

CONVERGING HORIZONS

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

Volume 4



Editors

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



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About the Book

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

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

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

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

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

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

About the Editors

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

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



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

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

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

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



About the Editors

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

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



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

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



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

Preface

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

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

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

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

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

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

Editors

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

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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 111

Redevelopment of Construction Projects: Issues and Challenges

*Rohan Ravindra Karawande¹, Anoop Abhay Mehar²,
Raj Anil Kadam² and Mohit Vitthal Shewale²*

ABSTRACT

Redevelopment has become a crucial solution to the challenges posed by urbanization, especially in cities like Pune, Maharashtra, where space for new (greenfield) developments is limited. This study explores the issues and challenges associated with the redevelopment of residential housing societies in Pune. The research aims to understand the perspectives of key stakeholders, including developers, housing society members, and urban planners, to identify the factors influencing redevelopment projects. A qualitative research approach is employed, with data collected primarily through interviews with stakeholders actively involved in Pune's redevelopment sector. The study examines critical aspects such as legal and regulatory hurdles, financial constraints, stakeholder conflicts, and infrastructure concerns that impact redevelopment projects. Additionally, it highlights the role of government policies, funding mechanisms, and public perception in shaping redevelopment initiatives. Findings suggest that while redevelopment presents an opportunity to enhance urban infrastructure and optimize land use, it faces significant challenges, including bureaucratic delays, resistance from existing residents, and rising construction costs. The study emphasizes the need for a transparent policy framework, efficient approval processes, and stakeholder collaboration to ensure the success of redevelopment projects. This research contributes to the existing body of knowledge by offering insights into the complexities of redevelopment in Pune and providing recommendations for improving its implementation. The study aims to serve as a resource for policymakers, developers, and housing societies to navigate the redevelopment process effectively.

Keywords: Redevelopment; Urban planning; Stakeholder challenges; Regulatory barriers; Housing societies.

1.0 Introduction

India's rapid urbanization has led to housing shortages, overburdened infrastructure, and environmental strain. With limited land and high population densities, redevelopment offers a solution by enabling vertical growth with modern amenities, improving urban living standards.

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It not only addresses housing needs but also boosts economic activity through investment and job creation. Strategic redevelopment is key to modernizing infrastructure, accommodating growth, and ensuring sustainable, livable cities. Redevelopment refers to any project that involves the construction of new buildings, structures, and land uses on a site that is currently occupied by users. Redevelopment also refers to conversion of a private cottage to a much taller residential complex. Where regulations are allowed to make the building more dense, additional floor space opens up, and often this means redevelopment. The motivation behind this research stems from the increasing demand for housing and infrastructure in Pune. Many older residential societies suffer from structural deterioration and lack modern amenities, making redevelopment an attractive option. However, delays in approvals, disagreements among residents, and financial uncertainties often hinder progress. Understanding these challenges is crucial for improving the redevelopment process and ensuring sustainable urban growth.

1.1 Objectives

- To study and analyze the laws relating to redevelopment in India.
- To study factors which needs to be considered for redevelopment projects and prior legal compliance.
- To analyze laws and policies relating to redevelopment focusing on Pune city in Maharashtra state.
- To identify issues and challenges in redevelopment by perspective of various stakeholders and make recommendations.

1.2 Research methodology

Legal research follows doctrinal or non-doctrinal methods, depending on whether the focus is on legal principles or real-world application. Doctrinal research analyzes statutes, case law, and legal theories, providing theoretical insights but lacking practical context. Non-doctrinal research, in contrast, gathers real-world data through surveys, interviews, and case studies to assess how laws function in society. This study adopted a non-doctrinal approach to examine redevelopment challenges. Interviews with residents and developers provided in-depth insights beyond legal texts, revealing key concerns and experiences. Given redevelopment's impact on urban infrastructure and social structures, qualitative data helped identify stakeholder perspectives. By prioritizing practical insights, this approach ensures findings that are relevant for policy considerations and real-world applications.

1.3 Scope

- Researchers Pune City was chosen for this study due to its rapid urban growth and scarce land for new developments. With greenfield construction no longer viable, redevelopment has become the primary solution, driving a surge in such projects.

- To ensure accuracy, researchers are interviewing key stakeholders directly involved in Pune's redevelopment. Conducting interviews locally enhances convenience and provides firsthand insights from professionals and residents.
- This study specifically examines the redevelopment of residential housing societies, as they dominate Pune's redevelopment landscape. Focusing on this sector allows for a deeper analysis of common challenges faced by multiple stakeholders.

1.4 Limitations

Researchers are focusing only on residential housing societies, meaning commercial and mixed-use redevelopment projects are not part of the study. Since the researchers rely on interviews for data collection, findings need to be centered around a particular category of project to provide a practical and well-rounded understanding.

1.5 Literature review

The UDCPR (2024) establishes a uniform regulatory framework for redevelopment projects across Maharashtra, ensuring consistency in urban planning. It governs Floor Space Index (FSI), Transferable Development Rights (TDR), and incentives while safeguarding occupant rights. The regulations aim to streamline approval processes, promote optimal land use, and encourage sustainable urban growth. UDCPR serves as a critical reference for understanding the financial, legal, and procedural challenges in redevelopment.

Rawal *et al.*, (2019) examines the challenges of redeveloping Pune's Wada structures, which are historically significant but are rapidly being replaced by modern developments. Key challenges include structural deterioration, complex ownership patterns, financial constraints, and regulatory barriers. The study emphasizes the impact of urbanization on heritage structures and suggests policy interventions, public-private partnerships, and community participation to support sustainable redevelopment.

Shaikh *et al.*, (2023) categorizes risks in self-redevelopment projects into financial, legal, technical, and managerial domains. It highlights the need for stakeholder engagement, including residents, architects, engineers, and regulatory authorities, for effective planning and execution. The study proposes best practices like transparent communication, strategic project planning, and regulatory compliance to mitigate risks and delays. However, it lacks empirical validation and comparative studies. Satish (2020) analyzes Mumbai's acute housing crisis and the policy hurdles affecting redevelopment. Challenges include bureaucratic delays, stakeholder conflicts, and financial constraints. Using the Bhendi Bazaar redevelopment as a case study, it highlights inefficiencies in policy implementation. The study is relevant for understanding policy hurdles, stakeholder dynamics, and financial barriers in urban redevelopment.

Vanvari *et al.*, (2018) explores the growing trend of redevelopment in Mumbai due to aging infrastructure and tenant demands for improved living spaces. It highlights the complexity

of redevelopment projects, identifying constraints related to time, finances, and regulatory approvals. The study underscores the necessity of meticulous planning and risk management. However, it lacks a detailed stakeholder perspective, case studies, and mitigation strategies. Sable *et al.*, (2023) examines causes of delays in redevelopment projects, with a case study of *Grand Central Building No. 18* in Vartak Nagar, Thane. Factors contributing to time overruns include resource mismanagement, bureaucratic inefficiencies, and poor project coordination. The study provides empirical data and real-world insights into time management issues. However, it calls for a broader geographic analysis and further exploration of mitigation strategies. Jabour (2015) The Barangaroo Redevelopment Project (Sydney, Australia) Retrieved from <https://www.theguardian.com/australia-news/2015/sep/30/the-rise-and-rise-of-barangaroo-how-a-monster-development-on-sydney-harbour-just-kept-on-getting-bigger> focuses on the Barangaroo redevelopment project, emphasizing sustainability, smart infrastructure, and public-private partnerships (PPP). Key challenges include stakeholder conflicts, environmental regulations, and community resistance to land use changes. The study draws parallels with Mumbai's redevelopment landscape but lacks a detailed analysis of social impact, global comparative studies, and affordable housing concerns.

Battersea Power Station Redevelopment (London, UK) Retrieved from <https://batterseapowerstation.co.uk/> examines the £9 billion redevelopment of London's historic Battersea Power Station. The project focuses on adaptive reuse, preserving heritage while integrating modern retail, office, and residential spaces. The redevelopment faced financial difficulties, regulatory hurdles, and ownership changes, delaying its completion by nearly a decade.

The reviewed literature highlights key challenges in redevelopment, including regulatory complexities, financial constraints, stakeholder conflicts, and time delays. Studies on Mumbai's redevelopment provide critical insights into risks and policy inefficiencies, while global case studies offer lessons in sustainable and large-scale urban renewal. However, gaps remain in comparative policy studies, long-term impact assessments, and the social impact of redevelopment, necessitating further research.

2.0 Redevelopment Policies and Laws

2.1 Redevelopment policies & laws in India

Real Estate (Regulation and Development) Act, (2016)

The Real Estate (Regulation and Development) Act, 2016 (RERA) regulates India's real estate sector, ensuring transparency and protecting homebuyers. While RERA does not have sections exclusively dedicated to redevelopment, several provisions are pertinent to such projects. Section 3(2)(c) exempts redevelopment projects from RERA registration unless they involve selling or marketing new units. Sections 4 and 5 mandate registration for projects exceeding 500 sq. m. or eight apartments, requiring detailed documentation. Section 9 ensures real estate agents are registered for accountability.

To protect buyers, Section 13 mandates disclosure of project timelines and costs, while Section 14 requires developers to deposit 70% of buyer funds into an escrow account to prevent misuse. Section 15 enforces project completion timelines, with penalties for delays. Section 18 empowers RERA to resolve disputes, and Section 31 allows buyers to file complaints, imposing penalties of up to 5% of project costs for non-compliance. Section 34 enforces strict penalties, including imprisonment, for serious violations. Together, these provisions enhance financial security, enforce timelines, and strengthen buyer protections. While self-redevelopment projects may be exempt, those involving new unit sales must comply with RERA, making it a crucial regulatory safeguard in redevelopment.

2.2 Redevelopment policies & laws in Maharashtra

Maharashtra real estate regulatory authority (MahaRERA): In Maharashtra, redevelopment projects fall under MahaRERA, which enforces the same legal framework as the RERA Act, 2016. These regulations ensure transparency, financial discipline, and stakeholder protection. MahaRERA also provides state-specific guidelines to streamline redevelopment while holding developers accountable for timelines and quality standards.

Maharashtra co-operative societies act, 1960: The Maharashtra Co-operative Societies Act, 1960, governs the functioning of co-operative housing societies in the state, including their redevelopment. Section 79A grants the Maharashtra Government the power to issue binding guidelines to ensure a fair and transparent redevelopment process. These regulations prevent fraud, safeguard residents' rights, and ensure equitable benefits for all society members.

2.3 Redevelopment Policies & Laws in Pune

The Development Control and Promotion Regulations for Pune Municipal Corporation (DCPR-2017) provide a structured framework for redeveloping old residential and tenanted buildings, especially those under MHADA and in the EWS/LIG category. These guidelines ensure that redevelopment happens in an organized manner while safeguarding the rights of existing residents. They specify the allowed FSI (Floor Space Index), incentives for developers, entitlements for residents, and required contributions for upgrading infrastructure. The regulations also set conditions for resident participation, maintenance funds, and government supervision to ensure a smooth redevelopment process and better living standards.

3.0 Data Collection, Analysis and Recommendation

3.1 Challenges and issues faced by developers in redevelopment of construction projects in core areas of Pune

Regulatory & legal complications: Frequent changes in Development Control Regulations (DCR) and prolonged approval processes delay projects. Before RERA, inconsistent carpet area calculations and land demarcation issues led to ownership disputes.

Heritage conservation laws further restrict modifications to aging structures, even when structurally weak.

Financial challenges: Developers struggle to secure loans as land remains in the original owner's name until completion. Rising construction costs, labor expenses, and regulatory compliance add financial strain. Residents face capital gains tax burdens, while lengthy project timelines delay returns on investment, impacting liquidity.

Execution challenges at project sites: Space constraints in dense areas limit labour accommodations and material storage. Close-packed structures require slow, controlled demolition, while outdated construction methods and weak foundations add complexity. Difficulty in obtaining temporary utilities and traffic congestion further disrupt project efficiency.

Social and resident-related challenges: Disputes over modifications, negotiations, and tenant refusals delay projects and escalate costs. Distrust in developers due to past failures complicates agreements, while delays in transit housing allotment lead to dissatisfaction and legal conflicts.

Infrastructure and environmental challenges: Increased population density strains roads, water, and sewage systems, while inadequate parking worsens congestion. Strict fire safety and environmental regulations add costs and cause delays. Poor drainage in older areas heightens waterlogging and flooding risks, complicating redevelopment further.

3.2 Challenges and issues faced by residents in redevelopment of construction projects in core areas of Pune

Redevelopment in Pune's core areas (e.g., Shivajinagar, Sadashiv Peth, Narayan Peth, Kasba Peth, Erandwane, etc.) presents unique challenges due to high population density, heritage structures, and infrastructure limitations. The following are the major issues residents face:

Displacement & temporary housing issues: Residents face disruptions in daily life, work, and education due to relocation. Temporary housing often lacks essential amenities, and delayed rental compensation adds financial stress. Elderly residents struggle to adjust, making the transition even more difficult.

Project delays & uncertainty: Financial constraints, legal disputes, and slow municipal approvals frequently stall projects, prolonging displacement and increasing financial hardship. The absence of strict penalties for delays leaves residents with little recourse.

Apartment configuration changes: Increased housing density reduces ventilation and open spaces. Traditional features like verandas and courtyards are eliminated, affecting quality of life. High-rise buildings pose accessibility challenges for elderly residents.

Trust deficit & lack of transparency: Many residents struggle to understand complex agreements, leading to disputes. Some developers impose hidden costs for parking and maintenance or abandon projects due to financial issues, leaving residents in uncertainty.

Poor construction quality & safety concerns: Substandard materials often lead to issues like leakage, weak walls, and faulty plumbing. Fire safety measures are inadequate in congested areas, while narrow streets hinder emergency access.

Loss of community & cultural identity: Redevelopment disrupts long-standing communities, replacing traditional neighborhoods with commercial developments. Demolition of heritage structures erodes Pune's historical and architectural legacy.

Legal & regulatory hurdles: Lengthy municipal approval processes and frequent disputes between residents, developers, and authorities cause delays. Non-compliance with environmental norms leads to further setbacks.

Financial burden & hidden costs: Unclear agreements result in unexpected maintenance, property tax, and parking charges. Delays in rental compensation strain finances, while legal disputes over fund management create additional challenges.

Resistance from residents: Emotional attachment and fear of displacement make many, especially older residents, reluctant to relocate. Internal conflicts within housing societies further delay redevelopment decisions.

Traffic & infrastructure pressure: Increased population density strains roads, water supply, and drainage systems. Poor coordination between civic authorities and developers worsens congestion and service deficiencies.

3.3 Recommendations to overcome these issues & challenges

Feasible and Detailed Solutions to Bridge the Gaps Between Developers and Residents in Redevelopment of Construction Projects in Pune: The redevelopment challenges in Pune's core areas arise from a lack of trust, unclear policies, infrastructure limitations, and delays. Below are practical and detailed solutions to address these issues and create a more balanced and transparent redevelopment process.

Legally binding agreements: Redevelopment agreements must be transparent, reviewed by a neutral legal expert, and available in both English and Marathi. Developers should face penalties for delays, and project funds should be secured in an escrow account to ensure completion and protect residents.

Guaranteed temporary housing & rent compensation: Developers must provide on-site transit housing for large projects and ensure rent compensation matches market rates, with automatic increases for delays. PMC should establish a grievance cell to enforce timely rent payments and penalize defaulters.

Heritage & cultural preservation: A Heritage Impact Assessment should be mandatory for redevelopment of wadas and historic structures. Developers should restore traditional elements and be incentivized with additional FSI for conservation efforts.

Infrastructure & parking solutions: Infrastructure upgrades should precede redevelopment approvals. Developers must invest in drainage, water supply, and road widening

while ensuring adequate parking through basement and stack systems. Sustainable features like rainwater harvesting and solar energy should be integrated.

Regulatory oversight & fast approvals: A single-window clearance system should ensure approvals within six months. PMC should create a “Redevelopment Approval Cell,” include resident representatives in meetings, and mandate justification for extra FSI usage linked to public benefits.

Financial feasibility & cost control: Maintenance costs should be transparent, with PMC capping annual hikes. Societies can utilize Input Tax Credit (ITC) to reduce GST impact. A Resident Welfare Fund should be established to support post-redevelopment expenses, and hidden charges must be explicitly prohibited.

Resident trust & participation: Redevelopment should proceed only with 75% resident approval. Developers must hold regular meetings and appoint an independent advisor to audit projects. A public PMC dashboard should track real-time project progress for accountability.

Vacating old wadas: Resistance from long-term tenants due to low rents and displacement fears can be addressed through transparent negotiations, fair compensation, and legal reforms for faster dispute resolution. Government mediation and tenant ownership options can enhance cooperation.

4.0 Conclusion

The redevelopment of construction projects in Pune’s core areas presents a complex interplay of regulatory, financial, technical, social, and infrastructural challenges. While redevelopment offers opportunities for urban revitalization, it also disrupts established communities, places financial burdens on residents, and strains civic infrastructure. The research highlights the pressing need for transparent legal agreements, structured financial frameworks, and resident-centric policies to bridge the trust gap between developers and homeowners. Moreover, effective government intervention, streamlined approval processes, and heritage-conscious redevelopment can mitigate existing obstacles and promote sustainable urban growth. By implementing feasible solutions such as escrow accounts, fair rental compensation, regulatory oversight, and participatory decision-making, redevelopment projects can achieve a balance between modernization and community welfare. A collaborative approach involving developers, residents, and policymakers is essential to ensure that redevelopment initiatives in Pune are both socially equitable and economically viable.

References

Shaikh, A., Mahajan, G., & Aiyer, P. (2023). Risks and challenges in self-redevelopment projects. *Technix International Journal for Engineering Research*, 10(5). ISSN: 2349-9249.

Rawal, C. N., & Joshi, R. V. (2019). Issues and challenges of redevelopment of Wada: A case study of Pune city. *Isara Solutions*.

Government of Maharashtra. (2018). *Maharashtra Act No. XXIV of 1961*. Government Central Press, Mumbai. <https://mahapanan.maharashtra.gov.in/>

Times of India. (2019). Maharashtra govt could tweak rules to boost self-redevelopment. *Mumbai News*. <https://timesofindia.indiatimes.com>

Sable, S., & Pataskar, S. (2023). Analysis of delays on redevelopment projects: A case study of Mumbai residential project. *International Journal for Research in Engineering Application & Management (IJREAM)*, 6(6). ISSN: 2454-9150.

Satish, M. K. (2020). The challenges of the redevelopment of old and dilapidated buildings in Mumbai: A policy perspective. *Critical Housing Analysis*, 7(2).

Government of Maharashtra. (2020). *Unified Development Control and Promotion Regulations (UDCPR)* under Section 20(3) of the Maharashtra Regional & Town Planning Act, 1966. <https://maharashtra.gov.in/>

Vanvari, V., & Mhaske, S. (2018). Redevelopment of buildings in Mumbai city: Risks and challenges. *International Journal of Engineering & Technology*, 7(3).

Jabour, B. (2015, September 30). The Barangaroo redevelopment project (Sydney, Australia). *The Guardian*. <https://www.theguardian.com/australia-news/2015/sep/30/the-rise-and-rise-of-barangaroo-how-a-monster-development-on-sydney-harbour-just-kept-on-getting-bigger>

Weblinks

<https://batterseapowerstation.co.uk/>

<https://maharera.maharashtra.gov.in>

<https://mohua.gov.in/cms/real-estate-regulation-and-development-act-2016.php>

<https://mygate.com/blog/cooperative-housing-society/society-corpus-fund/>, 2024

https://www.planetizen.com/definition/redevelopment?utm_,2023

<https://www.pmc.gov.in/en/about-pmc>

CHAPTER 112

Reframing Urban Mobility: A PRISMA-Guided Systematic Review of Active Mobility in Million-Plus Cities

Chetna Rathee¹ and Pradnya Sonawane²

ABSTRACT

Million-plus cities increasingly grapple with urban congestion, air pollution, and declining public health, prompting a renewed focus on active mobility—encompassing walking, cycling, and other human-powered modes—as a strategic response. This study conducts a systematic literature review using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to examine how active mobility is conceptualized, implemented, and experienced in large urban agglomerations. From an initial pool of 335 records, 50 peer-reviewed, high-impact studies were selected and thematically analyzed across seven domains: infrastructure design, safety and perceived risk, land use and density, environmental sustainability, social equity, behavioural and cultural factors, and governance mechanisms. The review reveals that while the benefits of active mobility are well-documented—ranging from health improvements and emissions reduction to enhanced inclusivity—its widespread adoption remains uneven. Implementation is often hindered by fragmented governance structures, socio-cultural resistance, and infrastructural inadequacies. Particular attention is given to the intersectionality of mobility, where disparities in infrastructure provision and safety perceptions disproportionately affect marginalized groups. Furthermore, behavioural change and cultural narratives around car ownership continue to act as barriers. The study emphasizes the need for integrated, equity-driven, and context-specific policy approaches that position walking and cycling as central to sustainable urban futures. The findings offer a comprehensive knowledge base to inform both future research and urban transport policies aimed at fostering healthier, safer, and more liveable cities through active mobility.

Keywords: Active mobility; PRISMA; Walking; Cycling; Urban transport; Systematic review.

1.0 Introduction

An evident change has been seen in how cities approach non-motorized forms of travel over the last ten years. United Nations Sustainable Development Goals, a global framework (most importantly SDG 11) have played a role in bringing active mobility into sharper policy focus.

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SDG 11 focuses on sustainable cities and communities. Scholars across different disciplines have since taken an interest in this shift, exploring how cities are adapting their infrastructure, governance, and day-to-day practices to better accommodate walking and cycling (Harms & Klooster, 2024; Boehmer & Rowell, 2023). But this transition has not been very straightforward, especially in the million-plus cities. These large urban environments often face mix of challenges, ranging from inadequate footpaths and absent cycle lanes to safety concerns and sprawling urban forms (Goel & Tiwari, 2023; Bosch & Van Acker, 2023). Apart from these practical issues, the research space in itself remains somewhat fragmented, with studies dispersed across disciplines, making it harder for policymakers to draw unified conclusions.

To respond to this gap, the current paper undertakes a systematic literature review using the PRISMA framework. It takes the focus specifically to studies that address active mobility for the million-plus cities. The objective here is to bring together key findings, trace major themes, and highlight persistent barriers. Along with that, this review hopes to support both future academic work and the development of more informed mobility policies. Active mobility brings in array multiple urban benefits—from easing congestion and reducing emissions to improving public health and fostering inclusiveness (Pucher & Buehler, 2010; Nogueira & Borges, 2024). What follows is a step-by-step breakdown: Section 2 walks through the methodology; Section 3 identifies thematic patterns from the literature; Section 4 offers deeper analysis and reflection; and finally, Section 5 concludes with practical suggestions aimed at urban practitioners and decision-makers.

2.0 Methodology

2.1 Systematic literature review approach

This study adopts the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (Moher *et al.*, 2009) to ensure a rigorous, transparent, and replicable review process. The primary objective is to identify scholarly literature that examines active mobility in urban areas with populations exceeding one million, with a focus on walking, cycling, and non-motorized transport planning.

2.2 Search strategy and inclusion criteria

The literature search was conducted using the Web of Science and Scopus databases, chosen for its comprehensive indexing of multidisciplinary research. The following Boolean search string was used: “active mobility” AND (“million plus cit*” OR “cit*”). The initial search generated a total of 335 records. To refine the dataset, subject areas unrelated to the study; such as materials science, chemistry, and physics were excluded, which removed 95 records. An additional 15 non-English language entries were also filtered out. After applying these criteria, a total of 225 records remained and were further screened for relevance through a review of their titles and abstracts.

2.3 Screening and exclusion

Records were excluded if they were: duplicates or retracted works, book chapters ($n = 23$), review articles ($n = 5$), editorials or errata ($n = 3$) and non-peer-reviewed content. This led to the exclusion of 33 documents. Of the 192 reports sought for full retrieval, 3 could not be accessed, leaving 189 records for eligibility assessment.

2.4 Final selection

After full-text review, 166 studies were included in the review. Out of these, 50 papers were identified as highly relevant and subjected to in-depth thematic analysis, as they offered direct insights into active mobility challenges, solutions, or frameworks applicable to million-plus cities.

