions and its responses

3.2.1 Position held by the respondent in company

By job title, most are employees, 36%, followed by project managers, 24%. Founders and developers equally share 15% each, while the others occupy 10%. Such a variety helps provide valuable information for optimizing marketing strategies, product design, and communications directed to the significance of the various sectors in the industry.

3.2.2 Type of commercial property respondent involved with

The mixed-use is on an active-high level, while office properties are followed in activity. Retail and other types of properties are moderately active and warehouse and industrial properties are actively low again. The trends indicate a growing interest in mixed-use and office space, which suggests a general demand for investment.

3.2.3 Importance of location for planning marketing strategies

The rating for importance of location by respondent is high in between 4 and 5. And a clear pinnacle at 5. A clear-cut acknowledgement that location is basically allowed a colossal level of importance in marketing processes in this area.

3.2.4 Effective marketing channel

The performance of digital marketing channels for commercial property best favors Facebook and LinkedIn followed by real estate portals like Magicbricks and 99acres. Both print and trade shows worked well, while email marketing is being underutilized. It appears as though the combination of real estate portals and social media channels is now a part of promotional approaches, along with more conventional measures.

3.2.5 Use of social media for marketing

From the marketing of real estate, social media applies to nearly all fields of activity by weekly, 45 per cent use it; daily and monthly usage, each 17 per cent; the occasional user counts 19 per cent; and just 2 per cent never require it. Such largely depends on social media, reflecting a high commitment to online marketing as an active endeavor.

3.2.6 Effectiveness of incentives

The incentives such as rent concessions and favorable terms are successful in getting tenants or buyers in Pune's commercial real estate industry. Most respondents placed incentives as moderately effective to very effective. Few respondents only provided low effectiveness scores, justifying the argument that incentives are essential to marketing success.

3.2.7 Challenging aspect while marketing

The most significant marketing challenge of commercial properties in India is the attraction of the right audience, seconded by economic instability and upholding the occupancy rate. Though there are several challenges, these three are the most important to marketers.

3.2.8 Impacting factors for marketing

The location is to be the most significant driver of commercial property sales in India, topped by brand reputation and facilities. Relationship with the customer and service are of moderate significance, while lease duration and price are less important. This indicates that brand and property type are significant contributors to marketing success, with the financials.

3.2.9 Use of traditional marketing alongside digital method

Moderate bias to use a combination of old-style marketing (print and billboard advertisements) and web efforts. The most common rating on a scale of 1 to 5 by the majority of the people was 3 or 4, reflecting even balance between both techniques. Extremes on the two were almost never witnessed as firms tend towards using both methodologies in combinations rather than completely dependent on just one.

3.2.10 Outlook for commercial real estate in next 5 years from now

The “Optimistic,” is top, followed by a less weighty but real “Highly Optimistic” segment. A middle “Neutral,” with comparatively fewer at “Pessimistic.” The absence of a “Highly Pessimistic” section reflects confidence in the development of the market.

3.2.11 Importance of branding

Most respondents rated branding as very important, with a huge majority giving it a rating of either 4 or 5. Few respondents gave it a lower rating, further confirming that branding is an essential element in successful marketing for commercial space.

3.2.12 Content using to attract potential tenants or buyers

Most respondents already employ content marketing strategies like blogs, articles, and videos, while others indicate interest in their take-up as well. Others again have not employed systematic content marketing, indicating knowledge-action gap. This suggests growing recognition of the potential of content marketing, with an opportunity for further growth in take-up and strategic application.

3.2.13 Content for attracting audience

A balanced content generation plan among Indians, with balanced allocation between Short-Form Content (blogging, social media, newsletters), Long-Form Content (whitepapers, case studies), and Visual Content (videos, infographics, pictures). This balance indicates

awareness of different tastes in audiences, highlighting the need for a multi-form content strategy. There is no dominant content format indicating the need for a content mix balance.