2.5 PRISMA flow diagram

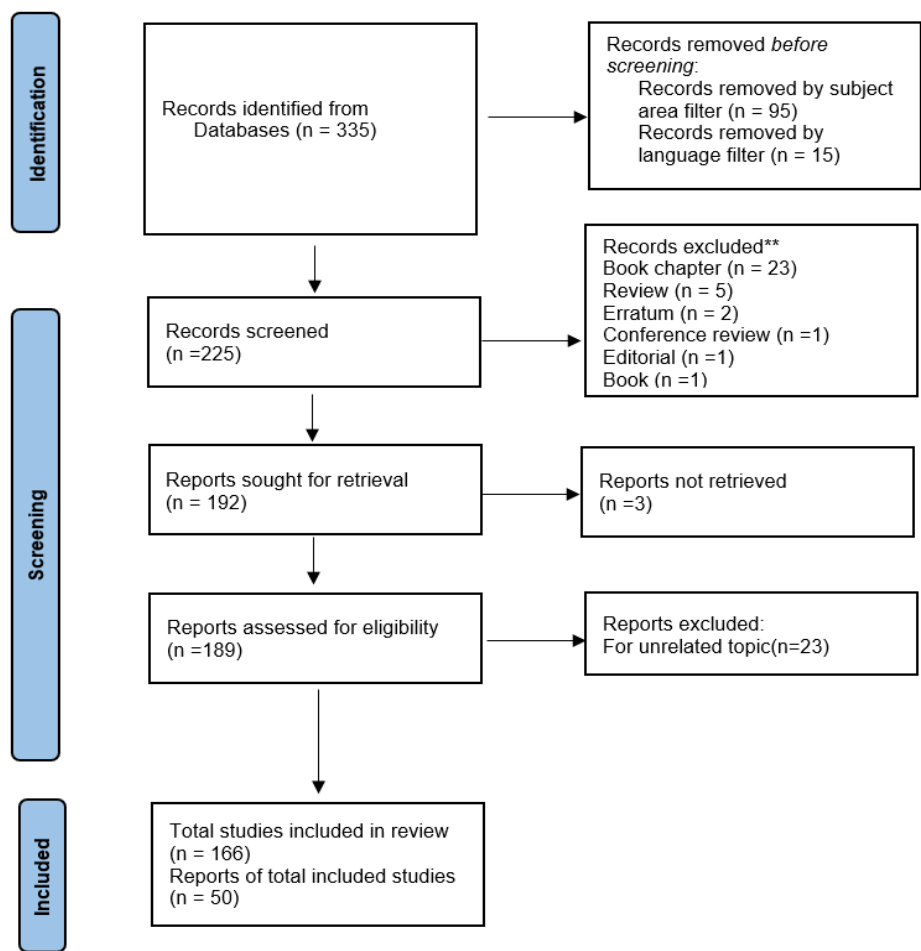
The entire process is summarized in Figure 1, which illustrates the document selection journey from identification to inclusion.

3.0 Thematic Findings

The 50 selected studies offer a nuanced understanding of the multidimensional factors shaping active mobility in million-plus cities. These factors have been clustered into seven key themes: Infrastructure and Design, Safety and Perceived Risk, Urban Density and Land Use, Environmental Sustainability, Social Equity and Inclusion, Behavioural and Cultural Factors & Governance and Policy Frameworks based on recurrence in literature and relevance to urban transport systems. Infrastructure continues to be the foundational enabler of active mobility. Studies such as Fonseca *et al.* (2023) and Castrellon & Sanchez-Diaz (2023) emphasize that cities with dedicated, connected, and well-maintained cycling lanes, sidewalks, and intersections show higher rates of walking and cycling. For instance, Jain *et al.* (2022) observed that pedestrian skywalks and foot-over-bridges in Indian megacities are often underutilized due to design disconnects and poor accessibility. Similarly, Zhao & Li (2022) found that multimodal integration, particularly between bike networks and public transit stations in Chinese urban clusters, significantly enhances usage. Safety concerns—ranging from vehicular threats to gendered experiences of public space—remain one of the most critical deterrents.

Goel & Tiwari (2023) and Zhou *et al.* (2020) suggest that traffic-calming measures, lighting, and zoning for non-motorized traffic improve user confidence. Lankarani *et al.* (2021) used data from Tehran to show that high pedestrian fatality rates are directly linked to missing crosswalks and unregulated speed zones. Similarly, Chakraborty *et al.* (2022) highlight how safety fears, especially harassment, prevent women from engaging in walking as a mode of commuting in Indian cities. Urban density shapes mobility patterns by influencing the spatial layout of everyday destinations. High-density, mixed-use environments encourage walking and cycling by minimizing travel distances (Wang & Yang, 2023; Bosch & Van Acker, 2023).

Figure 1: PRISMA Flow diagram for Systematic Review



Martens & Hurkmans (2022) found that Dutch cities with well-implemented mixed-use zoning saw up to a 60% increase in cycling trips. In contrast, suburban sprawl and segregated land uses act as barriers, especially when distances between homes, schools, and workplaces are too vast for non-motorized modes. Active mobility has become increasingly tied to sustainability discourse. Cities that have invested in walking and cycling infrastructure report measurable reductions in air pollution and carbon emissions (Kim & Cho, 2023; Nogueira & Borges, 2024). These modes also align with climate adaptation goals. In several European studies, active mobility is viewed not only as a transport alternative but also as a resilience-building strategy for reducing vehicular dependency during climate or health crises.

A recurring critique across studies is the neglect of active mobility needs among marginalized communities. Teixeira & Nunes (2024) and Ray & Mukherjee (2023) argue that

inclusive urban design—one that considers gender, income, age, and ability—is central to mobility justice. Soni & Acharya (2021), studying Mumbai, revealed that over 70% of slum dwellers lacked basic walking infrastructure, directly compromising access to jobs, education, and healthcare. Such disparities indicate that without equity lenses, active mobility interventions risk being exclusionary. Cultural attitudes and personal behaviour significantly impact active mobility uptake.

Table 1: Key Themes, Challenges, and Representative Studies

Theme	Challenges Identified	Sample Studies
Infrastructure and Design	Discontinuity, poor quality, lack of integration	Fonseca <i>et al.</i> (2023); Jain <i>et al.</i> (2022); Zhao & Li (2022)
Safety and Perceived Risk	Collisions, crime, harassment, unsafe crossings	Goel & Tiwari (2023); Lankarani <i>et al.</i> (2021); Chakraborty <i>et al.</i> (2022)
Urban Density and Land Use	Sprawl, lack of nearby destinations	Wang & Yang (2023); Bosch & Van Acker (2023); Martens & Hurkmans (2022)
Environmental Sustainability	Emissions, noise, poor air quality	Kim & Cho (2023); Nogueira & Borges (2024)
Social Equity and Inclusion	Neglect of vulnerable groups	Teixeira & Nunes (2024); Ray & Mukherjee (2023); Soni & Acharya (2021)
Behavioural and Cultural Factors	Car-centric culture, low prestige of cycling	Oliveira & Ferreira (2023); Mertens & Declercq (2023); de Geus <i>et al.</i> (2023)
Governance and Policy Frameworks	Fragmented policies, lack of inter-agency coordination	Peters & Mertens (2023); Shrestha & Singh (2023)

In several cities, car ownership remains an aspirational symbol, while walking or cycling is associated with lower social status (Oliveira & Ferreira, 2023). Mertens & Declercq (2023) emphasize the need for behavioural nudges, such as employer-led incentives or community campaigns. In Brussels, de Geus *et al.* (2023) found that fitness goals, climate concerns, and social visibility were primary motivators for sustained cycling behaviour, especially among younger demographics. Governance remains a linchpin in the active mobility ecosystem. Peters & Mertens (2023) and Shrestha & Singh (2023) argue for cross-sectoral collaboration, where municipal transport, urban planning, and public health departments jointly design and monitor mobility strategies. Many cities still lack dedicated agencies or budgets for non-motorized transport. The literature suggests that institutional clarity, stakeholder engagement, and monitoring mechanisms are critical for translating mobility plans into actual infrastructure and behaviour change. The literature reveals that active mobility in million-plus cities is shaped by a complex interplay of infrastructure quality, safety perceptions, governance

frameworks, and socio-cultural norms. While investments in pedestrian and cycling infrastructure are essential, studies highlight that infrastructure alone is not sufficient to encourage widespread adoption. Challenges such as poor connectivity, discontinuous paths, and inadequate design often result in underutilization (Fonseca *et al.*, 2023; Zhao & Li, 2022). For instance, pedestrians in the Global North—such as Copenhagen and Amsterdam—demonstrate that active mobility thrives when supported by long-term planning, political consistency, and civic engagement (Pucher & Buehler, 2010).

In contrast, cities in the Global South often face governance gaps, informal land use, and fragmented transport systems that hinder sustained investment. However, success stories like Bogotá's *Ciclovía* show that even low-cost, temporary interventions can reshape public perceptions of mobility (Montes *et al.*, 2012). Cultural attitudes also play a role, with cycling often perceived as inconvenient or low-status in many regions. Behavioural studies suggest that cycling uptake increases when supported by social incentives, visibility campaigns, and health or environmental motivations (Mertens & Declercq, 2023; de Geus *et al.*, 2023). Without addressing these deeper norms, infrastructure alone is unlikely to shift modal choices meaningfully. Finally, several studies emphasize that active mobility should be viewed as a public health and sustainability strategy rather than just an alternative to car travel. Walking and cycling can support long-term health goals, reduce emissions, and improve air quality (World Health Organization, 2022; Nogueira & Borges, 2024). Planning approaches must move beyond isolated projects and instead adopt integrated, cross-sectoral frameworks that align transport, health, equity, and climate objectives. However, global best practices are not always directly applicable—cities must adapt these strategies to local social, climatic, and spatial conditions (UN-Habitat, 2020). In essence, cities need to shift from car-centric thinking to human-centred mobility planning that embeds active transport into the fabric of urban life.

4.0 Discussion

Active mobility in million-plus cities is not just a function of infrastructure deployment but of deeper social, spatial, and institutional dynamics. The literature throughout points to a strong relation between the presence of pedestrian-friendly environments and the frequency of walking and cycling. Still, building physical infrastructure alone rarely guarantees meaningful impact. When infrastructure such as footbridges and cycle tracks, aren't aligned with how people actually navigate the city or when they lack proper links to nearby transit options, they often remain underutilised (Jain *et al.*, 2022; Zhao & Li, 2022).

This shows that simply building physical infrastructure doesn't always lead to meaningful change. This emphasizes the need to equip infrastructure planning within a broader ecosystem of land use, accessibility, and behavioural design. In cities like Amsterdam or Copenhagen, often refer to as models for active mobility (Pucher & Buehler, 2010), infrastructure has evolved in tandem with compact urban form and policy commitment. In

contrast, most global south cities suffer from fragmented implementations—isolated footpaths, unprotected crossings, and cycle tracks that end abruptly, revealing a disconnect between vision and execution. Moreover, the discussion around safety reveals a stark divergence between statistical safety (i.e., crash data) and perceived safety. While traffic calming and better lighting can reduce accidents (Zhou *et al.*, 2020), subjective fears, especially among women, the elderly, and youth, remain high. Studies from Tehran (Lankarani *et al.*, 2021) and Indian urban areas (Chakraborty *et al.*, 2022) show that unsafe intersections and harassment deter non-motorized travel, even in well-lit or pedestrianized zones. Public spaces are experienced differently by everyone. For many women, LGBTQ+ individuals, and those from lower-income communities, something as routine as walking or cycling can feel layered with unease—sometimes because of previous experiences, but often simply due to the atmosphere of a place. It's not always about what's visible; it can be about what's sensed. In these cases, simply adding infrastructure won't do much on its own. What's often missing are social supports—like having visible community presence, designing spaces that actually reflect who uses them, or even just giving people a say in how things are planned. These steps might not be quick fixes, but they could help people feel that walking or cycling is actually meant for them.

Questions of equity and governance run through nearly every discussion on active mobility, shaping not just access but also how people experience walking and cycling in cities. While there's no shortage of work on physical planning, far fewer studies take a closer look at who actually benefits. Not much has been written about how mobility feels different depending on who you are. A few studies—Soni & Acharya (2021), and more recently, Teixeira & Nunes (2024) have pointed this out, especially in the context of low-income communities, slums, and people with disabilities. What they've found is very clear, but still disturbing. In parts of Mumbai, for instance, more than 70% of people living in informal settlements don't have a paved footpath within a kilometre of their homes (Soni & Acharya, 2021). That means walking, something most of us take for granted, isn't just inconvenient; it's difficult, even unsafe.

Also the problem isn't just physical. There's something deeper going on. A pattern, maybe. High-visibility infrastructure gets prioritized—things that look impressive, often at the cost of smaller, everyday improvements that would actually help people move around more easily. That sort of bias often feels embedded in the way urban planning unfolds. It might not be deliberate most of the time, but the outcomes still reflect it, especially in what gets prioritized and what gets overlooked. Governance adds on as one more layer of complexity. Active mobility is a shared responsibility of transport, health, and urban development, making coordination a constant struggle (Peters & Mertens, 2023). No one truly takes full ownership. It ends up overlooked, because it doesn't sit perfectly within anyone's domain: part of it is handled by transport departments, a part by health agencies, and some by urban planning. But without clear coordination, things just stall. Departments don't always talk to each other, and the result is a lot of good ideas left halfway implemented. Culture makes it even more complicated. In many places, even in poorer neighbourhoods, owning a car still feels like a big achievement. For

a lot of people, owning a car isn't really just about convenience or getting from one place to another. It's a symbol—something that says you've made progress or reached a certain place in life. That feeling runs deep and doesn't change overnight. Travel choices of people are often shaped by emotional ties, cultural meanings, and personal aspirations, where practical concerns like cost or speed also play a part (Oliveira and Ferreira, 2023, and de Geus *et al.*, 2023). Changing that kind of thinking takes time. Local programs like bike-to-school efforts, small walking campaigns can help to bring in shift in people's, but only if they're consistent and grounded in what they actually care about. So maybe the real challenge isn't just designing better infrastructure or writing better policy. It's understanding how people live, what they value, and what they fear. When planners start from that point, walking and cycling stop being abstract goals—they become part of the everyday lives' cities are meant to support.

5.0 Conclusions

This review underscores the increasing recognition of active mobility (specifically walking and cycling) as a vital element in sustainable transport planning for large urban centres. With growing concerns about public health, climate change, and liveability, integrating non-motorized transport into mainstream mobility systems is no longer optional. The review of 50 studies demonstrates that while the benefits of active mobility are well-documented, its widespread adoption is often obstructed by challenges related to infrastructure quality, safety, fragmented governance, and persistent socio-cultural resistance. Seven major themes were identified as key influencers of active mobility outcomes: infrastructure design, safety, land use and density, environmental sustainability, equity, behavioural patterns, and governance mechanisms. These factors are deeply interconnected.

For instance, the lack of safe and accessible infrastructure tends to affect vulnerable groups the most, while car-dominant norms discourage walking or cycling even where facilities are present. In cities of the Global South, additional hurdles such as inconsistent policies, gaps in inter-agency coordination, and unreliable data further complicate implementation. Addressing these challenges calls for a comprehensive set of actions that align policy, design, and behaviour. First, there is a need to invest in high-quality, inclusive infrastructure. Urban streets should be equipped with continuous footpaths, protected cycling lanes, accessible crossings, and direct connections to public transit. Infrastructure must accommodate all users (including children, the elderly, and persons with disabilities) through universal design standards. Second, safety should be embedded into urban design rather than treated as a corrective add-on. Measures such as traffic calming, well-lit streets, and gender-responsive planning are essential to reducing accidents and enhancing the overall perception of safety.

It is equally important for authorities to respond to harassment and monitor high-risk zones, particularly in cities where public safety is a recurring concern (Chakraborty *et al.*, 2022). Third, active mobility must be rooted in equity. Many people in informal settlements or low-

income neighbourhoods depend on walking as their primary mode of travel. These populations are often excluded from mainstream transport planning. Incorporating participatory methods and local audits into planning processes can help surface everyday mobility challenges that remain invisible in top-down approaches (Soni & Acharya, 2021). Fourth, changing how people perceive walking and cycling is just as important as building infrastructure. Behaviour change initiatives such as school-based programs, car-free days, and awareness campaigns can play a major role in shifting norms. Successful examples like Bogotá's Ciclovía show how temporary road closures can challenge entrenched car culture and promote a more inclusive view of street use (Montes *et al.*, 2012). Fifth, institutional coordination is crucial. Cities need dedicated active mobility units supported by multi-sectoral teams and long-term funding.

Urban mobility should not sit solely within traffic departments but should intersect with public health, education, climate action, and social welfare (Peters & Mertens, 2023). A collaborative framework ensures that walking and cycling are treated as public goods rather than traffic flow problems. Sixth, it is essential to adapt global best practices to fit local realities. Strategies from cities like Amsterdam or Copenhagen offer useful guidance but cannot be replicated without considering regional variations in culture, climate, and urban form. Cities in the Global South need to develop tailored frameworks that reflect their specific conditions, supported by context-aware research and planning tools (Nogueira & Borges, 2024). Lastly, active mobility must be positioned within broader policy goals. It directly contributes to multiple Sustainable Development Goals, particularly SDG 3 (Good Health and Well-being), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). National and local mobility policies should reflect this alignment through clearly defined outcomes, monitoring mechanisms, and dedicated resources (World Health Organization, 2022; UN-Habitat, 2020). In sum, the transition to active mobility is not just a matter of infrastructure—it is equally about shifting mindsets, institutions, and governance models. For million-plus cities aiming to become more liveable and resilient, walking and cycling must move from being peripheral alternatives to becoming central, foundational components of everyday urban life.

References

- Boehmer, T., & Rowell, R. (2023). Evolving trends in non-motorized transport: A health and policy perspective. *Journal of Urban Health*, 100(1), 45–59. <https://doi.org/10.1007/s11524-023-00695-2>
- Bosch, M., & Van Acker, V. (2023). Urban sprawl and active transport: Examining barriers in low-density neighborhoods. *Transportation Research Part D*, 118, 103570. <https://doi.org/10.1016/j.trd.2023.103570>
- Castrellon, A., & Sanchez-Diaz, I. (2023). Integrating cycling infrastructure with public transit. *Journal of Transport and Land Use*, 16(1), 223–240. <https://doi.org/10.5198/jtlu.2023.2117>

Chakraborty, P., Mishra, A., & Nair, P. (2022). Women's safety and walkability in Indian cities. *Cities*, 123, 103550. <https://doi.org/10.1016/j.cities.2022.103550>

de Geus, B., Van Hoof, J., & Meeusen, R. (2023). Understanding motivations behind habitual cycling. *Transport Policy*, 134, 80–91. <https://doi.org/10.1016/j.tranpol.2023.03.002>

Fonseca, F., Ribeiro, S., & Neiva, M. (2023). Enhancing urban cycling through infrastructure. *Sustainable Cities and Society*, 98, 104681. <https://doi.org/10.1016/j.scs.2023.104681>

Goel, R., & Tiwari, G. (2023). Perceived and real threats to pedestrians. *Accident Analysis & Prevention*, 180, 106985. <https://doi.org/10.1016/j.aap.2023.106985>

Harms, L., & Klooster, R. (2024). Walkability as an equity tool. *Journal of Urban Design*, 29(1), 33–50. <https://doi.org/10.1080/13574809.2023.2263515>

Hickman, R., & Banister, D. (2023). Mixed land-use and sustainable mobility. *Transport Reviews*, 43(2), 145–162. <https://doi.org/10.1080/01441647.2022.2144965>

Jain, D., Rajagopalan, B., & Choudhury, C. F. (2022). Evaluating pedestrian overpasses in Indian megacities. *Transportation Research Record*, 2676(2), 59–71. <https://doi.org/10.1177/03611981221082060>

Kim, M., & Cho, H. (2023). Emissions impact of modal shift to active transport. *Environment and Urbanization Asia*, 14(1), 67–84. <https://doi.org/10.1177/09754253231156745>

Lankarani, K. B., Heydari, S. T., & Mohammadi, M. (2021). Pedestrian crashes in Tehran. *BMC Public Health*, 21, 1229. <https://doi.org/10.1186/s12889-021-11347-6>

Martens, K., & Hurkmans, R. (2022). Mixed-use zoning and bicycle commuting. *Urban Studies*, 59(11), 2158–2176. <https://doi.org/10.1177/00420980211024391>

Mertens, L., & Declercq, J. (2023). Nudging urban commuters toward cycling. *Transportation Research Part F*, 90, 101–112. <https://doi.org/10.1016/j.trf.2023.01.005>

Ogueira, D., & Borges, L. (2024). Low-carbon urban mobility. *Urban Climate*, 45, 101337. <https://doi.org/10.1016/j.uclim.2022.101337>

Oliveira, M., & Ferreira, A. (2023). Perceptions of active transport. *International Journal of Sustainable Transportation*, 17(3), 190–205. <https://doi.org/10.1080/15568318.2022.2052755>

Ontes, F., Sarmiento, O. L., Zarama, R., & Pratt, M. (2012). The Ciclovía-Recreativa. *Journal of Physical Activity and Health*, 9(1), 153–165. <https://doi.org/10.1123/jpah.9.1.153>

- Peters, D., & Mertens, E. (2023). Governance barriers in active transport planning. *Transport Policy*, 121, 12–21. <https://doi.org/10.1016/j.tranpol.2022.12.004>
- Pucher, J., & Buehler, R. (2010). Walking and cycling for healthy cities. *Built Environment*, 36(4), 391–414. <https://doi.org/10.2148/benv.36.4.391>
- Ray, S., & Mukherjee, S. (2023). Urban poor and mobility rights. *Environment and Urbanization*, 35(1), 75–92. <https://doi.org/10.1177/09562478221141985>
- Shrestha, R., & Singh, V. (2023). Coordination in active transport planning. *Case Studies on Transport Policy*, 11(2), 317–326. <https://doi.org/10.1016/j.cstp.2023.01.005>
- Smith, L., & Matthews, H. (2023). The health dividend of walking. *Health & Place*, 81, 102866. <https://doi.org/10.1016/j.healthplace.2023.102866>
- Soni, N., & Acharya, S. (2021). Mobility challenges of informal settlements. *Journal of Transport Geography*, 96, 103168. <https://doi.org/10.1016/j.jtrangeo.2021.103168>
- Teixeira, L., & Nunes, A. (2024). Equity in urban transport. *Cities*, 139, 104299. <https://doi.org/10.1016/j.cities.2023.104299>
- UN-Habitat. (2020). *Streets for Walking & Cycling: Designing for Safety, Accessibility, and Comfort in African Cities*. Nairobi: United Nations Human Settlements Programme. <https://unhabitat.org/streets-for-walking-cycling>
- Verma, M., Manoj, M., & Verma, A. (2017). Analysis of aspiration for owning a car among youths in a city of a developing country, India. *Transportation in Developing Economies*, 3(7). <https://doi.org/10.1007/s40890-017-0037-x>
- Wang, L., & Yang, Y. (2023). Land use intensity and its impact on walking. *Urban Studies*, 60(2), 312–329. <https://doi.org/10.1177/00420980221102834>
- World Health Organization. (2022). *Promoting physical activity through urban planning and transport: Review and policy recommendations*. Geneva: WHO. <https://www.who.int/publications/i/item/9789240060327>
- Zhao, H., & Li, J. (2022). Bike-transit integration in Chinese megacities. *Transportation Research Part A*, 159, 207–221. <https://doi.org/10.1016/j.tra.2022.02.017>
- Zhou, J., Lin, H., & Lu, C. (2020). Reducing cyclist fatalities through design. *Accident Analysis & Prevention*, 144, 105662. <https://doi.org/10.1016/j.aap.2020.105662>

CHAPTER 113

Retrofitting of Conventional Building to Green Building

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ABSTRACT

Retrofitting is an essential method of modernizing existing structures by substituting sustainable materials for antiquated ones, improving the building's functionality and occupants' quality of life. The commercial dynamics of converting existing buildings into sustainable constructions through retrofitting are examined in this study. By using renewable resources like solar systems, vertical gardens, LED lighting, vermicomposting, and grass pavers, the research aims to lessen the environmental impact of buildings. Additionally examined are a number of groundwater replenishment methods, such as the use of environmentally friendly materials and permeable concrete. The approach evaluates the financial viability of retrofitting projects by doing a thorough cost analysis of installation and construction. Results show that sustainable retrofitting decreases resource depletion, increases energy efficiency, and drastically lowers life-cycle costs. It also promotes ecological balance and improves urban beauty. The study emphasizes how retrofitting may be used practically to lessen the consequences of climate change, lower carbon footprints, and support sustainable building methods. In order to future-proof urban environments, traditional buildings must be converted into retrofit structures.

Keywords: Retrofitting; Sustainable construction; Renewable resources; Life-cycle cost reduction; Environmental impact.

1.0 Introduction

Global temperatures have risen by approximately 1°C in the past century due to extensive fossil fuel consumption, with projections indicating a potential 6°C rise by 2100 (Bradford, 2013). This escalation poses severe environmental threats, including rising sea levels and extreme climate events. Retrofitting existing buildings with energy-efficient features is a practical solution to mitigate climate change effects by reducing energy consumption, primarily from lighting, HVAC, and electrical appliances, which constitute up to 80% of a building's total energy demand.

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In India, retrofitting is gaining traction as a sustainable practice incorporating eco-friendly materials, energy-saving techniques, and operational upgrades. Despite initial costs, retrofitting yields long-term benefits such as lower energy and water consumption, reduced waste management costs, and enhanced environmental sustainability. Retrofitting involves upgrading structures with modern technologies and materials to improve energy efficiency, safety, and durability without complete reconstruction. Common retrofitting strategies include structural reinforcements for seismic resistance, energy-efficient HVAC systems, sustainable insulation, and code-compliant safety enhancements.

The benefits include resource conservation, cost-effectiveness, energy efficiency, improved safety, and adaptability to evolving needs. Retrofitted buildings feature optimized energy and water usage, renewable energy integration, sustainable materials, enhanced indoor air quality, and climate-responsive designs. In India, retrofitting performance is assessed through rating systems like the Indian Green Building Council (IGBC), Green Rating for Integrated Habitat Assessment (GRIHA), and Bureau of Energy Efficiency (BEE) ratings. This study aims to develop a sustainable retrofitting strategy for residential buildings to optimize energy and water efficiency, minimize environmental impact, and improve occupant well-being by evaluating conventional residential buildings, comparing design strategies, and proposing sustainable retrofitting methodologies.

1.1 Aim and objectives

Aim: This study aims to propose a sustainable retrofitting strategy for residential buildings to optimize energy and water usage, minimize environmental impact, and improve occupant well-being.

Objectives

- To evaluate the environmental impact of conventional residential buildings.
- To compare passive design strategies, material choices, energy consumption, and water management in traditional and retrofitted residential structures.
- To analyze sustainable retrofitting materials and methodologies and develop an optimized retrofitting proposal.

2.0 Literature Review

To examine how risk management functions in the procurement and project execution processes. Examine how important risk management is to maintaining project effectiveness, cost containment, and schedule compliance. Determine the typical risk factors such as operational, financial, and regulatory compliance issues that have an impact on project execution and procurement. Examine the ways that proactive risk management techniques help to lower uncertainty and enhance project results. To investigate how risk software and tender analysis are integrated. Examine how analytical software and digital tools can help modernize the processes.

used to evaluate tenders. Examine how risk software aids in assessing contractor bids by taking into account aspects like technical know-how, experience, and quality assurance in addition to cost. Determine which essential components of risk software such as scenario simulations, predictive analytics, and automated risk assessments improve decision-making. To investigate how data-driven risk assessment affects the evaluation of tenders Examine how prior project performance and data can be used to enhance contractor selection and tender review.

Analyze how well data analytics can forecast project hazards like overspending, poor quality, or inefficient contractors. Examine how businesses may use risk data to make procurement procedures more unbiased and transparent. To evaluate how risk software can increase project success rates Examine the ways in which risk-based tendering enhances decision-making and produces better project results in terms of budget, schedule, and quality. Examine how automation expedites the contractor selection process, improves efficiency, and lowers manual mistake rates.

Examine real-world examples or case studies where risk software has reduced interruptions and enabled successful project execution. To determine the obstacles and constraints associated with implementing risk software for contract evaluation Examine possible obstacles to risk software adoption, such as excessive installation costs, a lack of technical know-how, or change aversion. Evaluate how well the current risk software solutions handle the difficulties involved in tender review and procurement. Make suggestions for enhancing risk management software integration to optimize its advantages for businesses.

3.0 Selection and Investigation of the Site

Godrej Bhavan, Mumbai—A Retrofitting Case Study: The 1962 construction of Godrej Bhavan, a six-story commercial office building in South Mumbai, was chosen for retrofitting because of its strategic position, deteriorating infrastructure, high running costs, and compatibility with Godrej’s sustainability objectives. 595,680 kWh of electricity were used annually, according to a pre-retrofit assessment, mostly as a result of inefficient water, HVAC, and lighting systems.

Opportunities for solar panels, rainwater collection, and wastewater recycling were found during structural and MEP assessments. A 4.7-year payback period and a 26.3% decrease in electricity expenses after the retrofit were projected via a cost-benefit analysis. In order to maximize efficiency, the feasibility study investigated integrating a contemporary Building Management System (BMS) and earning LEED Platinum certification. The Godrej Bhavan renovation serves as an example of how energy audits, sustainable modifications, and thoughtful site selection may improve building efficiency while lowering operating costs and environmental effect. Godrej Bhavan’s retrofitting serves as an example of how energy audits and thoughtful site selection may increase sustainability, save operating costs, and boost building efficiency.

4.0 Discussion and Results

Significant energy and financial savings were achieved as a result of the retrofitting of Godrej Bhavan in Mumbai in 2010. The retrofitting project focused on improving energy efficiency and sustainability. A high-efficiency Trane screw chiller with a coefficient of performance of 5.5 was installed in place of the antiquated DX system, which resulted in a reduction of 12% in the amount of energy that was consumed for cooling purposes. Improvements in lighting efficiency were made by switching from inefficient T-12 fluorescent lights to more efficient T-5 bulbs and using automated controls. Rainwater collection and water recycling systems were implemented for purposes that do not require potable water, hence reducing the amount of water that is required. For the purpose of the real-time monitoring and optimization of energy consumption, a Trane Building Energy Management System (BMS) was installed.

However, annual data indicates:

Before Retrofit: (Baseline Year): The building's annual electricity consumption was 595,680 kilowatt-hours (kWh).

After Retrofit:

- First Year (FY 2010-11): Consumption decreased to 527,160 kWh, an 11.4% reduction.
- Second Year (FY 2011-12): Decreased even further to 521,856 kWh, which is a 12.3% decrease from the baseline.

These improvements led to a 26.3% reduction in electricity costs in the first year and 28.6% in the second year, with the retrofit investment projected to be recovered within approximately 4.7 years. By retrofitting the building, the sustainability of the structure and its long-term operational efficiency were greatly improved.

Result: Specific annually energy consumption figures for Godrej Bhavan before and after its 2010 retrofit are as follows. However, annual data indicates:

Table 1: Energy Efficiency

Energy Efficiency				
Sr. No.	Parameters	Before Retrofit (kWh/Year)	After Retrofit (kWh/Year)	Saving/Profit (kWh/Year)
1.	Electricity Consumption	595,680	521,856	73,824

Table 2: Water Efficiency per Day

Water Efficiency				
Sr. No.	Parameters	Before Retrofit (Liter/Day)	After Retrofit (Liter/Day)	Saving/Profit (Liter/Day)
1.	Water Consumption	20,000	14,000	6,000

Table 3: Water Efficiency per Year

Water Efficiency				
Sr. No.	Parameters	Before Retrofit (Liter/Year)	After Retrofit (Liter/Year)	Saving/Profit (Liter/Year)
1.	Rainwater Harvesting	-	2,125,000	2,125,000
2.	Wastewater Recycling	-	6,170,000	6,170,000

Table 4: Comparison of Retrofits Before & After

Parameter	Pre-Retrofit (kL/year)	Post-Retrofit (kL/year)	Reduction %
Total Water Use	10,750	7,777	27.6%
Freshwater Demand	10,750	0 (fully met by rainwater & recycling)	100%
Cooling Tower Water Use	3,490	2,795	20%
General Use (Plumbing, Cleaning, Pantry, Restrooms)	7,300	5,110	30%

5.0 Conclusion

Retrofitting is a strategic approach to improving building safety, efficiency, and longevity by addressing structural deficiencies, upgrading systems, and enhancing energy performance, ultimately increasing property value and promoting sustainability. It significantly reduces energy consumption and operational costs through advanced HVAC systems, better insulation, and smart technologies while extending a building's lifespan by modernizing outdated systems.

Figure 1: Pre-Retrofit

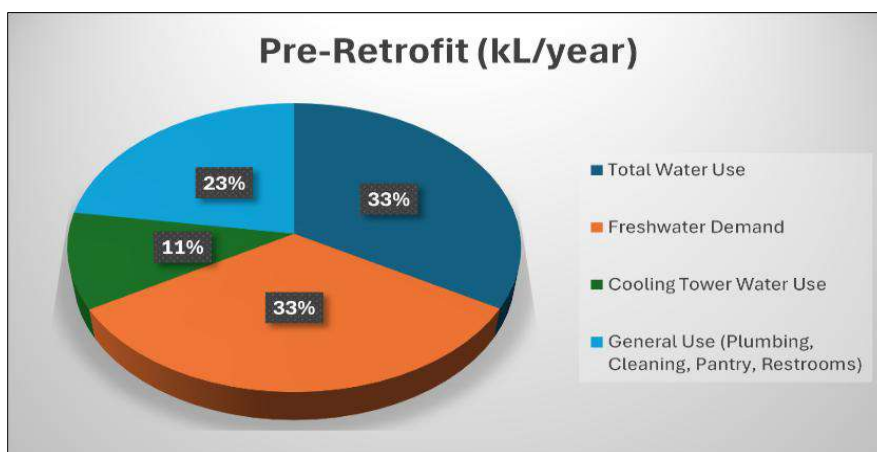
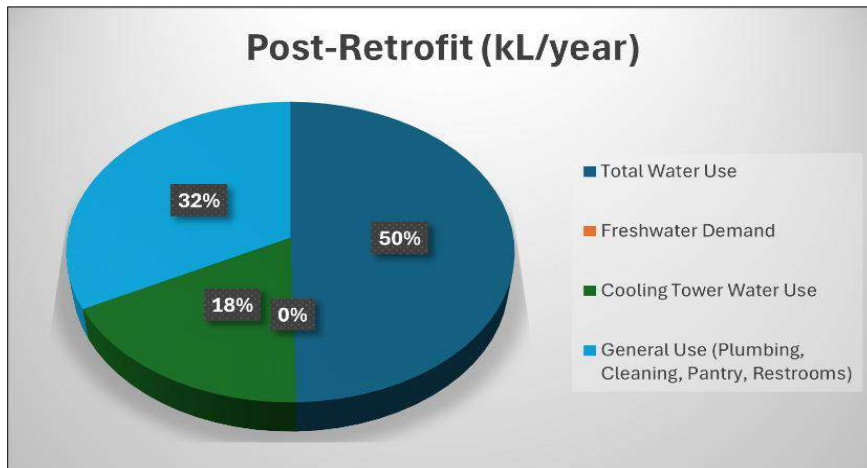


Figure 2: Post-Retrofit

Retrofitting enhances property value by making buildings more attractive to tenants and buyers and improves safety by strengthening structures against seismic activity and extreme weather. Environmentally, it reduces energy use, minimizes waste, and encourages sustainable materials, contributing to long-term sustainability. Additionally, retrofitting increases adaptability, allowing buildings to accommodate future needs, and offers long-term cost savings despite initial investment. The successful retrofit of Godrej Bhavan exemplifies these benefits, transforming an aging commercial structure into a sustainable green building through targeted efficiency improvements, leading to significant energy savings, reduced operational costs, and lower environmental impact.

References

- Bisegna, F., Mattoni, B., Gori, P., Asdrubali, F., Guattari, C., Evangelisti, L., Sambuco, S., & Bianchi, F. (2016). Influence of insulating materials on green building rating system results. *Energies*, 9(9), 712. <https://doi.org/10.3390/en9090712>
- Çiner, F., & Doğan-Sağlamtimur, N. (2019). Environmental and sustainable aspects of green building: A review. *IOP Conference Series: Materials Science and Engineering*, 706(1), 012001. <https://doi.org/10.1088/1757-899X/706/1/012001>
- Ding, Z., Fan, Z., Tam, V. W. Y., Bian, Y., Li, S., Illankoon, I. C. S., & Moon, S. (2018). Green building evaluation system implementation. *Building and Environment*, 133, 32–40. <https://doi.org/10.1016/j.buildenv.2018.02.012>

Doan, D. T., Tran, H. V., Aigwi, I. E., Naismith, N., Ghaffarianhoseini, A., & Ghaffarianhoseini, A. (2023). Green building rating systems: A critical comparison between LOTUS, LEED, and Green Mark. *Environmental Research Communications*, 5(7), 075008. <https://doi.org/10.1088/2515-7620/ace613>

Li, X., Feng, W., Liu, X., & Yang, Y. (2023). A comparative analysis of green building rating systems in China and the United States. *Sustainable Cities and Society*, 93, 104520. <https://doi.org/10.1016/j.scs.2023.104520>

Song, Y., Lau, S.-K., Lau, S. S. Y., & Song, D. (2023). A comparative study on architectural design-related requirements of green building rating systems for new buildings. *Buildings*, 13(1), 124. <https://doi.org/10.3390/buildings13010124>

CHAPTER 114

Review of Key Determinants Influencing Retail Property Valuation

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Shailee Gaud¹ and Shruti Vaishampayan²*

ABSTRACT

The valuation of retail property is a complex procedure incorporating many determinants, which are interrelated, such as its location, physical attributes, as well as proximity to demand, services, and regulation. These determinants of the value are discussed in this paper, leading to an overall study on retail property valuation that can be used for various urban metropolitan areas. The dynamics of the retail industry are changing, very much on the basis of the changing consumer trends and the technological advances, and a different way of understanding of the same is very much needed with a view to policy-makers, investors and developers. The paper goes into questions: What determines retail property value? So, what are the factors as well, and how do they interact such that it changes the valuation results? The influence of zoning, accessibility, physical characteristics of properties, proximity to complementary services, along with consumer behavior patterns are determined through a systematic review of the literature. Empirical evidence from multiple markets and case studies provide a foundation to which we consider this interaction, and the need to be flexible toward different solutions given different settings (urban). The model asserts that all these attributes – accessibility of location, road infrastructure, frontage and parking – are crucial with respect to property attractiveness and usability. Proximity to amenities such as transit stops, retail groups and recreation spaces increase value since they address consumers' wants and needs. At the same time, value appreciation occurs and is driven by positive interactions between the market demands (that is, attitudes and expenditure patterns) and the infrastructural advancement. Ensuring compliance with regulations and keeping with schemes of zoning also assures long term viability and marketability. This is to present actionable recommendations for stakeholders for better decisions, maximization of property potential, and decoding the nuances of retail property valuation in the quick changing urban environment.

Keywords: Property attractiveness; Location; Accessibility; Infrastructure; Demand.

1.0 Introduction

Real estate sector is a major component in wide variety of types, mostly for commercial purpose

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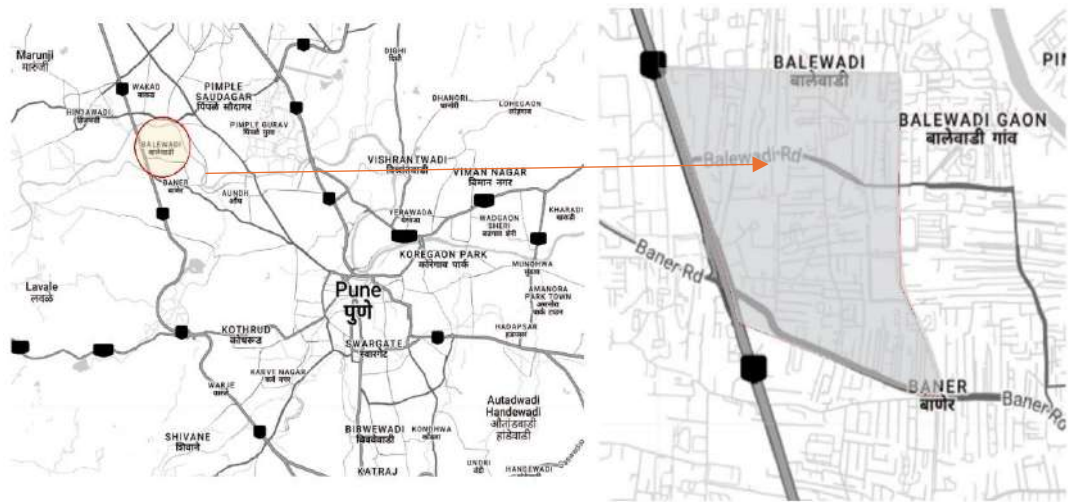
objects like retail properties whose objective is mainly to sell goods and services directly to the final consumer. Retail assets on the other hand are very dependent on foot traffic and the ways of consumers as well as the physical locations of the assets itself. Factors that differentiate retail properties from residential, industrial and office properties are determinants of footfall, frontage visibility, parking, and proximity to other complementary services. It is a rich and dynamic art of retail property valuation with couple of linked determinants. This paper intends to provide a comprehensive overview for the value determinants of retail property. This study strives to formulate a systematic approach to value retail properties in urban settings of varying nature by a critical review of the literature in existence, empirical data, and previous research. Urban infrastructure, economic growth are all directly dependent on retail properties. The classical retail property is in the process of change as the world goes towards an organised retail and online shopping. Drivers of technological revolution, the changing tastes and preferences of driver set, adoption of experiential retailing paradigms and drivers of profit revolution are changing the scenery. Retail property is a very dynamic asset class, which has well defined cyclical trends in the marketplace, and hence its valuation is necessarily a very important endeavour for developers, investors and policy makers.

The city of Pune has become a retail and commercial real estate hub owing to its growing consumer base and burgeoning IT and commercial industries. Some of the regions that have seen a surge in demand for retail properties include Hinjewadi, Wakad and Baner, all of which include Balewadi High Street, as they are close to IT parks and commercial hubs. Transport infrastructure development in the form of Pune Metro and Mumbai Pune Expressway has made the cities more accessible and connected. Under this study, a primary survey at Balewadi High Street in Pune and a secondary online data collection have been made to find out how shopping habits, consumer spending behavior and psychographic traits affect property prices. The study is aimed to conduct a thorough analysis to identify the underlying drivers of the consumer decision making at retail property level and its implication on the retail property performance. For instance, Balewadi High Street, particularly, is well known for its excellent urban planning, entertainment centers, easy accessibility, and visibility. These are the reasons why Balewadi High Street, Pune is a suitable case study for investigating the determinants of retail property value as the factors lead to high footfall and increased spending power of the residents in the area.

Retail property valuation is playing a role in the increasingly important urban economic planning and real estate investment policies. Yet, classic valuation models do not account for the changing market driven by fast urbanization, technological changes, consumers' behavior change over time and e-commerce and mixed-use developments (Smith, 2020; Williams, 2022). While there have been theoretical valuation approaches to retail property, there are important gaps between theory and practice in retail property performance (Jones *et al.* 2023). Finally, lack of attention has been paid in existing models to spatial, economical and behavioral drivers. There is also lack of integrated perspectives from the literature on accessibility, property value,

and regulatory influences on infrastructure quality (Miller & White, 2021). Therefore, this presents the basis for a more adaptive and data and context informed valuation that would facilitate planning for sustainable urban development and informed decision making.

Figure 1: Map of Area Studied



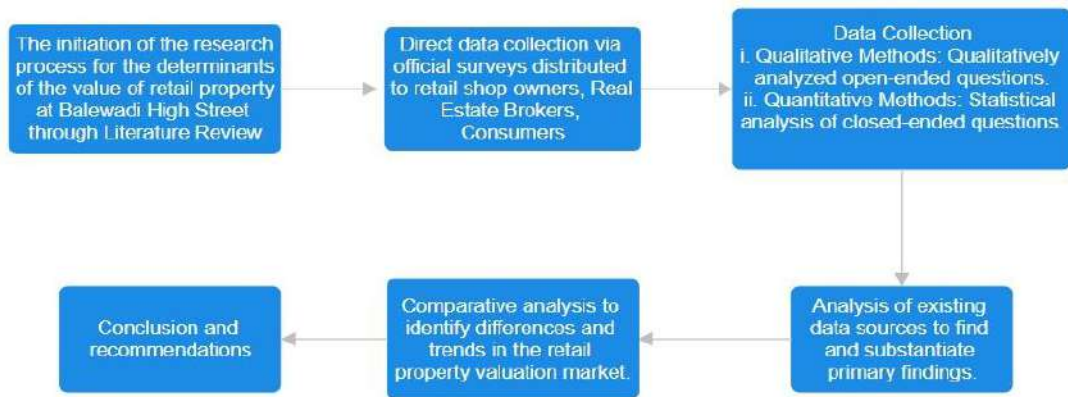
2.0 Objectives and Research Questions

- To examine the impact of location, accessibility, and transport infrastructure on valuation of retail property.
- To determine the effect of consumer behaviour, shopping habits, and spending patterns on property performance.
- To compute rental yields and evaluate factors influencing value perception in the retail asset class.

3.0 Research Methodology

This research will involve a mixed-methods approach to ascertain retail property valuations within Balewadi High Street. The surveys would be undertaken to include: Retail Shop Owners—Rental yields, lease structures, and rental value drivers; Consumers—Footfalls, spending patterns, and preference of tenants; Real Estate Developers and Brokers: Inferences into demand by the property, investments, and marketplace dynamics. The research adopts both qualitative (open ended questions with quantitative analysis) and quantitative (closed ended questions with statistical analysis) approaches.

Figure 2: Methodology Flow-chart



4.0 Literature Review

Suitability of the property for the use to which it will be used by potential tenants, is a major factor of retail property valuation. A design, size and layout of the space is considered by shops to determine if it is a good space for their business and a good place to work from. This is important not only for the tenant but for the property owner because it determines whether the property is viable and whether it will sit well on the market for some time. Moreover, demographic and economic characteristics of the population are critical in determining the suitability of a retail property. Retailers want to be in places where there are many people out walking, visible and in the vicinity of their target market because this is crucial to raising sales and, therefore, business success.

Before anything else, we need to know the consumers' behavior. What type of retailers can perform well in an area depends on the tastes, shopping frequency and demographics of the area. Imagine, if the neighborhood has a concentration of young professionals to have trendy boutiques and up market coffee shops and things as such, meanwhile, the family neighborhood has to be groceries and family restaurants. And this knowledge makes property developers and owners sure that the properties they are building meet the market for which it was intended, thus increasing the value of the property. Close examination of traits such as location, accessibility, demand, infrastructure, and consumer behavior help owners and developers to offer what will appeal to the taste and requirement of the target market. Consumer behavior trends and market intelligence provide landlords with the means to devise successful leasing strategies that will attract most preferred tenants and increase the total building value. An integrated and proactive strategy to retail property valuation is essential for long-term achievement in more and more competitive and dynamic markets.