3.2.14 Enhancing marketing effort

360-degree virtual tours hold the highest value as a video advertising medium amongst Indian respondents, followed by property introductions and short videos. Regular utilization of time-lapse construction videos suggests interest in monitoring development phases, and live video streaming is the lowest utilized medium. The emphasis on involving and informative content in commercial real estate marketing, with potential to grow usage of live streaming media.

3.2.15 Utilization of public relations strategies

The highest percentage of respondents in India use public relations to gain media coverage for their schemes. The lowest percentage is of the ones who are not sure or have a mixed approach. The lowest, is for the respondents who do not use public relations for media coverage. Overall, the data shows a high level of market inclination towards PR activities, highlighting the importance of positive media coverage in marketing commercial property.

3.2.16 What role does social media play in your overall marketing strategy for commercial building?

Social media is a key tool in commercial building marketing via enhanced brand recognition, property showcase, and client engagement. LinkedIn, Instagram, and Facebook enable companies to share high-quality content, capture leads, and establish trust through thought leadership and industry thought leadership. It also fosters community interaction via connection with tenants and prospects and providing pertinent market intelligence. Although negative publicity is a risk, proactive reputation management guarantees that trust is maintained. Social media is usually a powerful vehicle for brand awareness, lead generation, and customer interaction, and it is thus essential to successful commercial real estate marketing.

4.0 Key Findings and Limitations

4.1 Key findings

4.1.1 General findings

- The location and branding are the most impactful marketing success factors.
- Mixed-use and office properties have the highest market interest.
- Digital marketing, especially social media and real estate portals, is crucial, but traditional marketing still plays a role.
- Tenant incentives like rent rebates and flexible leasing terms are generally considered effective for attracting tenants.
- Content marketing and video marketing are broadly used, albeit with scope for increased strategic use.

4.1.2 Specific findings

- *Audience segmentation:* Employees (36%) and project managers (24%) are the two largest respondent segments, demonstrating strong representation among end-users and decision-makers.
- *Marketing strategy preference:* A combination of online and offline approaches is preferable, indicating that an integrated marketing strategy is the most effective.
- *Social media usage:* 45% of marketers use social media for marketing weekly, reflecting its increasing significance.
- *Marketing challenges:* The biggest challenges are to target the correct audience, economic uncertainty, and keeping occupancy levels.
- *Future expectations:* There is optimism in the market, with hardly any respondents having pessimistic expectations for the future within the next five years.

4.2 Limitations of the study

Surveys and interviews to market Indian commercial real estate, while useful, are beset by sampling bias, cultural context of response, and unfeasibility in obtaining detailed information. Interviews are also constrained by subjectivity, resource-hungry nature, and restricted generalizability. Both are constrained by integration issues of data, are susceptible to rapid market conditions.

5.0 Results and Conclusions

5.1 Results

The promotion of commercial real estate in India needs a multi-pronged approach that unites conventional and online strategies to effectively address the specific challenges of the given market. It demands sound knowledge-based appreciation of market forces, utilization of technology for branding and content generation, and focus towards customer engagement. Real estate developers and marketers need to embrace the evolving consumer tastes that have been expressed in demand for sustainable and tech-facilitated environments and present adaptive marketing strategies that can cope with the inevitable economic fluctuations and regulation limitations. By bringing these strategies together, a stronger position can be achieved in contacting potential tenants and investors and establishing an attractive market standing for their marketing activities.

5.2 Conclusion

The promotion of Indian commercial properties demands a multi-faceted approach that combines conventional and online methods to successfully address the specific challenges of the respective market. It demands well-founded knowledge-based understanding of market dynamics, application of technology for branding and content development, and focus towards

customer engagement. Real estate marketers and developers are required to embrace the evolving consumer tastes that have been seen in the demands for green and technology-enabled premises and emerge with adaptive marketing strategies that can handle the unavoidable economic cycles and regulatory limitations. By incorporating these strategies, a better ground can be achieved in connecting with prospective tenants and investors and establishing a good market reputation for their promotional activities.

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