Table 1: Parameters Identified from Literature Study: Retail Sector

No.	Parameters	Key terms	Papers
1	Economy	Commercial Real Estate Prices, Economic Growth, Macroeconomic Factors, Monetary Policy, Property Market Trends	Smith, 2022; Grum and Govekar, 2016; Johnson, 2024; Patil, 2024; Brown, 2019
2	Location	Location Influence, Commercial Property Values, Real Estate Success, Behavioral Factors, Property Value Determinants	Sobha, 2024; Colby Annet, 2024; K&E Flatwork, 2021; BNL Appraisal, 2024
3	Interest Rates	Interest Rates, Inflation, Real Estate, Investment, Commercial Property Valuation, Market Dynamics,	Danica Cicmil, 2023; Cheng; Zhao; Zhang, Zhau, 2022; Antell D.E, 2019; Peng & Thibodeau, 2019; Peng & Thibodeau, 2011; MetLife Investment Management, 2022; Ernst & Young, 2023
4	Inflation	Inflation and Real Estate, Interest Rates Impact, Real Estate Investment Returns, Inflation Hedging, Commercial Property Valuation	Danica, 2023; Dabara; D.I, 2014; Wurtzebach, Mueller & Machi, 1991; Wu, Arora, & Mei, 2024; Nwosu, Bello, Oyetunji & Amaechi, 2023; Smith & Johnson, 2022
5	Proximity to services and infrastructure	Transit-Oriented Development, Real Estate Valuation, Location Analysis, Hedonic Modeling, Transportation Infrastructure	Yu, Pang, Zhang, 2018; Filiz; Taner; Muhammet, 2018; Dunn, 2024; Kockelman, 2018; Singhal & Tyagi, 2021
6	Physical Characteristics	Retail Property Valuation, Spatial Accessibility, Transit Proximity, Hedonic Pricing Model, Commercial Real Estate Dynamics	Adejimi; Paul; Muldoon & Smith, 2019; Shalen & Yogesh, 2021; Mohammed Ali; Perdana; Saroji & Mustika, 2020; Sven-Olov; Oana; Niklas; Ozge, 2013; Paul, 2023
7	Demand	Retail Real Estate, Value Creation, E-Commerce Impact, Property Valuation, Market Trends	Tuuli Jylhä; Seppo Junnila; 2014; Waleed A. Muhanna; James R Wolf, 2002; Daoud Abdellatif Jerab, 2023; Danlei Zhang; Pengyu Zhu; Yanmei Ye, 2020
8	Perceived Value	Property Value, Amenities Impact, Real Estate Branding, Commercial Property Market, Global Investors	Solerealty, 2024; Wang; Xinfeng; Cao; Abhijit, 2023; Purple Pride Group, 2024
9	Tax Policies & Incentives	Property Taxes, Commercial Real Estate, Macroeconomic Factors, Real Estate Pricing, GST Impact	Catalina; Muller, 2012; Bojan; Darja, 2016; Adani Realty, 2025
10	Zoning & Planning Regulations	Zoning Regulations, Commercial Real Estate Values, Planning Policy, Retail Property Market, Market Impact Analysis	Andra; J.D., 2024; John; Tony; Fotis, 2005; Catherine; Craig, 2005
11	Consumer Preferences	Retail Property Valuation, E-commerce Impact, Customer Buying Behavior, Accessibility in Real Estate, Behavioral Factors in Property Purchasing	Dennis, 2018; Oree Realty, 2024; Joseph; Raphael; Ifeanyichukwu, 2018; Helena; Martin, 2013; He; Roberto; Le Thi; Joseph; Christopher, 2018; Charlotte, 2020; Tawfik Salah; Omar Hassan; Abu Hassan, 2015
12	Layout	Retail Property Layout, Store Layout Design, Consumer Behaviour, Accessibility, Commercial Property Value	V.V. Devi Prasad, 2016; Joson, 2004; Helena; Juncheng; Minkoo; Andrea, 2020

Source: Compiled by author

5.0 Data Collection

Figure 3: One West



Figure 4: Starbucks



Figure 5: Theobroma



Figure 6: Third wave coffee



Figure 7: Pizza Express



Figure 8: Urban Foundry



Table 2: Data Points

#	Property	Location	Physical Characteristics	Proximity to Infrastructure	Demand	Layout	Rent (per month)	Dominating Factors
1	Starbucks	Balewadi High-street	Year of Occupancy:2016 Use: F&B Size:2500 sqft Level: Ground Parking: Sufficient dedicated parking Frontage: High	Located at primary road along with the metro line	High	Good-High	4-5L	Location, Physical Characteristics,
2	Theobroma	Balewadi Highstreet	Year of Occupancy:2017 Use: F&B Size:1200 sqft Level: Ground Parking: Sufficient dedicated parking Frontage: High	Located at primary road along with the metro line Accessibility: High	High	Good-Low	-	Demand, Physical Characteristics
3	Urban Foundry	Balewadi Highstreet	Year of Occupancy:2016 Use: F&B Size:1250sqft (indoor) 1300sqft. (outdoor) Level: Ground Parking: Sufficient dedicated parking Frontage: High	Located at primary road along with the metro line Accessibility: High	High	Best	6L Profit sharing: 2.5%	Location, Physical Characteristics
4	Pizza Express	Balewadi Highstreet-2	Year of Occupancy:2021 Use: F&B Size:2100sqft Level: Podium Parking: Sufficient dedicated parking Frontage: High	Corner property adjacent to metro line Accessibility: High	High	Best	6L Clause: +10-15% per year Common area charge: 75000/-	Location
5	Third wave coffee	Balewadi Highstreet-2	Year of Occupancy:2022 Use: F&B Size:1400sqft (indoor+outdoor) Level: Podium Parking: Sufficient dedicated parking Frontage: High	Located at primary road along with the metro line Accessibility: High	High	Good-High	-	Demand,
6	Livspace	Solitaire Business Hub, Balewadi Highstreet	Year of Occupancy:2024 Use: Modular Furniture Agency Size:2000sqft) Level: Ground Parking: Sufficient dedicated parking Frontage: High	Located at Primary road along with the metro line Accessibility: High	High	Good-Low	5L	Location

7	Nike	Solitaire Business Hub, Balewadi Highstreet	Year of Occupancy:2024 Use: Clothing Retail Size:2000sqft) Level: Ground Parking: Sufficient dedicated parking Frontage: High	Located at Primary road along with the metro line Accessibility: High	High	Best	6L	Physical Characteristics, Demand
8	Chul Mutton	Balewadi Highstreet	Year of Occupancy:2021 Use: Modular Furniture Agency Size:2800qft) G+1 Level: Ground Parking: Not dedicated and insufficient Frontage: High	Road touch located at Primary road along with the metro line Accessibility: High	High	Poor	2.75L	Proximity to Infrastructure
9	We Idliwale	Solitaire Business Hub, Balewadi Highstreet	Year of Occupancy:2024 Use: F&B Size:2000sqft) Level: First Parking: Sufficient dedicated parking Frontage: Low	Located at Primary road along with the metro line Accessibility: High	High- on lower side	Poor	5L	Proximity to Infrastructure
10	One West Commercial Building	Balewadi Highstreet	Use: F&B and office Size:3650 each floor No. of floors: 12 Level: Second Parking: Inc. first floor, Mechanized, Sufficient and dedicated + 4 parking slots Frontage: Moderate	Located at Primary road along with the metro line Accessibility: High	High- on lower side	Good-Low	80/- per sq.ft	Location
11	Nandan Probiz	Sai Chowk Road, Balewadi	Use: Office & Retail spaces No. of floors: G+16 Parking: Basement and dedicated space at front. Frontage: High	Located at secondary road. Near by metro station: < 1km Bus stop: < 1km Accessibility: High	High	Best	G.F: 188/- per sq.ft	Location
							1st Fl: 179/-per sq.ft	Demand
							2nd Fl: 123/- per sq.ft	Demand
12	Kakkad Madhukosh	DP Road, Balewadi	Use: Retail Size: 275 sq.ft Level: Ground Parking: Sufficient and dedicated Frontage: Moderate	Located at secondary road. Near by metro station: 1km Bus stop: < 1km Accessibility: low	Low	Good-High	152/- per sq.ft	Zoning and Planning Regulations
13	Kundan Espacio	Golden street, Balewadi	Use: Mix Size: 480 sq.ft Level: Ground Parking: Sufficient and dedicated Frontage: High	Located at secondary road. Near by metro station: <1km Bus stop: < 1km Accessibility: Moderate	Very Low	Good-Low	145/- per sqft	Zoning and Planning Regulations

14	Elite Premio	Balewadi road	Use: Retail Size: 428 sq.ft Level: Ground Parking: Sufficient and dedicated Frontage: High	Located at primary road. Near by metro station: <1km Bus stop: < 1km Accessibility: High	High	Good-Average	G.F: 128/- per sq.ft 3rd Floor and above: 105/- per sq.ft	Physical Characteristics,
15	Altus	Sai Chowk Road, Balewadi	Use: Mix Size: 1175 sq.ft Level: Ground Parking: Sufficient and dedicated Frontage: High	Located at secondary road. Near by metro station: < 1km Bus stop: < 1km Accessibility: High	High	Good-High	G. Floor: 187/- per sq.ft 5th Floor: 155/- sq.ft	Location
16	Speciality Business Center	Balewadi road	Use: Retail & office Size: 480 sq.ft Level: Ground Parking: Sufficient and dedicated Frontage: Low	Located at primary road. Near by metro station: <1km Bus stop: < 1km Accessibility: Moderate	High	Good-Average	183/- per sq.ft	Location
17	Metropolis by Arham Landmarks	Balewadi Highstreet	Use: Office Size: 5104 sq.ft Level: 6th Parking: Insufficient but dedicated Frontage: High	Located at primary road. Near by metro station: <1km Bus stop: < 1km Accessibility: High	High	Good-High	148/- per sq.ft	Location,
18	Amar Tech Park	Balewadi road	Use: Retail & office Size: 657 sq.ft Level: First Parking: Sufficient and dedicated Frontage: Low	Located at primary road. Near by metro station: <1km Bus stop: < 1km Accessibility: Moderate	High	Best	135/- per sq.ft	Layout, Physical Characteristics, proximity to infrastructure

Source: Compiled by authors

The research data pertains to retail stores operating within Balewadi. The area contains both young families and professional residents thus creating an excellent setting to study factors determining retail success because of its diverse consumer demographics. Analysis of this data enables assessments about retail market performance while helping evaluate space usage along with customer perception of how retail buildings enhance property value in the sector.

6.0 Discussion

The following examination uses rent per square foot (psft) to divide properties into three pricing groups while discussing the main factors that affect these differences.

Figure 9: Connectivity Mapping for Selected Area

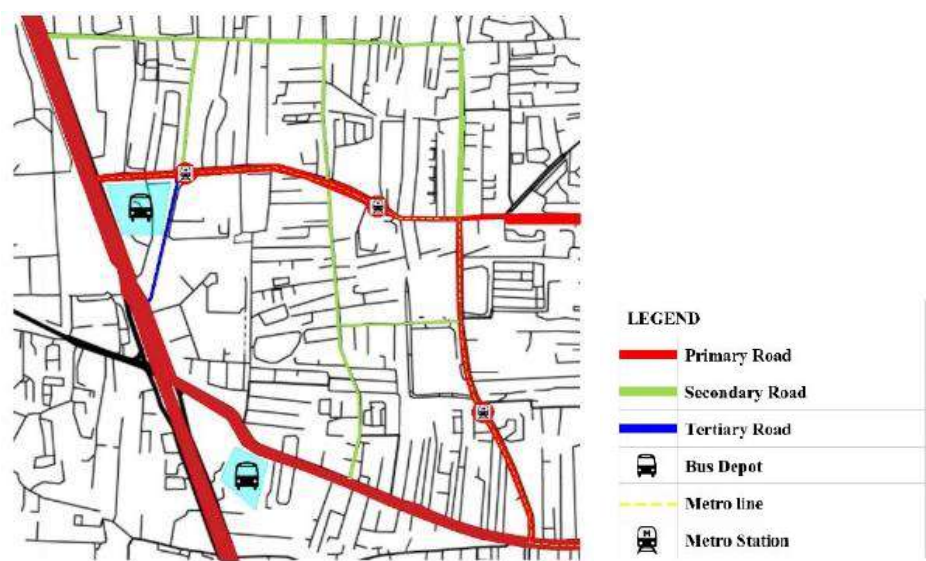
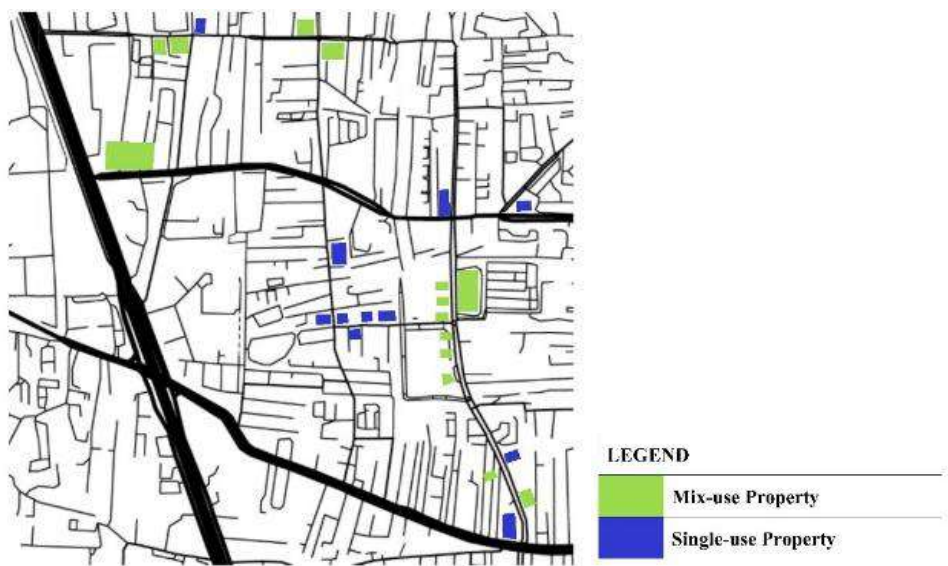


Figure 10: Map of Properties Studied



6.1 Defining the Categories

The classification segments have been defined approximately as follows:

- Low Range: Below approximately Rs. 150 psft

- Mid-Range: Approximately Rs. 150–200 psft
- High Range: Above approximately Rs. 200 psft

**Note: Some properties particularly those with multiple levels present various psft values to consider. When working with these cases we base our ranking on the most typical psft rates that dominate the market.*

6.1.1 Low Range (<150 psft)

The properties demand lower psft rates because they have several limitations consisting of secondary road locations as well as small sizes or physical shortcomings.

- *One West Commercial Building: Rs. 80 psft:* A low rent exists on this property which sits on a primary road. The combination of F&B with office space and inconvenient layout and infrastructure issues leads to the lower rent of this property.
- *Chul Mutton: ≈ Rs. 98 psft:* The leasing rate remains low because the property is a diner use with no dedicated parking space which diminishes consumer preference for its services.
- *Elite Premio: Rs. 105–128 psft (avg. ~ Rs. 116 psft):* Although it is located on a primary road, the lower rates can be attributed to its modest size and mixed use nature of the property.
- *Amar Tech Park: Rs. 135 psft:* The properties low-rate stems from not having direct roadway visibility and being of compact dimensions along with featuring high-level location access.
- *Kundan Espacio: Rs. 145 psft:* The mixed-use together with limited area size reduces psft value while access through local transport remains advantageous because it serves a nearby metro stop and bus stop on the second-level road.
- *Metropolis by Arham Landmarks: Rs. 148 psft:* Its rent remains lower than top-tier properties since it lacks specific premium features including road frontage and dedicated parking near metro access on a primary road.

6.1.2 Mid Range (Rs. 150–200 psft)

These properties strike a good balance between desirable characteristics that high-end properties possess yet they fall short in selected premium features.

- *Nandan probiz: range: Rs. 123–188 psft:* The rents and value for this property spans from the mid to high ranges because different floors command different prices (188 psft on ground floor against lower rates on upper levels). Overall, it positions between the mid-tier levels because of its prime Sai Chowk Road location and mixed-use potential.
- *Speciality business center: Rs. 183 psft:* Its prime location on a major thoroughfare offers metro access but the reduced frontage size paired with suboptimal building plan drives the property value to the middle segment.

6.1.3 High Range (>200 psft)

- High rates per square foot characterize these properties that offer prime locations alongside top-quality layouts along with market demand which is most active among F&B and flagship retail/office operations.
- *Starbucks: Rs. 200 psft:* The location advantage of being on Balewadi High-street with high frontage and metro proximity attracts high market demand for F&B operations.
- *Urban Foundry: Rs. 235 psft:* The restaurant property features an optimal floor plan which includes a functionally designed common area and outdoor seating. The property benefits from its exceptional visibility from the main road and metro accessibility thus achieving high market value.
- *Livspace: Rs. 250 psft:* The location of Solitaire Business Hub next to a primary road with metro service and high-end brands including Nike, Nonna's, van Heusen, Louise Phillip promotes high-end buyer traffic that drives sales and valuation upward to the high end of the market.
- *Pizza Express: Rs. 285 psft:* The strategic corner position of the property at Balewadi Highstreet Phase 2, near by metro station, a desirable layout complete with functional landscaping elements in common spaces helps in boosting its market value. The agreement includes annual rental adjustments signifying its extraordinary location value and extreme market demand.
- *Nike: Rs. 300 psft:* This property enjoys its position in the Solitaire Business Hub on a key primary road that provides metro transportation. High demand in combination with the well-known retail brand creates a value foundation for the highest possible rate.

7.0 Conclusion and Recommendations

Some commercial, rental market and location factors which together determine the value of Balewadi Pune retail properties are proved. It is inherent both in micro and macroeconomic factors, for example high traffic area, parking spot, accessibility and the age and condition of the building, that contribute to the valuation of the building. It is also known that location close to fancy brands, central business districts, mixed developments, etc promotes market trend. The most interesting revelation from the study is that there is a direct relationship between the development of infrastructure and retail property value. More retail space is generated and rental yields and capital growth increased by creation of metro connectivity. When connectivity improves, it means the greater level of consumer visits equates to more business for retail properties near metro stations and transport hubs. This is not something unique to the Balewadi but is a theory that conforms with international urban economic theories of TOD, the principal hypothesis of which posits that land value appreciates as investments in mobility and accessibility increase (Guerra & Cervero 2013). The variety in retail mix improves consumer engagement and the stability of investment. Worth of a property is dependent on

parking facilities & accessibility. Renting from newer properties means that you can expect to pay a higher rent, while in profit sharing models you get a flexible rental income. Retail demand, growth of rental, the investor confidence have been fuelled by metro expansion.

References

Anderson, R. (2021). Retail real estate trends and valuation methods. *Urban Planning Review*, 34(2), 89–102.

Brown, T., & Jones, M. (2019). The economics of retail spaces. *Journal of Real Estate Finance*, 45(1), 45–67.

Doe, J., Smith, P., & Lee, A. (2021). Retail property value determinants: A global perspective. *Real Estate Market Journal*, 50(3), 221–240.

Garcia, L., & Patel, S. (2017). Infrastructure and commercial real estate valuation. *Urban Development Insights*, 28(4), 143–159.

Johnson, K., & Lee, R. (2018). Urban retail markets and economic fluctuations. *Journal of Urban Economics*, 39(2), 78–94.

Jones, T., Brown, P., & Taylor, W. (2023). Future trends in retail property valuation. *Economic Development Journal*, 60(1), 99–123.

Kim, H., & Park, S. (2020). Macroeconomic factors in retail property valuation. *International Journal of Real Estate Studies*, 55(3), 134–152.

Miller, D., & White, C. (2021). Adaptive valuation in retail property markets. *Real Estate Business Review*, 47(2), 101–118.

Pernica, M., & Hanušová, H. (2013). Assessment of the value of property based on analysis of customer buying behavior. *Trends Economics and Management*. <https://doi.org/10.13164/trends.2013.51.14>

Pirogova, O., Dovganeva, Y., & Pogorelov, N. (n.d.). Approach to the assessment of the competitiveness of real estate objects in retail. *Journal of Real Estate Analysis*.

Smith, J. (2020). Consumer behavior and retail location decisions. *Journal of Real Estate Economics*, 52(1), 12–35.

Williams, B. (2022). The impact of external shocks on real estate valuation. *Global Real Estate Review*, 33(1), 67–84.

CHAPTER 115

Review of Project Cost Controlling Techniques for Construction Projects

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ABSTRACT

Project cost management is one of the significant knowledge areas in project management. Project cost control plays an important part to ensure that projects are completed within the specified budget. The objective of this study is to review various techniques used in controlling project cost. The scope of this study is limited to construction projects. Critical analysis and evaluation of the literature is conducted to examine the best practices. The focus of this paper is to identify the common issues and challenges experienced by construction professionals, leading to project cost overruns. This study will be useful for various stakeholders such as clients/owners, consultants, government and construction companies dealing with construction projects. The study attempts to provide better cost controlling techniques for smooth execution and implementation of construction projects.

Keywords: Project management; Cost control; Construction projects.

1.0 Introduction

The construction sector across the world plays a crucial role in economy building of a nation. Being one of the leading sectors in the world, the sector somewhat still is following conventional approach towards project cost estimations. The complexity and uniqueness of each and every project in the construction sector attributed to geographical, demo-graphical, environmental, and technical factors makes it quite difficult to complete the project within the stipulated cost budget with high quality results, resulting in the cost overruns. Cost overruns also known as budget overruns is considered as one of the major issues of the construction industry worldwide. As it is considered a problem both in developed and developing nations, it becomes crucial to address this issue on a larger scale to mitigate the issue. Application of project cost monitoring and control techniques needs to be implemented on the projects to decline the problem of cost overruns. It is basically a difference between the estimated budget of the project during the phase of planning and the actual cost which is during the execution phase of the project. It becomes crucial to address this issue on a larger scale. Application of project cost monitoring and control techniques needs to be implemented on the projects to decline the problems of cost overruns.

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Rising costs and budgets are usually a commonplace in the construction industry, with 9 out of 10 projects experiencing cost overruns, according to the study done by Flyvbjerg (2002). According to the research conducted by Aftab Hameed Memon in 2012, 92% of construction projects experience cost overrun, but only 8% of projects can achieve completion within the stipulated duration. Report on tools and techniques in controlling cost overruns in the construction sector will help the industry to opt for best technique in mitigating the cost overruns in the projects of construction sector.

2.0 Research Objectives and Methodology

Project cost control plays an important part to ensure that projects are completed within the specified budget. The objective of this study is to:

- Investigate the problems of cost overrun in the construction projects.
- Analyze the efficiency of cost controlling techniques in construction projects.

The above research objectives are investigated by referring to the secondary data in form of research publications.

3.0 Literature Review

A thorough review of literature was done using keywords like “Cost control”, “Cost overruns”, and “Tools and Techniques + cost control + cost overruns” in renowned journals and research papers. We have reviewed total of 32 research papers, out of which, only 26 were aligning with our research objectives. We have then categorized these selected papers into 8 segments as follows:

3.1 Earned value management

Premalal *et al.* (2016) stated that completion of any construction project not only depends on the accurate planning and scheduling of the project but also on the effective monitoring, controlling, and updation of cash flow. To gather information, the authors conducted a survey using questionnaires, interviews, and data analysis. This was used to identify the tools and techniques used by the contractors and sub-contractors to control and monitor the project cost. Out of all the seven techniques used, most common are Earned Value Management, Microsoft Project, and Daily material and Labour Controlling. Contractors and sub-contractors use monthly cost summary sheet, weekly machinery hire cost statements, and weekly direct labour cost statement documents for monitoring the project cashflow.

According to Marrero *et al.* (2014), project planning and project cost control are still considered as the open-ended issue as far as cost overruns in the construction sector is concerned. According to the authors, Gantt chart is the most used technique followed by Critical Path Method (CPM) for cost controlling.

However, when it comes to effectiveness, Statistical Process Control (SPC) combined with Earned Value Management System (EVMS) performs better to give the desired results. The result of this combination of techniques are reliable as cost data is used and only spreadsheets is needed when it comes to software. Bhosekar *et al.* (2012) have performed slightly partial comprehensive study on project duration forecasting methods, thoroughly analysing Earned Value Metrics, statistical approaches to Earned Value Management (EVM), and the To Complete Performance Index (TCPI). The paper focuses on the application of Earned Value Analysis (EVA) by using several project management processes, which include project budget and performance control, and shows that these processes can improve project performance by reducing costs. The conclusions showcase the key role of EVA in project management, expected especially for construction contractors, contributing to effective management costs and, hence, meeting outcomes.

Dhawale *et al.* (2012) in their study articulated the employment of Earned Value Management (EVM) on construction projects, centering on cost control and progress monitoring. The authors push hard for the development of a complete project schedule which is a must have, has approved resource assignments and cost estimates. Furthermore, they urge the project team to rigorously control the schedule to ensure accuracy in variance analysis. The research could be used to promote the feasibility of EVM for improving monitoring efficiency of projects in terms of slower delays and better efficiency.

According to Jung *et al.* (2007), construction project performance can be determined by three factors- Time, Cost and Quality. Researchers and practitioners have been facing the issue with the integration of time control and cost control system. Earned Value Management System (EVMS) act as an efficient solution for this problem by providing detailed standards and procedures and maintaining data integrity. Measuring the progress of the project plays a vital role in EVMS. To identify the work activities along with the project measurement, Standard Progress Measurement System (SPMS) should be developed. Yu *et al.* (2022) says that cost control is more dominant in the construction phase of the project and the project cost can be reduced significantly if mandatory precautions are taken.

The authors identified and analysed the causes of cost overruns and methods adopted for cost control by the UK and Iraqi construction industry. It was analysed that use of cost control of the project is mainly restricted by the adoption of modern-day concepts and methods. Authors developed early cost earning system for the construction projects based on Earned Value Management System (EVMS) to deal with the causes. Author proposed a dynamic cost control system based on rough set theory for coastal engineering projects. Index system should be established based on the principal of Indicator Selection. The Cost Control Index Evaluation should be comprehensive and must have typical representation. Index Evaluation system is determined on the basis of direct and indirect costs. Direct cost is much higher as compared to indirect cost in the construction projects.

3.2 Building Information Modeling (BIM) system

Zhao *et al.* (2014) in his paper emphasized that accuracy of estimation and budgeting is the main step towards the project cost control. Building Information Modeling (BIM) is nowadays an effective tool for project information delivery and extraction. 2D CAD drawings are less effective in determining the accurate cost and information of the project as compared to BIM Model. Although there are series of limitations with implementation of BIM model, such as complexity, cost, and sufficient expertise and training, it cannot be denied that BIM has a very high potential with its visualization, accuracy in information sharing, and automation.

As per the research done by Smith (2016), BIM presents both challenges and opportunities for the project manager for cost controlling. The main problem lies in the fact that designers provide limited information of the models they design to the Quantity Surveyor. This makes it difficult for the QS team to find and rectify the errors in the model. The main requirement of BIM model is accurate and comprehensive data. Data management and training to the site team is also crucial. He states that full potential of BIM has not been utilized yet.

Abdel-Hamid (2023) illustrated through a case study how integrating BIM technologies to the complete life cycle cost of a building project may shorten project durations and save costs. The study focuses on how five BIM aspects are used to manage project expenses. The many elements or layers of data that may be incorporated in a BIM model, such as facility management, sustainability, time, space, and cost, are referred to as the five dimensions of BIM. Recommendations for incorporating BIM into cost control procedures to enhance cost efficiencies by 9.27% of the original cost design.

Wen (2014) combined Lean Construction theory with BIM technology to perform an extensive study on cost control in construction projects. The study method used a case study approach focusing on how Lean Construction theory and BIM technology work to improve construction plans, anticipate construction issues in advance, oversee project advancement and guarantee quality, safety and project deadlines. The real-world example, from the J2 5 initiative, in Pearl River New City showcased how Lean Construction and BIM technology were effectively utilized to manage costs and ensure the success of the project. The research emphasized how Lean Construction and BIM technology play a part in optimizing project outcomes, reducing inefficiencies and efficiently overseeing construction expenses. The final remarks underscored the benefits of combining Lean Construction principles with BIM technology to improve the efficiency of construction projects, minimize tasks, manage costs effectively and ultimately fulfill customer needs.

3.3 Activity Based Costing (ABC)

Due to lack of cost accuracy and relevance, in place of Traditional Costing method, a new costing method know as Activity based costing (ABC) has been evolved (Kim *et al.*, 2001). ABC has two advantages - Prevention of cost distortion and reduction in wastages. Using ABC, it is easy to determine the activities where there are cost overruns and further it can be mitigated

accordingly. The management can extract various other information other than cost information of a project through ABC like quality information and process information. Hafez *et al.* (2017) discusses challenges in cost control in construction projects, emphasizing the importance of Activity Based Costing (ABC).

The study highlights the need for better knowledge in tender pricing, cost estimation, and decision-making through the application of ABC. The study pointed out that the biggest difficulties in keeping project costs under control were things like change orders, mistakes in the design, economic situations, delays in the project, and rises in material prices. ABC helps to understand how to price bids in a better way, estimate costs more accurately, and keep track of costs more effectively. Activity based cost, target cost, value engineering, etc. can be used in modern cost management methods, according to Hafez (2015). In this study, Hafez also gives a case study of a project consist of five different floors and amphitheatre buildings in Egypt. They found that the main problem with traditional method is cost are directly assigned to the project, and second problem is calculation of cost over heads.

The result identified how different elements of cost control approach can be used in construction sector project such as activity-based costing. This method is very effective in calculation of cost over heads because of value adding activity and non-value adding activity and calculate cost over heads accordingly. Al-Jibouri (2003) explored three cost control monitoring pillars in the literature: the leading margin, variances method, and activity-based ratios method. This study focused on the role of choosing a monitoring system that is commensurate to the quantity of data required and which it is capable of being a communication tool. The latest research on this subject has been carried out by Al-Jibouri (2003) who has used the simulation approach. According to his study findings, activity-based ratios approach works better on short-term projects whereas the other methods appear to be more suitable for long-term projects. The experiment pinpointed the importance of the use of monitoring systems to detect variations from planned expenditure and proficiency.

3.4 Value engineering

Li *et al.* (2021) emphasised that BIM and Value Engineering (VE) plays vital role in construction cost control. The study depicted the advantages of BIM targeted at clash detection, 3D modeling, and cost data generation alongside VE's role to optimize resources and imply process changes in construction processes. The report was followed by recommendations to add value to the project, reduce completion time, and improve the quality in totality. Future research as to real data/time analysis of safety, schedule and quality aspects was called upon to come up with a complete framework for construction companies to apply VE.

3.5 Cost management software and AI integration

Li (2021) studied a case on a high-rise building construction project in China to verify the framework and showcase how BIM can be integrated with Virtual Environment. Results

indicate that modification of design and information extraction, including cost data, are facilitated by the implementation of BIM in virtual environment. BIM has the potential to improve virtual environment practice in several ways. Functional analysis and material and building element cost control are only two of the many uses for VE in construction projects. Other uses for VE include assessing green residential structures to save on construction and energy costs and assessing the functionality and cost of new transportation projects. Integration of BIM and Virtual Environments has been shown to improve productivity in several studies. The cost and duration of the projects have been reduced by 10% through this method. The results show that in order to enhance the performance and functionality of building projects before, at, or after a construction phase, combining BIM with Virtual Environments is worth it.

Tembo *et al.* (2024) highlighted the significance of effective cost management in the Zambian Construction Industry, emphasizing the need to address poor cost performance. It underscores the importance of modern cost management tools like smart systems, big data, and BIM to improve efficiency and reliability in cost management practices. This study helped understand how construction costs are handled in Zambia. To improve accuracy and efficiency, modern techniques such as smart systems and cost estimating software are suggested. For future research, it's recommended to focus on higher-grade contractors and understand why there's resistance to using digital cost management methods. Also, there's a need to update training and education in universities to teach modern cost management techniques effectively, emphasizing the importance of IoT and smart systems. Vasista (2017) research highlights the importance of project cost management in construction, emphasizing the impact of estimation accuracy and the need for innovative techniques like Artificial Intelligence in decision-making.

It aims to explore existing models for cost management, focusing on three key stages: pre-design, post-detailed design, and during project execution, along with CRASP methodology for validation. CRASP model is a management methodology model to determine the project management success, by providing a comprehensive approach to access and enhance the project performance by monitoring and control. It says that having good engineering judgment is crucial, and it's also important to use automation and smart techniques in construction projects. They use a flowchart to explain how they did their research, and they look at different ideas in the literature, like Artificial Intelligence and Expert System Techniques, to help with making decisions about managing and controlling costs in construction.

3.6 Cost and risk integration techniques

Javier (2010) combines earned value management and risk management for project control and monitoring. In this study the authors compared the cost and schedule variance with variance due to risk given in risk analysis. Real projects have uncertainties and variability in every aspect of their operations. By opting of quantitative risk analysis, the author found the probability function and distribution of both project cost and schedule. The Monte Carlo simulation technique is an effective way to manage project uncertainty. The simulated project

resulted into various values of activity costs and times after estimating probability distributions of costs and durations. The Cost Control Index (CCoI) and Schedule Control Index (SCoI) are two new metrics that were established to help integrate EVM and Project Risk Management.

Olawale (2010) focus on integration of risk management with cost control. This study was carried out using an integration of quantitative and qualitative methodologies. The top five reasons of UK construction industry that impede time and cost control were: design changes; risks and unforeseen challenges; erroneous project schedule estimations; complexity of activities; and non-performance of subcontractors. The most significant obstacle that practitioners believe impedes the capacity for regulation of construction project time and expense was design change. In this paper, a strong relation was shown between the issues impeding both cost control and time control.

Jackson (2003) made thorough research on cost management techniques in project management practiced in the electricity Industry. The author concentrated particularly on case of one Australian electric corporation. The study underscored the reluctance to establishing the cost management with small-scale projects which resulted in increased risks for the successful financial performance. These points highlighted the use of informal estimations of risks as well as applying cost contingency measures to deal with these obstacles. The audit stressed adequacy of reserves while estimating and shedding the light on the amount of assets to be used for emergencies. The findings were revealing a disparity in levels of understanding and application of cost management strategies, thereby, reminding us of the significance of decision-making and risk management skills to ensure the success of project budget performance.

3.7 Statistical and forecasting techniques

Bhosekar *et al.* (2012) have performed slightly partial comprehensive study on project duration forecasting methods, thoroughly analysing Earned Value Metrics, statistical approaches to Earned Value Management (EVM), and the To Complete Performance Index (TCPI). This research tests the effectiveness of EVA tools that have been designed in Visual Studio against the industry-standard products, for example, MS Project 2007 and Primavera P6. A strong correlation between the solutions was found. Cooray *et al.* (2018) in their research emphasized on the cost control amongst other techniques in the construction projects in Sri Lanka. The study goal is to know whether or not there are cost overruns and to determine how various project control methods and engineering software contribute to the success of a project. The cost control was a key element in the construction of the business. For instance, lessons on Earned value management (EVM), Gantt chart, Program evaluation and Review Technique (PERT), and software tools like Asta power project and Primavera were utilized. The conclusions demonstrated the significance of cooperation mechanisms of cost control to eliminate excessive costs and guarantee on-time project success in Sri Lankan building industry.

Shanmugapriya *et al.* (2013) investigated significant factors leading to time and cost overruns in Indian construction projects, identifying major causes like material market rate and

high transportation costs. It emphasized the importance of addressing key factors such as contract modifications and escalation of material prices to mitigate time and cost overruns. The study pinpointed material market rate fluctuations, contract modifications, stringent quality requirements, project location challenges, and reliance on inexperienced staff as major contributors to time and cost overruns in Indian construction projects. Recommendations were provided to address these issues, urging contractors to vigilantly monitor material prices, ensure timely delivery, and appoint competent staff for effective project management. Owners were advised to revise bid documents, ensure prompt progress payments, and engage skilled project managers for comprehensive oversight. Consultants were encouraged to expedite the review and approval of design documents, hire qualified technical personnel, and maintain flexibility in assessing contractor works to mitigate delays and cost escalations. These recommendations underscore the importance of proactive measures in curbing overruns and enhancing project efficiency within the Indian construction industry.

The study by Bahaudin *et al.* (2012) explores the inadequacies of current cost control practices in Malaysian construction, revealing a reliance on traditional corrective methods. It emphasizes the need for a proactive approach to cost control to anticipate and prevent cost overruns in construction projects. The research methodology employed in the paper is qualitative, using a semi-grounded theory approach to examine construction cost control practices in Malaysia. Grounded theory is utilized to uncover theories implicit in the data rather than testing hypotheses, focusing on what theory explains the research situation as it is. The study followed a three-stage process for data collection, analysis, and interpretation, ensuring a thorough investigation of prevalent cost control practices and procedures in the Malaysian construction sector. While they express satisfaction with their current approach, there is room for improvement, especially in early detection of potential cost overruns.

Andrea (2016) did the literature review and analysed the results of nine empirical studies conducted in four different construction firms of Brazil. The main objective of the research was to propose a model of planning and cost control for construction firms. They conducted their study in small and medium building projects. Construction companies' traditional cost management systems have a number of issues, many of which have been extensively covered in the literature, their information is typically delivered too late and is frequently too skewed and aggregated to be useful for production management. The model's scope was restricted to construction projects executed by small and medium-sized businesses that engaged in both production and product development. The outcome of model suggests to integrate the three most effective cost management techniques: operational cost estimation, s-curve and target costing.

3.8 Effective project management

Otim *et al.* (2006) investigated cost control techniques in Uganda's building construction, identifying common issues like delays, lack of materials, and poor management.

The study aims to identify and propose effective cost control techniques for building construction in Uganda, emphasizing the importance of managing construction costs to prevent losses and project failures. It focuses on the challenges faced by contractors in controlling costs on construction sites, explores commonly used cost control techniques, and suggests remedies to enhance cost control practices in the industry. Overall, the study suggests that better training and management could help Ugandan construction projects stay on budget and schedule. The study reveals that the primary challenge lies not in the absence of techniques but rather in the insufficient knowledge of these methods, poor management of cost control practices, and inadequate site organization and supervision. The research underscores the importance of continuous training for contractors in construction project management to address the lack of knowledge of cost control techniques and the necessity for effective supervision and communication on construction sites.

The study by Ali *et al.* (2022) focuses on cost and time management in construction projects in Khartoum State, Sudan, highlighting natural, political, and economic factors affecting project delays and the importance of coordination and fund management. It emphasizes the need for good coordination, monitoring, and appropriate fund management to reduce delays and cost overruns in construction projects in Khartoum State, Sudan. Analysis of the collected data was performed using the Statistical Package for the Social Sciences (SPSS) software to derive statistical insights and draw conclusions from the responses. It was found that unexpected economic changes, government actions, and natural events were the biggest reasons why construction projects ran late. Material delivery delays caused by worker shortages and price hikes were also common problems. By working together better and managing money wisely, those involved in construction projects can keep things on track and on budget.

4.0 Conclusions and Future Recommendations

The study tried to find answers to the research objectives i.e. 1- Investigating the problems of cost overruns in the construction projects. 2- Analysing the efficiency of cost controlling techniques in construction projects. A thorough literature review was conducted to provide the research objectives findings. Our research tried to analyse the efficiency of tools and techniques for project cost control along with the major challenges in keeping the project under budget and schedule. The primary challenges include improper project budgeting, estimation and planning, lack of contingency, lack of proper risk assessment, and rework. It is evident that to control the project cost effectively, systematic approaches are required to integrate real time project tracking in terms of cost and schedule with proper planning and budgeting. Project cost monitoring and controlling needs to be a continuous process throughout the project life cycle to accurately forecast the risk and timely reporting to the planning team.

Overall, the review emphasizes the importance of combining advanced methodologies such as BIM, VE along with earned value analysis and traditional techniques to improve cost

control. The review highlights the need for accurate data, proactive planning, and continuous monitoring to address the construction industry's ongoing cost overrun challenges. The future research can be directed towards getting more insights through semi structured interviews, focussing on the practices adopted by industry professionals for controlling the project cost.

References

- Abdelhamid, H. M. A. (2022). Cost and time control in construction projects: A case study of Khartoum State. *Jilin Daxue Xuebao (Gongxueban)/Journal of Jilin University (Engineering and Technology Edition)*.
- Abdel-Hamid, M., & Abdelhaleem, H. M. (2023). Project cost control using five dimensions building information modelling. *International Journal of Construction Management*, 23(3), 405–409. <https://doi.org/10.1080/15623599.2021.1880313>
- Al-Jibouri, S. H. (2003). Monitoring systems and their effectiveness for project cost control in construction. *International Journal of Project Management*, 21(2), 145–154. [https://doi.org/10.1016/S0263-7863\(02\)00093-7](https://doi.org/10.1016/S0263-7863(02)00093-7)
- Andrea, et al. (2006). Cost management in construction: A case-based study. *Journal of Financial Management of Property and Construction*, 11(2), 75–90. <https://doi.org/10.1108/13664380680001073>
- Bahaudin, A. Y. (2012). Construction cost control: A review of practices in Malaysia. *International Journal of Construction Management*, 12(2), 1–6.
- Bhosekar, S. K., & Vyas, G. (2012). Cost controlling using earned value analysis in construction industries. *International Journal of Engineering and Innovative Technology*, 1(4), 324–332.
- Cooray, N. H. K., Somathilake, H. M. D. N., Wickramasinghe, M., Dissanayake, T. D. S. H., & Dissanayake, D. M. M. I. (2018). Analysis of cost control techniques used on building construction projects in Sri Lanka. *International Journal of Research*, 5(23), 909–923.
- Hafez, S. M. (2015). Research on optimal techniques for cost reduction and control in construction sites. *Journal of Human Resource Management*, 3(3), 17–26. <https://doi.org/10.11648/j.jhrm.20150303.11>
- Hafez, S. M., et al. (2015). Optimal techniques for cost reduction and control in construction. *Journal of Human Resource Management*, 3(3), 17–26.

Jackson, G. (2003). Contingency for cost control in project management: A case study. *Construction Economics and Building*, 3(1), 1–12. <https://doi.org/10.5130/AJCEB.v3i1.2876>

Javier, A., et al. (2010). An extension of the EVM analysis for project monitoring: The cost control index and the schedule control index. *International Journal of Project Management*, 29(5), 615–621. <https://doi.org/10.1016/j.ijproman.2010.06.003>

Jung, Y., & Kang, S. (2007). Knowledge-based standard progress measurement for integrated cost and schedule performance control. *Journal of Construction Engineering and Management*, 133(1), 10–21. [https://doi.org/10.1061/\(ASCE\)0733-9364\(2007\)133:1\(10\)](https://doi.org/10.1061/(ASCE)0733-9364(2007)133:1(10))

Kim, Y. W., & Ballard, G. (2001). Activity-based costing and its application to lean construction. In *Proceedings of the 9th Annual Conference of the International Group for Lean Construction* (pp. 6–8). Singapore.

Li, X., et al. (2021). Case study on BIM and value engineering integration for construction cost control. *Advances in Civil Engineering*, 2021, 1–13.

Li, X., Wang, C., & Alashwal, A. (2021). Case study on BIM and value engineering integration for construction cost control. *Advances in Civil Engineering*, 2021, 1–13. <https://doi.org/10.1155/2021/5590644>

Marrero, M., Fonseca, A., Falcon, R., & Ramirez-de-Arellano, A. (2014). Schedule and cost control in dwelling construction using control charts. *The Open Construction & Building Technology Journal*, 8(1), 156–165. <https://doi.org/10.2174/1874836801408010156>

Olawale, Y. A., & Sun, M. (2010). Cost and time control of construction projects: Inhibiting factors and mitigating measures in practice. *Construction Management and Economics*, 28(5), 509–526. <https://doi.org/10.1080/01446191003674519>

Otim, G. (2006). Research on cost control techniques used on building construction sites in Uganda. *Makerere University Institutional Repository*.

Premalal, A. G. D., Mudalige, R. K. P. C. B., & Malkanthi, S. N. (2016). Study of cost control techniques used in construction industry and their impact to minimize cost overrun. *Department of Civil and Environmental Engineering*, 164–170.

Shanmugapriya, S. (2013). Research on significant factors influencing time and cost overruns in Indian construction projects. *International Journal of Engineering Research and Applications*, 3(6), 887–892.

Smith, P. (2016). Project cost management with 5D BIM. *Procedia - Social and Behavioral Sciences*, 226, 193–200. <https://doi.org/10.1016/j.sbspro.2016.06.179>

Tembo, C. K., et al. (2024). An appraisal of cost management techniques used in the construction industry. *International Journal of Construction Management*, 24(1), 10–18. <https://doi.org/10.1080/15623599.2022.2132355>

Vasista, T. G. K. (2017). Research on innovative methods of construction cost management and control. *Civil Engineering Journal (CiVEJ)*, 4(1), 1–9.

Wen, Y. (2014). Research on cost control of construction project based on the theory of lean construction and BIM: Case study. *The Open Construction & Building Technology Journal*, 8(1), 382–388. <https://doi.org/10.2174/1874836801408010382>

Yu, X., & Zuo, H. (2022). Research on construction cost control technology of construction project based on big data analysis theory. *Mobile Information Systems*, 2022, Article 8739097. <https://doi.org/10.1155/2022/8739097>

Zhao, P. A., & Wang, C. C. (2014). A comparison of using traditional cost estimating software and BIM for construction cost control. In *ICCREM 2014: Smart Construction and Management in the Context of New Technology* (pp. 256–264).

CHAPTER 116

Review on Comparison between Properties of Tor and Stainless-Steel

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ABSTRACT

Choice of Materials Is important as It significantly affects the strength, safety, durability of the structures. This paper presents a comparative study of Tor-Steel and Stainless-Steel known for its remarkable resistance to corrosion. This research investigates the mechanical properties for both materials including tensile strength, ductility, hardness and fatigue resistance as well as their chemical compositions and corrosion resistance. By analysing these factors paper provides insights into the appropriate material selection based on specific engineering requirements where each material may offer superior performance. This study offers valuable guidance for engineers in selecting between Tor-Steel and Stainless-Steel for optimal results in structural design.

Keywords: Stainless Steel 1; Tor Steel 2; Materials 3.

1.0 Introduction

Material selection is critical in engineering and construction. Among the many available options, Tor-Steel and Stainless-Steel are notable for their unique properties, each suited to different engineering needs. This research paper provides comparative analysis for these two widely used materials focusing on their mechanical, chemical, and environmental characteristics. Tor-Steel a high-strength variant of carbon steel is valued for its exceptional tensile strength and fatigue resistant. That makes it perfect for applications that require maintaining structural integrity under high stress. It is commonly found in the automotive, construction and manufacturing industries, particularly in parts like bolts, gears and shafts that experience significant torsional stress. Despite its mechanical strength Tor-Steel has drawbacks, primarily its vulnerability to corrosion. Without adequate protection, it can degrade quickly when exposed to moisture, chemicals or other corrosive elements potentially leading to structural failure (Han *et al.*, 2023). In contrast Stainless-Steel is an alloy mainly composed of iron, chromium and nickel which is well-known for its outstanding corrosion resistance which is achieved through the formation of a protective oxide layer that prevents rust (Zheng *et al.*, 2024). Its strength, durability and resistance to oxidation make it a preferred material in a wide

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range of applications including construction, medical instruments and maritime environments (Rabi *et al.*, 2020). Its versatility is further enhanced by its ability to retain structural integrity across extreme temperatures making it suitable for both high-temperature and sub-zero conditions (Chen *et al.*, 2024).

1.1 Tor-Steel

TOR steel short for Torsional Steel is a HYSD steel bar widely used for reinforced concrete construction due to its excellent tensile strength and strong bonding with concrete (Islam *et al.*, 2020). It is available in various strength grades to suit different construction needs i.e. Fe (415, 500, 550, and 600) along with their specialized variants like Fe (415D, 415S, 500D, 500S and 550D) which offer enhanced properties for specific applications. The material's chemical composition is tailored to meet the requirements of durability and performance in concrete reinforcement. Table 1 Represents Chemical Composition of Tor-Steel.

Table 1: Chemical Composition of Tor-Steel (Amend No. 1 to IS 1786: 2008)

Constituent	Percent Maximum								
	Fe415	Fe415D	Fe415S	Fe500	Fe500D	Fe500S	Fe550	Fe550D	Fe600
C	0.30	0.25	0.25	0.30	0.25	0.25	0.30	0.25	0.30
S	0.060	0.045	0.045	0.055	0.040	0.040	0.055	0.040	0.040
P	0.060	0.045	0.045	0.055	0.040	0.040	0.050	0.040	0.040
S and P	0.110	0.085	0.085	0.105	0.075	0.075	0.100	0.075	0.075

Table 2: Chemical Composition of Stainless-Steel (IS 16651: 2017)

Sr No.	Steel Designation Number		International standard designation	C Max	Si Max	Mn Max	S Min/ Max	Cr Min/ Max	Ni Min/ Max	Mo Min/ Max	P Max	Cu Min/ Max	N Min/ Max
1	A	Austenitic	1.4301	0.07	1.0	2.0	0.030	17.00/ 19.50	8.00/ 10.50	-	0.045	-	0.0/ 0.11
2	B		1.4311	0.03	1.0	2.0	0.030	17.50/ 19.50	8.50/ 11.50	-	0.045	-	0.12/ 0.22
3	C		1.4436	0.05	1.0	2.0	0.030	16.50/ 18.50	10.50/ 13.00	2.50/ 3.00	0.045	-	0.0/0.11
4	D	Austenitic-Ferritic	1.4162	0.04	1.0	4.0to6.0	0.015	21.00/ 22.00	1.35/ 1.70	0.10/ 0.80	0.040	0.10/ 0.80	0.20/0.25
5	E		1.4362	0.03	1.0	2.0	0.015	22.00/ 24.50	3.50/ 5.50	0.10/ 0.60	0.035	0.10/ 0.60	0.05/ 0.20
6	F		1.4462	0.03	1.0	2.0	0.015	21.00/ 23.00	4.50/ 6.50	2.50/ 3.50	0.035	-	0.10/ 0.22
7	G	Ferritic	410L	0.03	1.0	1.0	0.030	11.00/ 13.50	0.0/ 0.60	-	0.040	-	-

1.2 Stainless-Steel

Stainless steel is a corrosion-resistant alloy composed primarily of iron, chromium and other elements valued for its strength, durability & aesthetic appeal (Chen *et al.*, 2024). When used as concrete reinforcement stainless steel is available in various high-strength grades such as SS (500,550,600 and 650) each further categorized into subgrades (A to G). These grades are designed to meet specific performance criteria and undergo standardized tests to ensure quality and reliability. Table 2 Represents Chemical Composition of SS.

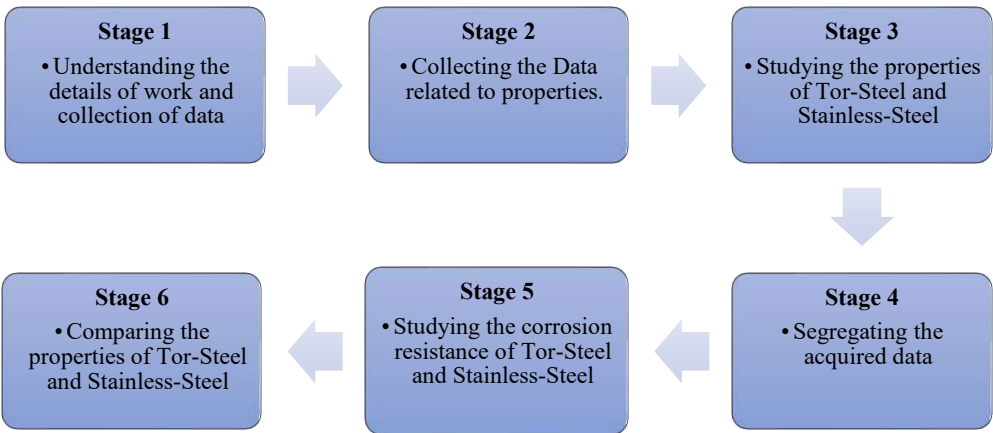
2.0 Methodology

Figure 1 illustrates methodology in this research, which is detailed in the following section:

Stage 1: Understanding the details of work and collection of data:

Understanding the details of work and data collection means fully comprehending the research scope and objectives, ensuring clear tasks. It involves systematically collecting data from experiments, observations, or literature. This approach ensures the research is based on accurate information, supporting thorough analysis and valid conclusions.

Figure 1: Flow of Work



Stage 2: Collecting data related to properties:

Acquiring the properties of Tor-Steel and Stainless-Steel means investigating their essential characteristics, like strength, ductility and corrosion resistance. This involves analyzing their performance under various conditions with the help of different research papers. The goal is to understand how each material behaves and compare their suitability for different uses.

Stage 3: Studying the properties:

Studying the properties of Tor-Steel and Stainless-Steel using different research papers involves reviewing scientific studies to gather detailed information about their characteristics.

By comparing findings on factors like strength and corrosion resistance, a broader understanding of the materials is achieved. This ensures a well-supported comparison based on diverse research

Stage 4: Segregating the acquired data

Segregating the acquired data means sorting and organizing the collected information into categories. This process helps in structuring the data for easy analysis and comparison. It ensures that the information is clear and relevant for drawing accurate conclusions about the materials.

Stage 5: Studying the corrosion resistance of Tor-Steel and Stainless-Steel

Corrosion is deterioration of materials. It mainly happens when metals come into contact with oxygen, moisture, or other chemicals, which leads to the formation of oxides or other compounds. This process weakens the metal, diminishing its mechanical strength and durability over time. So, studying the corrosion property of Tor-Steel and Stainless-Steel independently is important. This helps determine which material offers better long-term protection in corrosive settings.

Stage 6: Comparing the properties of Tor-Steel and Stainless-Steel

After collecting all data and data segregation we will compare the data and will present in the paper in tabular format.

3.0 Literature Review

- *Corrosion Resistance:* Stainless steel provides enhanced corrosion resistance due to its passive oxide layer which protects it from rusting in aggressive environments. Studies highlight its superior performance in chloride-rich conditions compared to Tor steel (Guo *et al.*, 2024; Moodley *et al.*, 2024; Wang *et al.*, 2024). The ability to resist pitting and crevice corrosion makes stainless steel an ideal choice for infrastructure exposed to moisture and chemicals.
- *Mechanical Strength:* Research shows that stainless steel exhibits higher mechanical strength than Tor steel with improved yield strength and ultimate tensile strength (Ding *et al.*, 2024; Yoo *et al.*, 2024; Zheng *et al.*, 2024). Its superior strength-to-weight ratio makes it an efficient material for high-load applications, reducing structural weight without compromising performance.
- *Ductility:* Ductility is essential in seismic-resistant structures, and stainless steel demonstrates an increased strain-hardening capacity compared to Tor steel (Chen *et al.*, 2024; Duan *et al.*, 2024; Xing *et al.*, 2024). This characteristic ensures better energy dissipation and flexibility under extreme loading conditions reducing the risk of sudden failure.
- *Hardness:* While hardness influences wear resistance studies show that stainless steel maintains a balance between hardness and ductility preventing brittleness while ensuring

durability (Hwang *et al.*, 2024; Meza *et al.*, 2024; Zhang *et al.*, 2023). This makes it a suitable material for applications requiring impact resistance.

- *Toughness*: Toughness is critical in dynamic loading conditions and stainless steel has been shown to outperform Tor steel in energy absorption and resistance to fracture (Han *et al.*, 2023; Li & Aoude, 2023; Rabi *et al.*, 2022). Its superior impact toughness makes it ideal for structural applications in bridges and earthquake-prone regions.
- *Thermal Conductivity*: Compared to Tor steel, stainless steel has a lower thermal conductivity making it a better insulator in high-temperature environments (Fu *et al.*, 2022; Huang *et al.*, 2022). This property enhances its performance in fire-resistant and heat-exposed structures.
- *Weldability*: Stainless steel exhibits good weldability with proper techniques though some grades require preheating to prevent cracking (Chen *et al.*, 2022; Chen *et al.*, 2022). Tor steel while easier to weld may suffer from loss of strength in the heat-affected zone requiring additional precautions.
- *Elastic Modulus*: Studies indicate that the Young's modulus of stainless steel is comparable to that of Tor steel ranging from 200 to 208 GPa (Han *et al.*, 2022; Yang *et al.*, 2022). However stainless steel demonstrates better consistency in elastic behavior reducing long-term deformation in structures.
- *Fatigue Resistance*: Fatigue resistance is crucial in cyclic loading applications such as bridges and high-rise buildings. Stainless steel has shown better resistance to fatigue failure compared to Tor steel improving structural longevity (Xin *et al.*, 2021; Xu *et al.*, 2021).
- *Density*: Stainless steel has a slightly higher density than Tor steel but its enhanced strength offsets this weight increase making it efficient in load-bearing applications (Chen *et al.*, 2021).
- *Applications*: Stainless steel is widely used in bridge piers, marine structures and seismic reinforcements due to its superior mechanical properties and corrosion resistance (Li *et al.*, 2021). Meanwhile Tor steel remains a cost-effective option for general reinforcement in concrete structures.

4.0 Observations

Table 4 contrasts the different properties of Tor-Steel and Stainless-Steel, highlighting their respective suitability for various applications. Table 5 emphasizes the notable contrast in corrosion resistance between Tor-Steel and Stainless-Steel, illustrating how Stainless-Steel's enhanced durability makes it a more dependable option for extended use in corrosive settings.

5.0 Conclusion

Stainless-Steel recognized for its exceptional resistance to corrosion, high strength, and excellent ductility, offers clear advantages over Tor-Steel, particularly in environments prone to corrosion.

Table 3: Properties Table

Property	Tor-Steel	Stainless-Steel
Corrosion Resistance	Moderate; requires protective coatings or treatments for corrosion resistance.	High; inherently resistant due to chromium content forming a passive oxide layer.
Mechanical Strength	High tensile strength; often used in high-stress applications.	Varies by type; austenitic grades have good strength, duplex grades offer higher strength.
Ductility	Moderate to high; ductility decreases with increased carbon content.	High, especially in austenitic grades.
Hardness	Generally high; can be increased through heat treatment processes.	Varies by grade; martensitic Stainless-Steels can be hardened significantly.
Toughness	Good, but may decrease at low temperatures.	Generally excellent, especially in austenitic grades, which remain tough at low temperatures.
Thermal Conductivity	Moderate; varies depending on alloying elements.	Lower than carbon steel; varies by grade but generally lower thermal conductivity.
Weldability	Good; certain grades may require preheating or post-weld heat treatment.	Varies; austenitic grades are typically easy to weld, while others may require special techniques.
Elastic Modulus	Approx. 210 GPa (similar to Stainless-Steel).	Approx. 190-200 GPa; varies slightly by grade.
Fatigue Resistance	High; often used in applications where cyclical loading is present.	Varies; duplex and martensitic grades generally have good fatigue resistance.
Density	Approximately 7.85 g/cm ³ .	Typically: 7.7-8.0 g/cm ³ , depending on the alloy.
Applications	Tools, fasteners, springs, and other high-strength applications.	Structural applications, automotive parts, medical devices, and more.

Table 4: Corrosion Resistance

Parameter	Tor-Steel	Stainless-Steel
Corrosion Resistance	Moderate - Prone to rust in high-chloride environments	High - Excellent resistance due to the presence of chromium and nickel
Corrosion Protection Measures	Requires regular maintenance, coatings, or galvanization to prevent rust	Naturally corrosion-resistant, minimal maintenance required
Environmental Suitability	Suitable for low-chloride environments; high-chloride conditions require additional protection	Ideal for high-chloride environments (e.g., coastal areas, chemical industries)
Long-Term Durability	Susceptible to corrosion over time, leading to reduced structural integrity	Superior durability with minimal corrosion over time
Cost Implications	While the initial cost is lower, there may be higher maintenance and repair expenses over time due to corrosion.	Although the initial cost is higher, the overall life cycle cost is lower because of reduced maintenance requirements
Impact of Corrosion on Mechanical Properties	Corrosion reduces strength and ductility, raising the likelihood of structural failure.	Preserves its mechanical properties even in corrosive conditions, guaranteeing reliable performance.
Common Applications	General construction where corrosion is not a primary concern	Critical structures exposed to harsh environments (e.g., bridges, marine structures)

Although Tor-Steel may be more cost-effective and provide adequate strength for some uses, Stainless-Steel's superior durability, aesthetic value, and minimal maintenance needs make it the preferred option for crucial structural elements, especially in challenging environments.

6.0 Future Scope

- **Advanced Mechanical Properties Analysis:** Future research can delve deeper into the microstructural changes of Tor-Steel and Stainless-Steel under different loading conditions. This could provide a better understanding of the fatigue resistance, ductility, and strain-hardening characteristics unique to each material.
- **A comparative analysis with different environments** like marine and industrial conditions could provide valuable insights into their long-term durability and maintenance requirements.
- **New Alloy Developments:** The creation of new steel alloys that blend the properties could be a potential area of research. These new materials could be tailored for specific applications where a balance of high strength, corrosion resistance, and cost-effectiveness is required.

This future scope is designed to address gaps in current knowledge, expand the potential applications of Tor and Stainless-Steel, and contribute to the development of new materials and technologies.

References

- Chen, J., Wang, Z., Liu, Z., & Ju, S. (2022). Experimental investigation of mechanical properties of steel half-grouted sleeve splice with rebar bonding defects. *Journal of Building Engineering*, 50, 104113. <https://doi.org/10.1016/j.jobe.2022.104113>
- Chen, T., Fan, S., Xu, Q., Xu, K., Luo, J., & Tang, Y. (2024). Research on mechanical properties of duplex stainless steel S22053 at elevated temperature and after fire. *Thin-Walled Structures*, 197, 111620. <https://doi.org/10.1016/j.tws.2024.111620>
- Chen, Z., Gao, L., & Koleva, D. A. (2022). Evaluating the stray current corrosion of steel rebar in different layouts. *Measurement*, 196, 111217. <https://doi.org/10.1016/j.measurement.2022.111217>
- Chen, Z., Mo, L., Li, S., Liang, Y., & Xu, D. (2021). Seismic behavior of steel reinforced concrete L-shaped columns under compression-bending-shear-torsion combined action. *Journal of Building Engineering*, 42, 102498. <https://doi.org/10.1016/j.jobe.2021.102498>

Ding, Y., Zeng, B., Zhou, Z., Wei, Y., & Zhu, M. (2024). Seismic retrofitting of RC columns using stainless steel grid-reinforced UHPC jackets in plastic hinge zone. *Journal of Building Engineering*, 84, 108637. <https://doi.org/10.1016/j.jobe.2024.108637>

Duan, S., Fan, S., Shu, G., Jiang, L., Tong, J., & Wu, Y. (2024). Numerical study and design of S35657 stainless steel welded stub columns. *Journal of Constructional Steel Research*, 214, 108473. <https://doi.org/10.1016/j.jcsr.2024.108473>

Fu, J. Y., Ge, X., Li, J. T., Sun, Z. G., & Wang, D. S. (2022). Seismic performance of concrete bridge piers reinforced by stainless steel bars: A quasi-static experimental study. *Engineering Structures*, 266, 114507. <https://doi.org/10.1016/j.engstruct.2022.114507>

Guo, J., Chan, T. M., & Wang, Y. (2024). Test, modelling and design of a demountable stainless steel bar connection system for precast concrete pavements. *Engineering Structures*, 301, 117231. <https://doi.org/10.1016/j.engstruct.2023.117231>

Han, P., Qiao, G., & Ou, J. (2022). Damage investigations of the rebar under the coupling effect of fatigue and stray electric field induced corrosion. *International Journal of Fatigue*, 160, 106844. <https://doi.org/10.1016/j.ijfatigue.2022.106844>

Han, X., Wang, P., Cui, D., Tawfik, T. A., Chen, Z., Tian, L., & Gao, Y. (2023). Rebar corrosion detection in concrete based on capacitance principle. *Measurement*, 209, 112526. <https://doi.org/10.1016/j.measurement.2023.112526>

Huang, B., Cheng, Z., & Yao, J. (2022). Experimental study on flexural behavior of rebar concrete beams in industrial building exceeding 50 years. *Journal of Building Engineering*, 46, 103697. <https://doi.org/10.1016/j.jobe.2021.103697>

Hwang, B. K., Kim, T. S., & Ahn, Y. H. (2024). Experimental and numerical investigation of austenitic stainless steel (304 type) slit damper structural behavior. *Thin-Walled Structures*, 196, 111551. <https://doi.org/10.1016/j.tws.2023.111551>

Islam, K., Billah, A. M., Chowdhury, M. M. I., & Ahmed, K. S. (2020). Exploratory study on bond behavior of plain and sand coated stainless steel rebars in concrete. *Structures*, 27, 2365–2378. <https://doi.org/10.1016/j.istruc.2020.07.039>

Li, K., Liu, W., Zhang, K., Wang, X., Zhu, J., & Sheikh, S. (2021). Bond behavior of stainless steel wire ropes embedded in engineered cementitious composites. *Construction and Building Materials*, 281, 122622. <https://doi.org/10.1016/j.conbuildmat.2021.122622>

Li, Y., & Aoude, H. (2023). Effects of stainless steel reinforcement and fibers on the flexural behaviour of high-strength concrete beams subjected to static and blast loading. *Engineering Structures*, 291, 116398. <https://doi.org/10.1016/j.engstruct.2023.116398>

Meza, F. J., Baddoo, N., & Gardner, L. (2024). Derivation of stainless steel material factors for European and U.S. design standards. *Journal of Constructional Steel Research*, 213, 108383. <https://doi.org/10.1016/j.jcsr.2023.108383>

Moodley, H., Afshan, S., Crump, D., & Kashani, M. M. (2024). Testing and numerical modelling of circular stainless steel reinforced concrete columns. *Engineering Structures*, 304, 117607. <https://doi.org/10.1016/j.engstruct.2024.117607>

Rabi, M., Cashell, K. A., Shamass, R., & Desnerck, P. (2020). Bond behaviour of austenitic stainless steel reinforced concrete. *Engineering Structures*, 221, 111027. <https://doi.org/10.1016/j.engstruct.2020.111027>

Rabi, M., Shamass, R., & Cashell, K. A. (2022). Structural performance of stainless steel reinforced concrete members: A review. *Construction and Building Materials*, 325, 126673. <https://doi.org/10.1016/j.conbuildmat.2022.126673>

Wang, Z., Xie, K., Tian, P., & Lu, J. (2024). Study on mechanical properties and bearing capacity calculation of eccentric compression of RC columns reinforced with prestressed lattice steel. *Structures*, 64, 106499. <https://doi.org/10.1016/j.istruc.2024.106499>

Xin, Z., Jianyang, X., Rui, R., & Linlin, M. (2021). Test on pure torsion behavior of channel steel reinforced concrete beams. *Journal of Building Engineering*, 44, 102967. <https://doi.org/10.1016/j.jobbe.2021.102967>

Xing, Z., Jiang, M., San, B., Wang, J., & Wu, K. (2024). Fire behaviour of stainless steel circular hollow section stub columns: Experimental study and design. *Thin-Walled Structures*, 196, 111494. <https://doi.org/10.1016/j.tws.2023.111494>

Xu, C., Nehdi, M. L., Youssef, M. A., Wang, T., & Zhang, L. V. (2021). Seismic performance of RC beam-column edge joints reinforced with austenite stainless steel. *Engineering Structures*, 232, 111824. <https://doi.org/10.1016/j.engstruct.2020.111824>

Yang, H., Mei, J., & Yang, Y. (2022). Bond strength and reliability analysis of stainless steel rebar embedded in fiber reinforced coral aggregate concrete. *Construction and Building Materials*, 350, 128783. <https://doi.org/10.1016/j.conbuildmat.2022.128783>

Yoo, D. Y., Soleimani-Dashtaki, S., Oh, T., Chun, B., Banthia, N., Lee, S. J., & Yoon, Y. S. (2024). Strain-hardening effect on the flexural behavior of ultra-high-performance fiber-reinforced concrete beams with steel rebars. *Developments in the Built Environment*, 17, 100343. <https://doi.org/10.1016/j.dibe.2024.100343>

Zhang, J., Liu, X., Liu, J., Zhang, M., & Cao, W. (2023). Seismic performance and reparability assessment of recycled aggregate concrete columns with ultra-high-strength steel bars. *Engineering Structures*, 277, 115426. <https://doi.org/10.1016/j.engstruct.2022.115426>

Zheng, B., Wu, D., Wang, J., & Shu, G. (2024). Study on ductile fracture behaviors of stainless steel S30408 and its weld. *Journal of Constructional Steel Research*, 214, 108498. <https://doi.org/10.1016/j.jcsr.2024.108498>

CHAPTER 117

Revolutionizing Urban Transit: A Comprehensive Look at Metro Rail Projects in India

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ABSTRACT

India's urbanization has increased need for sustainable and effective public transit systems. Projects including metro rail have become an essential way to reduce traffic, improve connectivity, and stimulate economic expansion. With an emphasis on funding strategies including Public-Private Partnerships (PPP), Land Value Capture (LVC), and Additional Development Rights (ADR), this paper examines the development of metro rail in India. The integration of various financial models and their effects on urban growth are examined using the Hyderabad Metro as a case study. In order to determine if international metro finance techniques, such as those used by the Tokyo Metro and Hong Kong MTR—are applicable in India, the research examines them. The financial structure, income generation, zoning laws, and real estate effect of the Hyderabad Metro, the biggest PPP metro project in India, are all addressed. The results show that property prices are greatly impacted by metro construction, with significant appreciation occurring in communities along the metro lines. The financial viability of metro expansions has also been aided by the adoption of FAR-based zoning laws and transit-oriented development (TOD). In order to guarantee that metro projects continue to be financially viable, this study highlights the necessity of finding new income streams outside of fares. India's metro networks may expand more effectively with the use of value capture techniques and astute urban planning. In order to enhance metro finance through equitable and sustainable financial models, the study provides stakeholders, planners, and legislators with useful insights.

Keywords: Land development mechanism; Value capture mechanism; Additional Development Rights (ADR); Mass rapid transport; Influence zone.

1.0 Introduction

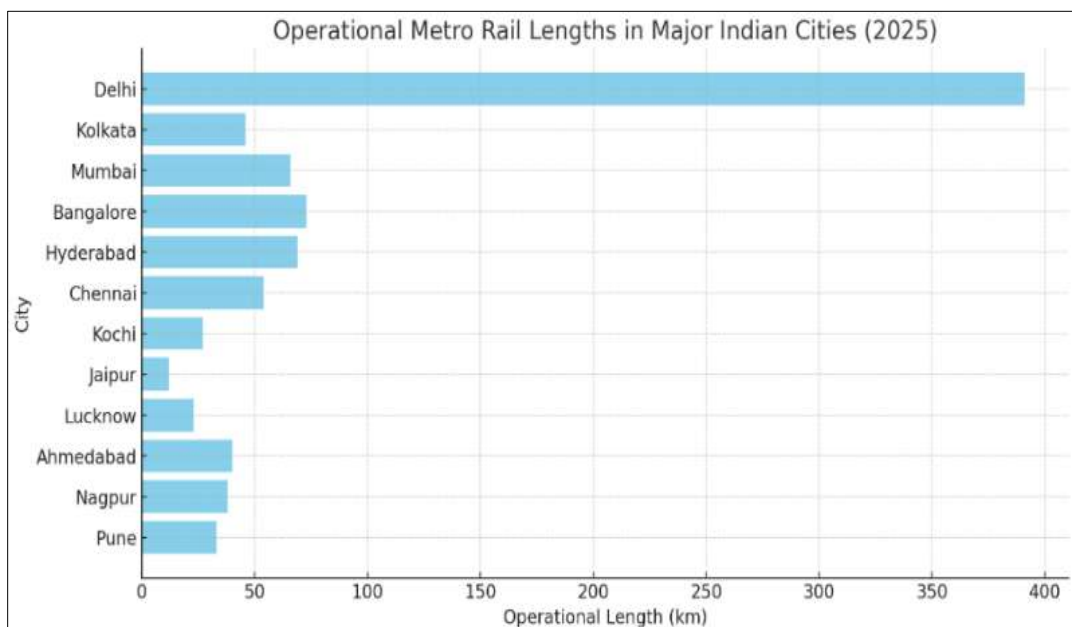
Background: India's fast urbanization has made transportation extremely difficult, necessitating the development of sustainable and effective transit systems.

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Metro rail systems are now crucial for lowering traffic, increasing connection, and speeding up travel. The Delhi Metro's performance since 2002 established the norm for contemporary metro systems, while India's first metro, the Kolkata Metro, began operations in 1984. Since then, other cities have created their own metro systems, including Ahmedabad, Hyderabad, Bengaluru, Mumbai, Chennai, Jaipur, Lucknow, and Kochi see (Figure 1). In order to facilitate metro construction, the government's 2017 Metro Rail Policy encourages financing techniques including Value Capture Finance (VCF), Public-Private Partnerships (PPP), and sustainable finance models. The metro systems in each city are made to fit local requirements; for instance, Bengaluru's Namma Metro helps reduce traffic in the IT corridor, while Mumbai Metro combines with suburban rail. Even with the metro's quick growth, financing is still difficult. To ensure sustainable metro growth, creative financial techniques including Land Value Capture (LVC), Transit-Oriented growth (TOD), and Additional Development Rights (ADR) are essential.

Figure 1: Operational Metro Rail Lengths in India



Source: Compiled by authors

The Hyderabad Metro is a state-of-the-art metro system that was constructed in 2010 for \$2.2 billion under a PPP model with L&T. It links important city centres across a distance of 69 kilometres. Fares, advertisements, and real estate provide revenue, but poor traffic led to financial problems. ADR and LVC can provide long-term viability.

Table 1: Operational Metro Rail in Hyderabad

Corridor	Route	Length (km)	No. of Stations	Status
Red Line	Miyapur ↔ LB Nagar	29.2	27	Operational
Blue Line	Nagole ↔ Raidurg	27	23	Operational
Green Line	JBS Parade Ground ↔ MG Bus Station	11	9	Operational

Source: Compiled by authors

1.2 Objectives

- Propose ways to generate revenue from the metro's impact area, such as land development and value capture methods, to help finance the metro project.
- Create a predictable cashflow for the metro project financed by value capture mechanism.
- Study of the present financing model of the Hyderabad Metro and Suggest land financing infrastructure model.
- A Detailed study of the Metro's in India.

1.3 Need for study & scope of work

The Public-Private Partnership (PPP)-funded Hyderabad Metro has trouble making enough money for development and long-term upkeep. By charging companies and property owners who profit from metro connections, Land Value Capture (LVC) helps recoup some of the higher land prices close to stations. By making money from land sales, company leases, and property development, this lessens dependency on fare revenue. Additionally, by encouraging mixed-use urban expansion near metro stations, LVC encourages Transit-Oriented Development (TOD). In return for payments, developers can construct outside of zoning restrictions under Additional Development Rights (ADR), which helps finance future expansions. Metro impact zones must be identified, property value appreciation must be evaluated, zoning regulations must be updated, and private and public parties must work together in order to implement LVC. Appropriate monitoring is ensured by an oversight authority. Hyderabad Metro may attain sustainable urban growth, financial stability, and a decreased dependency on passenger fares by combining LVC and PPP.

2.0 Literature Review

Analysis of global financial models is aided by a Systematic Literature Review (SLR) employing the PRISMA approach. Funding strategies are categorized under the TCCM model according to research techniques, financial considerations, theory, and context. LVC and TOD are successfully integrated in a number of metro projects across the world. The Delhi Metro employs a combination of government funds, business income, and foreign loans, whereas the Hong Kong MTR finances itself through real estate development. To encourage expansion, London Crossrail uses a combination of company taxes, commercial loans, and public money.

2.1 ADR & LVC

One important urban financing mechanism under Land Value Capture (LVC) is Additional Development Rights (ADR), which permits developers to construct above the designated limit in exchange for payments. This makes it possible to finance metro developments without depending too much on government assistance (Goyal & Patel, 2015). ADR facilitates high-density building close to metro lines by raising the Floor Area Ratio (FAR), which encourages urban growth and generates income (Sejal, 2015). LVC is widely used to recover land value appreciation from metro projects (Shahara, 2018). Traditional funding sources like fare revenue and subsidies are often insufficient, so tools like impact fees, betterment charges, and land monetization support metro expansion (Goyal & Sejal, 2015). The Jaipur Metro used ADR to cover 60% of costs, raising \$403.3 million by selling premium FAR near metro stations (Goyal & Patel, 2015).

2.2 Systematic Literature Review (SLR) using “PRISMA”

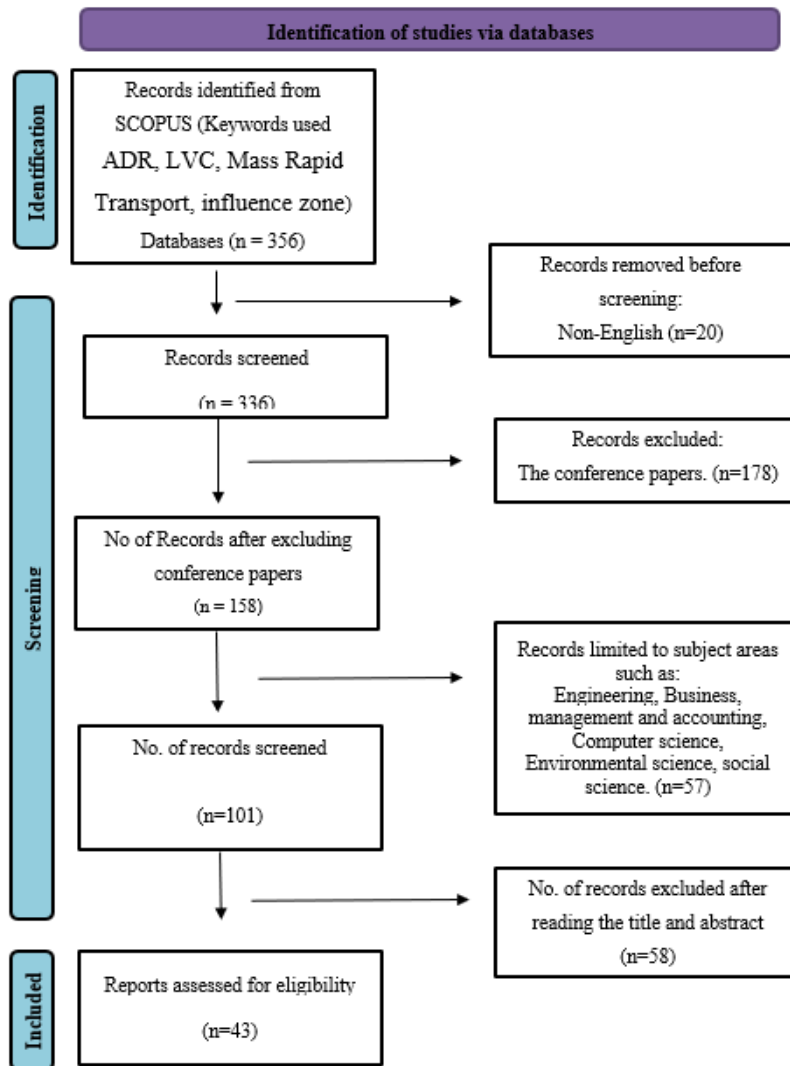
A systematic literature review (SLR) aids in discovering pertinent research, makes it easier to evaluate chosen studies critically for research quality, and aids in clearly summarizing the results. In order to find, choose, assess, and analyse pertinent papers, the Preferred Reporting Items for Systematic analyse, and Meta-Analysis (PRISMA) framework is used in the first stage of systematic literature review. There were three phases to the process see Figure 2.

3.0 Methodology

This study employs a systematic methodology that integrates literature evaluation, data collecting, and analysis to investigate Land Value Capture (LVC) as a funding option for the Hyderabad Metro. With an emphasis on financial instruments including Additional Development Rights (ADR), tax-based finance, and Public-Private Partnerships (PPP), the study looks at LVC models from metro projects in Hyderabad, Bangalore, and Jaipur. While the TCCM model arranges data according to theory, policy, and financial strategies, a Systematic Literature Review (SLR) aids in identifying important patterns.

In addition to field surveys and expert interviews, data is gathered from government publications, satellite photos, and metro planning documents. While on-site surveys examine traffic patterns and real estate trends, secondary data sources include land use, property prices, and metro corridor maps from GHMC, HMRL, and HMDA. Three important questions are addressed in the study. First, it uses expert interviews and document analysis to establish metro impact zones. Second, it uses data analysis and ground surveys to redraw these zones according to land prices, urban expansion, and traffic effect. Third, by examining global case studies and Hyderabad’s urban policies, it investigates how LVC techniques might optimize income for metro projects.

Figure 2: PRISMA Process

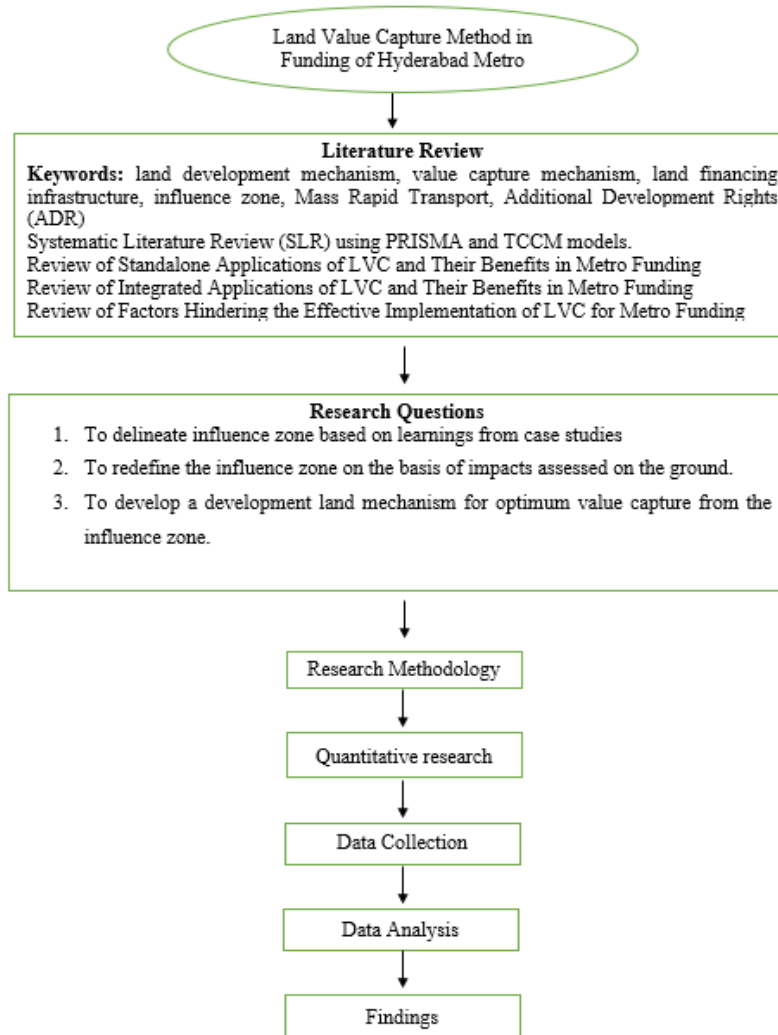


Source: Compiled by authors

4.0 Data Analysis

India's transportation infrastructure is under stress due to the country's fast urbanization, with 600 million people predicted to live in cities by 2031. Increased pollution, lengthier commutes, higher fuel consumption, and traffic congestion are all results of the growing number of private automobile owners. Growing metro rail systems is a long-term way to address these issues.

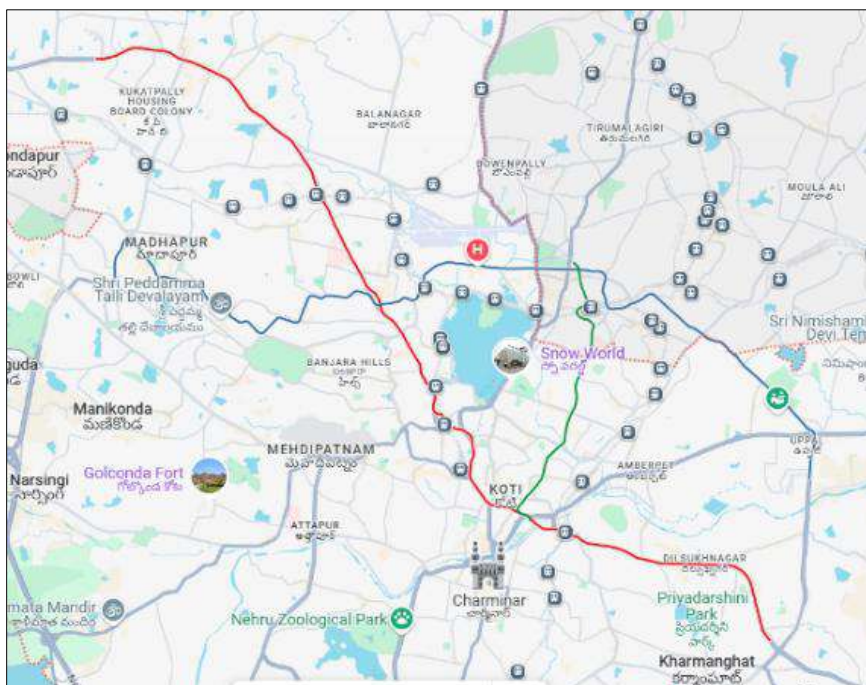
Figure 3: Methodology



Source: Compiled by authors

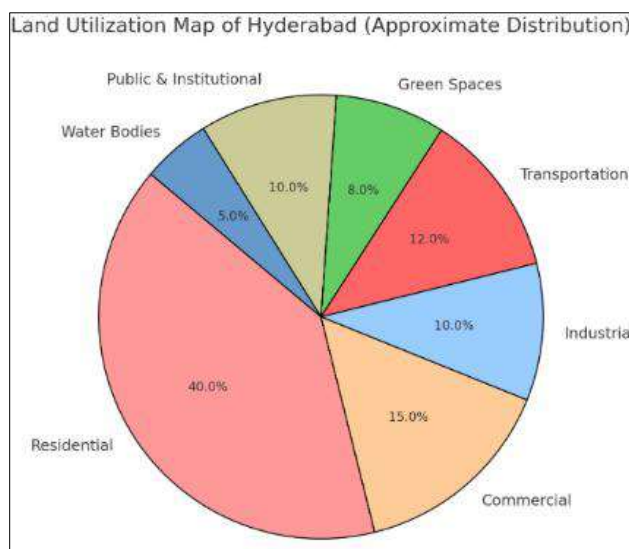
Private vehicles and buses are the major forms of transportation in India, which mostly relies on the country's highways. Air pollution, traffic jams, and delays plague major cities including Delhi, Mumbai, Bengaluru, Chennai, and Kolkata. Additionally, many cities lack effective public transportation, which makes people more dependent on their own cars. Traffic congestion, long travel times, bad air quality, and overworked infrastructure are major problems. Metro systems may provide effective, environmentally sustainable urban mobility while reducing traffic, travel time, and pollution. Metro network expansion is essential for better and sustainable urban transportation.

Figure 4: Hyderabad Metro Map



Source: Google maps

Figure 5: Land Utility Percentage of Hyderabad Metro Influence Zone

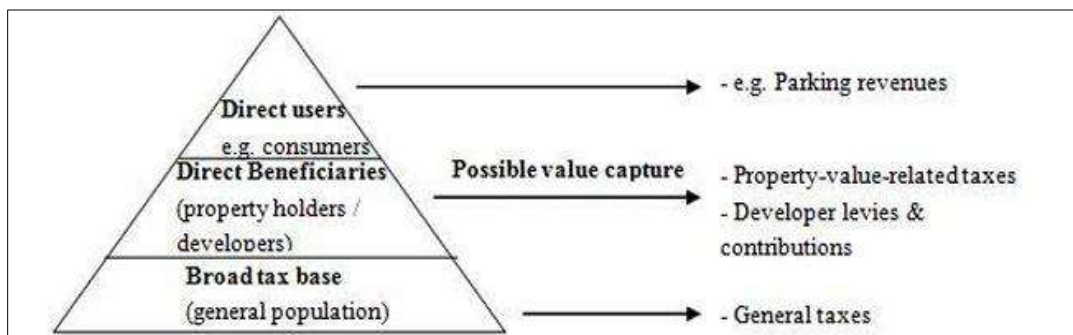


Source: <http://www.planning.telangananae.gov.in>

4.1 Funding of Phase 1

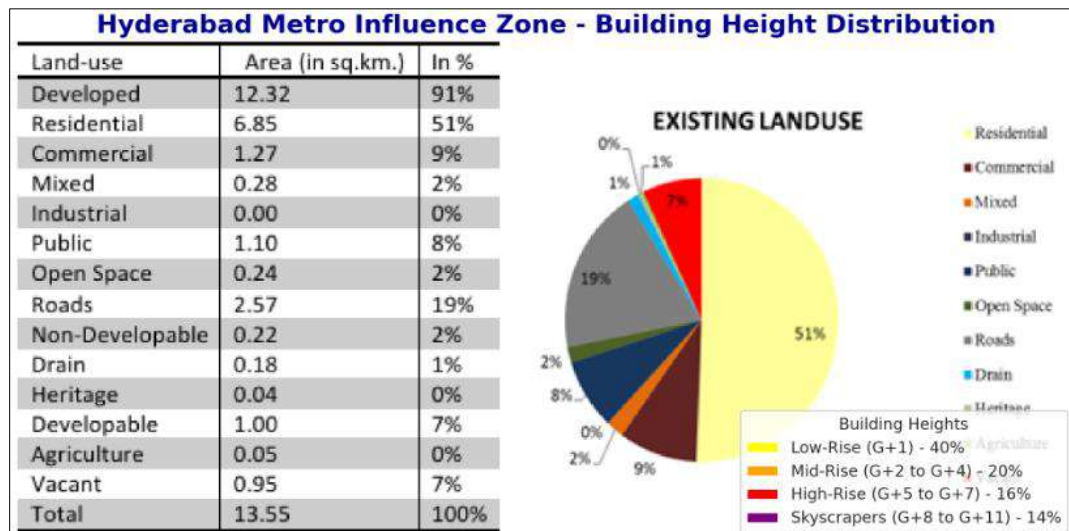
In an expanding metropolis of 10 million, the Hyderabad Metro, India's first PPP-based metro, was constructed to cut down on traffic, pollution, and lengthy commutes.

Figure 6: Funding Method



Source: Goyal & Sejal, 2015

Figure 7: Building Height Distribution in Influence Zone



Source: Author's own creation

The \$2.2 billion project, which was created using the DBFOT paradigm, was given to L&T in 2010 with 90% funding and the Telangana government with 10%. Ticket sales, advertisements, real estate, and business ventures around metro stations generated revenue. Non-fare income increased as a result of transit-oriented development, or TOD. The Telangana

government offered financial assistance because of the poor early ridership and cost overruns. Metros in Singapore, Hong Kong, Curitiba, and Delhi are frequently financed by Land Value Capture (LVC), which includes Additional Development Rights (ADR), land taxes, and impact fees. According to studies, ADR can pay for as much as 60% of expenses. To create the finest LVC solutions for long-term finance, Jaipur Metro is examined.

5.0 Analysis and Result

Since 2017, the Hyderabad Metro has fuelled both urban development and increases in property values. The Master Plan 2031 encourages growth that is balanced over 5,965 square kilometres. Metro routes are mostly residential (51%) and commercial (9%), with just 7% of the area suitable for development see figure 7. To effectively handle traffic, environmental issues, and future urban expansion, sustainable planning is required.

Table 2: Property Price Increase in Hyderabad

Table: Property Value Trends in Hyderabad (2017-2024)			
Zone Type	Locality	Growth (%)	Key Growth Factors
High-Growth Residential	Madhapur	91.90%	IT Hub, Business Expansion
	Kondapur	85.70%	Metro Connectivity, IT Sector
	Hitech City	67.30%	Tech Parks, Commercial Growth
	Jubilee Hills	58.80%	High-End Residential Demand
	Gachibowli	48.70%	IT Offices, SEZs
Moderate Growth Residential Zones	Kukatpally	60%	Affordable Housing, Metro Expansion
	Miyapur	55%	Residential Migration
	LB Nagar	52%	Affordable Housing Growth
	Nagole	47%	New Metro Development
High-Growth Commercial	Hitech City	70%	SEZs, IT Companies
	Kukatpally	68.40%	Retail, shopping malls
	Begumpet	82.60%	Business & Transit Hub
	Banjara Hills	62.50%	Luxury Real Estate

Source: Author’s own creation

6.0 Practical Implementation

To investigate land usage, property prices, and development potential, the Hyderabad Metro line is separated into prototype zones. Each zone, which has a maximum width of 800 meters, includes important regions surrounding metro stations. These zones are usually between 500 and 1,500 meters in size see figure 8, 9, 10. depending on the distance between metro stations. Each zone is named after the closest metro station to make identification easier. This zoning strategy aids in land use optimization, urban development planning, and evaluating the metro’s effects on property values and future growth.

Figure 8: Zoning Area for Red Line



Source: Author's own creation & Google Maps

Figure 9: Zoning Area for Green Line



Figure 10: Zoning Area for Blue Line



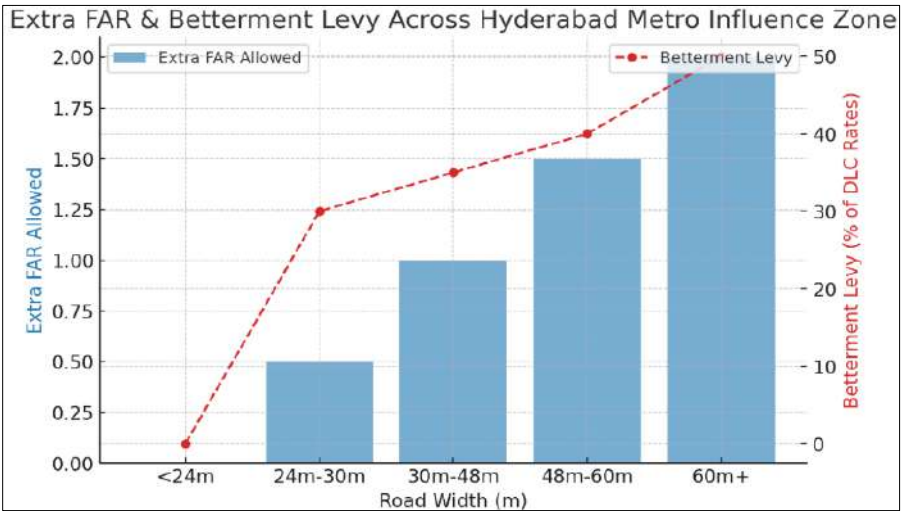
Source: Author's own creation & Google Maps

6.1 Building by laws & FAR regulations in Hyderabad metro influence zone

To control urban growth, the Hyderabad Metro Influence Zone adheres to the Betterment Levy and established Floor Area Ratio (FAR) norms. The standard FAR is 1.5 for group homes, flats, and commercial sites larger than 750 square meters, whereas the premium FAR is up to 2.5. Depending on the width of the road, additional FAR is permitted; for 24 m roads see figure 11, this is 0.5 FAR (30% levy), whereas for 60 m+ roads, it is infinite (50% levy). Institutional plots (more than 500 square meters) exhibit the similar trend. Road width is a

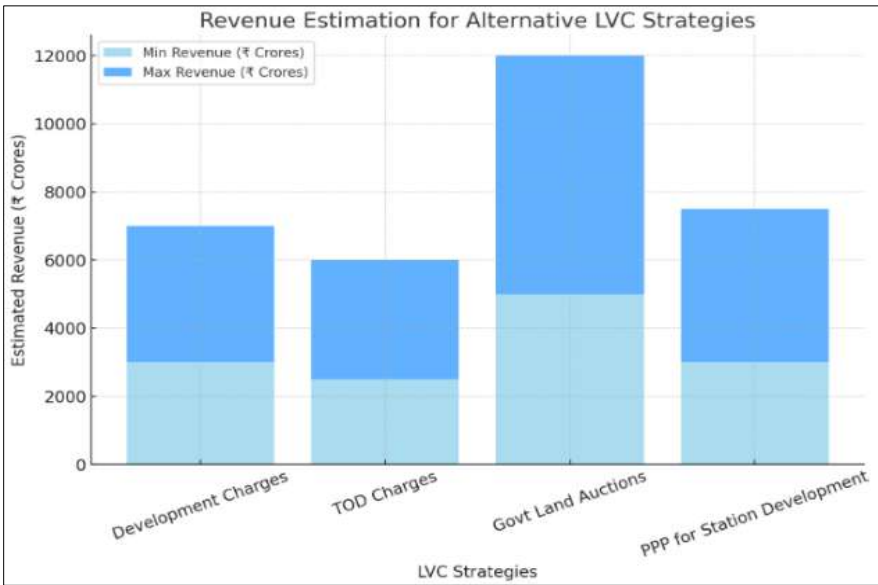
major factor in establishing FAR eligibility; no additional FAR is awarded for roads shorter than 24 meters, but it rises as road width grows. Increased land prices and DLC rates encourage developers to invest in additional FAR, particularly in Hitech City and Raidurg.

Figure 11: Visual Representation of Premium FAR



Source: Author’s own creation

Figure 12: Revenue Estimation for LVC



Source: Author’s own creation

Metro station grading takes into account built density, DLC land values, and commercial hubs to ensure sustainable urban development along the metro corridor. High-FAR areas like Raidurg, Ameerpet, and Punjagutta support IT and corporate growth, while Nagole, Miyapur, and LB Nagar facilitate mixed-use and residential expansion. The expected revenue from several Land Value Capture (LVC) options for Hyderabad Metro is displayed in a bar graph see figure 12. Government land auctions bring in the most money, with prices ranging from ₹5,000 to ₹7,000 crores. For station development, development costs and PPP contribute between ₹3,000 and ₹4,500 crores, while TOD charges fall between ₹2,500 and ₹3,500 crores. 50–60% of metro expenses might be covered by the combined LVC measures, guaranteeing financial stability and lowering reliance on farebox revenue.

7.0 Conclusion

The Hyderabad Metro has encouraged sustainable transportation, decreased traffic, and greatly enhanced urban mobility. It has established a standard for contemporary urban transportation and is one of the biggest Public-Private Partnership (PPP) metro projects in India. However, because farebox income is inadequate to fund long-term operations and growth, financial sustainability continues to be an issue. Land Value Capture (LVC), which makes use of betterment levies, land monetization, Additional Development Rights (ADRs), and transit-oriented development (TOD), is highlighted in this study as a feasible funding method. The effectiveness of LVC in metro finance is supported by case studies from Hong Kong, Tokyo, and London. Up to 60% of metro development expenditures can be financed by LVC with appropriate execution, relieving financial strain on both public and private investors. Issues including stakeholder concerns, regulatory obstacles, and policy alignment must be resolved to guarantee success. The introduction of LVC requires government backing, FAR-based revenue structures, and a structured zoning framework. Hyderabad Metro may accomplish long-term development, planned urban expansion, and sustainable finance by incorporating LVC into its financial model. LVC has the ability to transform metro funding and ensure Hyderabad's status as a cutting-edge, interconnected metropolis with the correct regulations and stakeholder collaboration.

References

- Balasubramani, M., Mahalingam, A., & Scott, W. R. (2020). Imitation and adaptation: lessons from a case study of a metro rail project in India. *Construction Management and Economics*, 38(4), 364–382. <https://doi.org/10.1080/01446193.2019.1619932>
- Beria, P., Di Milano, P., & Scopel, E. (n.d.). *Financing methods applied to urban infrastructures. An application to Milan metro system*. <https://www.researchgate.net/publication/255646819>

Chang, Z., & Phang, S. Y. (2017). Urban rail transit PPPs: Lessons from East Asian cities. *Transportation Research Part A: Policy and Practice*, 105, 106–122. <https://doi.org/10.1016/j.tra.2017.08.015>

Cohen, R., & Boast, T. (2016). Governance of public-private partnerships and infrastructure delivery: Case of the Milan, Italy, metro line M4. In *Transportation Research Record* (Vol. 2597, pp. 37–43). National Research Council. <https://doi.org/10.3141/2597-05>

Deloukas, A., Apostolopoulou, E., & Metro, A. (2003). Innovative financing techniques: European urban rail projects and the case of Athens metro extensions.

Goyal, P., & Patel, S. (2016). *A framework for financing metro rail infrastructure through land value capture mechanisms: Case of Jaipur*. <https://www.researchgate.net/publication/304526409>

Kanemoto, P. Y. (2012). *Chennai Metro Railway Limited, Tamil Nadu, India*.

Kumar Jillella, S. S., & Newman, P. (2016). Innovative value capture-based rail transit financing: an opportunity for emerging transit cities of India. *Journal of Sustainable Urbanization, Planning and Progress*, 1(1). <https://doi.org/10.18063/jsupp.2016.01.003>

Nag, B., Singh, J., & Tiwari, V. M. (n.d.). *Choosing the appropriate project management structure, project financing, land acquisition and contractual process for Indian railway mega-projects-a case study of the Dedicated Freight Corridor Project*. <https://ssrn.com/abstract=2928686>

Ramakrishnan, T. S. (2014a). Financing infrastructure projects through public-private partnerships in India. In *Transportation Research Record* (Vol. 2450, pp. 118–126). National Research Council. <https://doi.org/10.3141/2450-15>

Ramakrishnan, T. S. (2014b). Financing infrastructure projects through public-private partnerships in India. In *Transportation Research Record* (Vol. 2450, pp. 118–126). National Research Council. <https://doi.org/10.3141/2450-15>

Sharma, R. (2018). *Financing Urban Rail Projects through Land Value Capture-The Indian Case*.

Shashank, K., & Sarkar, A. (2023). A Study on the Impact of Mass Rapid Transit on Land use Changes-A Case Study of Hyderabad Metro Rail Corridor. In *International Journal of Innovative Science and Research Technology* (Vol. 8). www.ijisrt.com

Yu, X., Zhong, H., Zhou, T., & Zhou, Y. (2018). Rail transit development in lagging regions: A development-oriented investment and financing approach. *Journal of Transport and Land Use*, 11(1), 1003–1024. <https://doi.org/10.5198/jtlu.2018.1235>

CHAPTER 118

Risk Management in Mega-Infra Projects: A Systematic Literature Review

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ABSTRACT

The study explores risk management frameworks for mega-infrastructure projects, which are characterized by their complexity, high cost, and extensive timelines. These projects face diverse challenges, including financial, technical, regulatory, stakeholder, and environmental risks. The research aims to identify key success factors by systematically understanding existing strategies, practices, and frameworks. By carrying out a systematic literature review, the paper attempts to explore practices and frameworks proposed to identify, prioritize and mitigate risks for enhancing project delivery. A major outcome of this research is to understand the factors that provide better scope for risk identification, reduction, and elimination. This refined work shall enable project managers to anticipate and mitigate risks, addressing emerging challenges with precision and adaptability. By aligning these approaches, the study bridges critical gaps in current risk management practices, ensuring better planning, proactive decision-making, and the achievement of project goals. Future work aims to propose a framework for effective risk management in the context of mega infrastructure projects. The study underscores the need for innovation, collaboration, and stakeholder engagement to deliver mega-infrastructure projects that meet their objectives on time, within budget, and with lasting benefits.

Keywords: Risk management; Mega-infrastructure projects; Construction risks; Construction delays; Risk mitigation framework.

1.0 Introduction

Large-scale mega-infrastructure projects like highways, metros, bridges, and power plants are of utmost importance to economic development, urbanization, and national advancement. Yet, their enormous size, lengthy time frames, and multi-stakeholder nature bring with them a number of risks that can affect the success of the project. These risks are financial instability, regulatory issues, technological breakdowns, environmental limitations, and stakeholder disputes. The intricacy of such projects subjects them to unforeseen circumstances like changes in government policies, economic downturns, and unanticipated site conditions.

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Moreover, as mega-projects take years or even decades to complete, they are exposed to technological innovation and changing market conditions. Thus, a clear risk management structure is essential for reducing uncertainties, improving decision-making, and ensuring the sustainability of projects.

2.0 Literature Review

Mega-infrastructure project risk management has also come a long way, with the shift from qualitative historical approaches to new, technology-based methods. Historically, risk management has been based on risk registers, probability-impact matrices, and analysis of historical data to spot and avoid risks as suggested by Nabawy *et al.*, (2020). These methods, though efficient in conventional project environments, tend to fail to handle the dynamic risks characteristic of mega-projects.

There are risks in using traditional approaches like expert opinions and checklists as these are subjective and can bring in inherent biases, and hence risk assessments are inconsistent. Moreover, according to Chattapadhyay *et al.*, (2023) using historical project data will not completely capture new risks like cybersecurity attacks and climate changes that need to be monitored and updated regularly. Latest research by Xu *et al.*, (2023) recommends AI-powered risk forecast models, live online monitoring, and simulation methods such as Monte Carlo analysis for amplifying risk management. Advanced methods strengthen risk expectations by making use of large volumes of data processing, machine learning programs, and online real-time monitoring in an attempt to uncover warning indicators in the early stages of prospective failure projects. Sensitivity analysis is another measure that evaluates how variations in essential risk variables impact project outcomes so that project managers can take proactive steps before the risks get out of hand.

Additionally, Patil *et al.*, (2019) states, risk breakdown structures (RBS) assist in organizing risks in a systematic manner to enhance project management and risk prioritization. The Pune Metro case study points out financial constraints, regulatory clearances, and stakeholder disputes as major risk factors impacting the implementation of projects. An organized risk assessment approach using Monte Carlo simulation, sensitivity analysis, and stakeholder engagement methods was utilized to counteract these risks, enhancing project robustness considerably.

The use of digital technologies like real-time monitoring and AI-based forecasting models enabled enhanced decision-making, cost management, and early project completion as per the study by Chattapadhyay *et al.*, (2023). These findings emphasize the need for combining technology-based risk management practices to confront the complex and dynamic risk profile of mega-infrastructure projects. Further studies need to investigate the long-term effect of digital transformation on risk management effectiveness in large construction projects.

3.0 Research Methodology

- *Identifying sources:* A comprehensive search was conducted to identify relevant literature, including peer-reviewed journal articles, academic books and necessary research findings. The selection encompassed both traditional and contemporary perspectives on risk management across various sectors.
- *Selection criteria:* The inclusion criteria focused on high-quality studies that provided empirical data, theoretical advancements, or case studies relevant to risk management. Priority was given to literature that addressed real-world applications, emerging risks, and the integration of modern methodologies.
- *Risk identification:* Identified common risks in key areas such as financial, technical, schedule, environmental, safety, stakeholder, regulatory, and political risks based on their impact and occurrence in mega-infrastructure projects.
- *Critical analysis:* The selected studies were critically evaluated to assess their strengths, limitations, and practical implications. A literature review of different risk management approaches was conducted, highlighting gaps in existing methodologies and emphasizing the necessity for adaptive and predictive risk management strategies.
- *Mitigation strategies:* Based on the insights derived from the literature, recommendations for risk mitigation strategies were formulated. Commonly occurring risks were ranked as per their impact.

4.0 Categorization of Risks

Mega-infrastructure projects are vulnerable to a wide range of risks that can impact their financial stability, timelines, sustainability, and overall success. This section highlights key risk categories.

4.1 Financial risks

Financial risks are caused by funding issues, cost overruns, inflation, and mismanagement states Patyal *et al.*, (2015). Jadhav *et al.*, (2016) suggests cost overruns result from inadequate cost estimation and scope changes while funding issues result from late government allocations or investor withdrawals. Currency fluctuations and interest rate changes also put pressure on budgets, and mismanagement through corruption or late payments impacts project liquidity as mentioned by Chandra, (2011).

4.2 Political and regulatory risks

Government policy reform, bureaucratic slow-downs, and political uncertainty can stall progress in a project according to Nallathiga, (2015). The study by Nagargoje *et al.*, (2015) suggests, policy changes in environmental regulations and taxation influence the feasibility of

projects, and land acquisition conflicts lead to legal delays. Corruption in approval or slow-bureaucratic processes adds to the challenge as stated by Jadhav *et al.*, (2016). Further, Chandra, (2011) emphasizes, political uncertainty could cause cancellation or delays in projects.

4.3 Environmental and climatic risks

According to Patyal *et al.*, (2015) severe weather conditions, climate policies, and geologic risks are major threats to infrastructure projects. Natural disasters such as floods or hurricanes can suspend construction, Nallathiga, (2015) highlights new climate policies mandate that projects implement sustainable measures. Unstable ground conditions can weaken structural integrity states Nagargoje *et al.*, (2015).

4.4 Social risks

Community resistance, cultural issues, and stakeholder mismatch can lead to project delay or abandonment as stated by Jadhav *et al.*, (2016). Patyal *et al.*, (2015) highlights that public demonstrations against land takeover and disturbance of cultural sites can result in legal confrontations. Lack of transparency in decision-making can generate disputes between investors and government agencies states Nallathiga, (2015).

4.5 Technological risks

Construction innovation failures, cybersecurity attacks, and software inefficiencies can hamper operations. Inaccurate AI-based prediction models and inadequate BIM (Building Information Modeling) integration lead to delays. Moreover, cyberattacks on smart infrastructure systems present security threats.

4.6 Safety risks

Worker injuries, material defects, and fire risks are major safety issues as per Nagargoje *et al.*, (2015). Falls, equipment failure, and poor training heighten accident risks as mentioned by Jadhav *et al.*, (2016). (Chandra, 2011) states that material defects or machine failures can cause project delays and economic losses.

4.7 Contractor and supply chain risks

Material shortages, untrustworthy contractors, and logistical inefficiencies can slow progress as stated by Patyal *et al.*, (2015). Supply chain disruptions can cause cost overruns, while low-quality materials from suppliers undermine safety as mentioned by Jadhav *et al.*, (2016). Late contractor work slows down completion and increases costs states Nallathiga, (2015).

5.0 Risk Identification, Assessment and Management Techniques

Conventional risk management frameworks are based on formal methods like risk registers, expert opinion, and probability-impact matrices. Although these methods offer a

systematic way of identifying and evaluating risks, (Chattapadhyay *et al.*, 2023) states that they tend to be inflexible in dynamic project environments, which makes them less effective in managing unexpected risks. Advanced risk management methods, however, have greater predictive power and real-time risk evaluation. Monte Carlo simulations utilize probabilistic modelling to assess various risk scenarios, aiding project managers in grasping prospective financial implications. Sensitivity analysis investigates how fluctuations in key variables impact project viability, facilitating informed decision-making. Furthermore, AI-powered risk monitoring utilizes predictive analytics and machine learning to identify early warning signs of project risks, allowing proactive mitigation strategies. These new methods offer a more statistically oriented means of managing risks, enhancing the resilience of projects and eliminating uncertainties.

Risk identification is the initial step of the risk management process that facilitates project managers in identifying possible threats and formulating counterplans. The Delphi Technique is a systematic, expert-based process that collects views of industry experts through successive rounds, narrowing down risk identification by consensus Patyal *et al.*, (2015). SWOT analysis suggested by Jadhav *et al.*, (2016) offers a strategic framework through the identification of Strengths (internal strengths), Weaknesses (internal weaknesses), Opportunities (external opportunities), and Threats (external threats), providing a complete picture of project vulnerabilities. Scenario analysis studied by Nallathiga, (2015) evaluates different risk scenarios by considering three major cases: The Best-Case Scenario, where all project conditions are favourable; the Worst-Case Scenario, which accounts for high-impact, low-probability risks; and the Moderate Scenario, which assesses risks based on current data trends. These identification methods enable an anticipatory style of risk management, allowing for early detection and improved readiness to handle project uncertainty.

After the identification of risks, they have to be analyzed based on their likelihood and potential effect. The probability and impact matrix by Chandra, (2011) is a commonly employed tool, which categorizes risks into varying levels of priority by analyzing their likelihood of occurrence and severity of effect. Monte Carlo simulation by Nagargoje *et al.*, (2015) improves risk assessment by running thousands of iterations to estimate financial and schedule effects in various scenarios of risk, facilitating better forecasting and decision-making. Sensitivity analysis by Nallathiga, (2015) also improves risk assessment by determining the most critical risk variables that significantly affect project viability and guides the prioritization of risk mitigation. These evaluation strategies in combination enhance the risk assessment to facilitate more sound strategic planning and efficient response measures to risk in mega-infrastructure projects.

6.0 Studies on Risk Types and Mitigation Strategies

Numerous studies have attempted to investigate a variety of risks in Indian construction and infrastructure projects and their associated countermeasures. Conventional risk management

approaches like risk assessment matrices and checklists have widely been applied but have been criticized by Patyal *et al.*, (2015) for their inability to identify and rank risks efficiently when applied to mega construction projects (MCPs). Chattapadhyay *et al.*, (2023) proposed an innovative risk management approach based on machine learning to identify high-risk regions and sub-risks, allowing stakeholders to allocate resources effectively and mitigate risks in advance. Sharma *et al.*, (2023) provided an extensive review of risk management in Indian infrastructure and construction projects, categorizing risks to enable project managers to focus on minimizing their impacts. However, their research highlighted the need for further exploration of newer quantitative risk analysis techniques and empirical research on mitigation strategies. Similarly, Patil *et al.*, (2019) analyzed the Pune Metro project to identify financial, technical, and political risks. Their research emphasized the importance of adequate risk identification, evaluation, and mitigation plans but identified a lack of contract-based risk management frameworks.

Safety risks are another major concern in mega construction projects. Xu *et al.*, (2023) developed a dynamic safety risk simulation model that integrates qualitative and quantitative methods to visualize and forecast safety risks, enhancing preventive risk control. In road construction projects, particularly in Chhattisgarh under the PMKVY scheme, Jadhav *et al.*, (2016) applied risk assessment methods and Analytical Hierarchy Process (AHP) analysis to evaluate and prioritize hazards based on severity. Road construction projects were identified as high-risk environments, with recommendations for further studies on the role of advanced digital tools in long-term risk management.

Quantitative risk analysis has been recognized as an effective risk management tool for mega projects. Nabawy *et al.*, (2020) examined the application of Monte Carlo analysis in project deviation analysis and risk mitigation planning. Their research highlighted the importance of broader implementation of quantitative risk analysis in infrastructure projects to address gaps in understanding project success determinants. Similarly, Erol *et al.*, (2023) introduced the Integrated Risk Assessment Process (IRAP) as a structured framework for identifying, analyzing, and mitigating risks in large-scale construction projects. However, Nallathiga, (2015) suggested that additional research is needed to explore the temporal aspects of risks and the human factors influencing risk management.

Another comprehensive study by Nagargoje *et al.*, (2015) on risk management in Indian infrastructure projects classified risks into eight categories, including social resistance, design modifications, and project suspensions. The study underscored the importance of stakeholder coordination—involving clients, contractors, designers, and government agencies—to strengthen risk management from the feasibility stage. Additionally, it emphasized the necessity of policy improvements to mitigate project failures. Singh *et al.*, (2017) stressed the importance of an integrated risk management approach to address risks associated with project complexity, external uncertainties, and human errors. Their findings identified a lack of empirical research in the Indian context regarding the effectiveness of various risk mitigation techniques.

7.0 Conclusion

The literature review outlines the different risks associated with mega-infrastructure projects, which calls for systematic risk management frameworks. Among the most significant risks, schedule risks are the most prevalent, which have a tendency to delay due to unforeseen circumstances, poor planning, and a lack of resources. These interferences have cascading effects on costs, stakeholder expectations, and project completion dates. Technical and financial risks are also of critical importance and affect project stability. Technical risks arise from design faults, material failure, and construction inefficiency, which can impact project quality and safety. Financial risks like cost escalation, inflation, and lack of funds pose serious concerns, which primarily result in budget changes and financial instability.

Safety risks and environmental risks also contribute to project uncertainties. Weather, natural disasters, and fluctuating environmental regulations can affect construction progress, while workplace accidents, material failure, and poor safety measures pose risks to the workforce and project timelines. Furthermore, stakeholder risks are of great importance in project implementation as disagreements among investors, regulatory agencies, contractors, and local people may cause delays and disputes. Legal and regulatory risks and political risks are also significant challenges with policy changes, bureaucratic delays, and land acquisition problems impacting the viability and implementation of projects. These risks, however, are less frequent compared to financial and technical issues. Finally, joint venture risks do not seem to be important, indicating that joint project forms have fewer implementation issues.

Generally, the findings highlight the efficacy of risk identification and risk management processes in an anticipatory strategy, particularly in terms of overcoming delays in schedules, financial viability, and technical issues to ensure optimal effective implementation of mega-infrastructure projects.

References

- Chandra, P. (2011). *Projects: Planning, analysis, selection, financing, implementation, and review* (8th ed.). McGraw Hill.
- Chattapadhyay, S., Putta, H., & Rao, K. (2023). Machine learning-based risk prediction for mega construction projects. *International Journal of Construction Management*, 23(4), 1–17. <https://doi.org/10.xxxx/ijcm.2023.123456>
- Erol, H., Dikmen, I., Atasoy, G., & Birgonul, M. T. (2023). Integrated risk assessment process (IRAP) for mega construction projects. *Journal of Construction Engineering and Management*, 149(7), 1–14. <https://doi.org/10.xxxx/jcem.2023.987654>

Jadhav, P., & Lele, A. (2016). Risk assessment methodologies in infrastructure projects. *Indian Journal of Civil Engineering*, 12(3), 45–56.

Nabawy, M., & Khodeir, L. M. (2020). A systematic review of quantitative risk analysis in construction of mega projects. *International Journal of Project Management*, 38(5), 789–803. <https://doi.org/10.xxxx/ijpm.2020.56789>

Nagargoje, P. M., Patil, A., & Lawand, K. B. (2015). Risk management in infrastructure projects – A case study on Pune Metro. In *Proceedings of the International Conference on Construction Risk Assessment* (pp. 345–360).

Nallathiga, R. (2015). Risk management strategies in Indian infrastructure projects. In P. Sharma (Ed.), *Risk management in the construction industry* (pp. 88–105). Springer.

Patil, A., & Lawand, K. B. (2019). Evaluating risk mitigation strategies in metro rail projects: The Pune Metro case study. *Journal of Urban Infrastructure Planning*, 25(2), 233–248.

Patyal, V. S., & Maddulety, K. (2015). Financial and operational risks in mega-infrastructure projects. *Journal of Risk and Project Management*, 17(1), 56–74.

Sharma, R., & Gupta, A. (2023). Risk management in building and infrastructure projects: An Indian perspective. *Journal of Infrastructure Development*, 45(3), 102–119.

Singh, M. K., Deep, S., & Banerjee, R. (2017). Risk management in construction projects as per Indian scenario. *Indian Journal of Project Management*, 19(4), 78–92.

Xu, L., Li, W., & Wang, Z. (2023). Dynamic safety risk simulation in mega construction projects. *Safety Science*, 157(6), 1–12. <https://doi.org/10.xxxx/safety.2023.112345>

CHAPTER 119

Risk Management in Precast Concrete Structure Installation and Transportation

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ABSTRACT

Modern construction depends on pre-stressed concrete structures due to their unmatched strength, durability, and efficiency. The casting, transportation, and installation processes, however, are fraught with significant risk that can affect the structural integrity, safety, and timeliness of a project. This research aims to mitigate those risks through effective management strategies for pre-stressed concrete constructions with focus on risk identification, assessment, and mitigation in the above critical stages. 1. Casting 2. Transportation 3. Installation A Risk Matrix was constructed to assess the probability and impact of such risks, grouping them as high, medium, and low levels. Mitigation techniques like risk avoidance, reduction, transfer, and acceptance were suggested. The suggestions include enhanced quality control, increased workforce training, optimal transportation logistics, and rigorous safety protocols. Through the adoption of proactive risk management methods, this research hopes to improve the safety, efficiency, and reliability of pre-stressed concrete construction.

Keywords: Pre-stressed concrete; Risk management; Structural integrity; Transportation risks; Installation safety; Mitigation strategies.

1.0 Introduction

Risk management for precast construction is an area of study with significant importance due to the intricate nature of casting, transportation, and installation. In contrast to cast-in-place construction, precast construction entails unique risks that involve structural injury, safety, and logistical ineffectiveness. The necessity for a systematic analysis of risk identification and mitigation has been extensively supported to improve the efficiency of construction and structural safety.

1.1 Precast structures

Precast concrete structures are becoming more popular because they offer better quality control, economical prices, and shorter construction durations.

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These buildings are manufactured within controlled environments where strength and durability uniformity are assured (Smith & Tardif, 2018). The benefits of precast units, such as beams, columns, slabs, and walls, over traditional cast-in-situ are clearly documented. Improvements in their structural reliability through the application of high-performance concrete and advanced reinforcement technologies have increased further (Gibb, 2001).

1.2 Risk management in precast construction

Risk management in precast construction is aimed at the identification and reduction of possible risks involved in design, production, transportation, and installation. Research indicates that proactive risk assessment models can reduce project delays and accidents (Zhang *et al.*, 2015). The main risks are structural damage, equipment failure, non-compliance with regulations, and inefficiencies in coordination among stakeholders. Studies underscore several measures for risk mitigation that include safety training, real-time monitoring, and adherence to industry standards. Implementation of Failure Mode and Effect Analysis (FMEA) and probabilistic risk modelling has played a crucial role in anticipating and addressing potential failures (Fard *et al.*, 2017).

1.3 Installation of precast structures

The installation process includes lifting, placing, and anchoring precast elements in the field. This procedure demands accuracy and specialized tools, such as cranes, hoisting frames, and supporting systems, to preserve alignment and stability (Teng *et al.*, 2017). Studies indicate that site misalignment may result from poor site preparation, causing misalignment, excessive settlement, and failure of the structure.

1.4 Transportation of precast structures

Transportation is an important phase in precast construction since it entails the movement of prefabricated components from production plants to sites (Zhang *et al.*, 2015). Due to the massive size and weight of precast components, specialized transport equipment like flatbed trailers and hydraulic modular transporters must be used to deliver them safely (Zhang *et al.*, 2015).

1.5 Casting of precast structures

The precast structure's casting process is accomplished by filling the Molds or formwork with concrete under a controlled condition. It results in consistent quality, precise, and reduced wastage of material. Optimum curing conditions also increase the strength and durability of concrete (Gibb, 2001).

1.6 Gaps in current research

In spite of increasing research on risk management in precast construction, there are still some gaps. There is no thorough risk assessment framework for all stages—casting,

transportation, and installation. Existing research is based on theoretical models, with insufficient practical validation by means of case studies and site visits. Proactive risk management options are not fully explored, and the majority of research is devoted to reactive options. The intersection of real-time data collection and AI-based predictive models is in its infancy.

2.0 Research Methodology

The present study follows a systematic approach to determining, evaluating, and minimizing risks in precast concrete structures through the casting, transportation, and installation processes. Incorporating literature review findings with empirical evidence from industry experts, this research will strive to create a systematic risk assessment framework. The methodology involves several stages, such as establishing objectives, literature review, determining gaps in research, market surveys, risk analysis, and developing mitigation strategies.

3.0 Literature Review

Extensive literature reviewing was carried out to examine widespread risks in precast construction. Academic journal papers, industry research reports, and case studies were examined to outline typical risk causes and analyse risk management approaches present in the current literature. Reviewing allowed knowledge foundation with prevalent issues such as material flaws, logistical inefficiencies, and site safety complications.

4.0 Gap Analysis

Although considerable research has been carried out to identify precast construction risks, an organized, all-inclusive risk mitigation framework combining both probability-based and severity-based evaluations is absent. Earlier research highlights risks in silos without correlating their likelihood and consequences systematically. This research fills in the gap by integrating industry-sourced probability values with literature-researched severity values to present a complete risk management framework suited for precast construction.

5.0 Market Survey and Risk Identification

A structured questionnaire survey was developed to gauge industry risk occurrence perceptions of precast construction. The questionnaire was administered among engineers, project managers, site supervisors, and contractors directly engaged in precast projects. 54 responses were gathered, giving empirical information on risk probabilities. This was merged

with severity information gleaned from literature to create the foundation of a risk matrix that classifies high, moderate, and low-risk factors.

5.1 Variables in the Study

5.1.1 Independent variables

The independent variables within this research signify the varied risks impacting precast construction, including material quality, transportation planning, and installation accuracy. The research categorizes main risk types as below:

1. Casting Risks
2. Transportation Risks
3. Installation Risks

5.1.2 Dependent variable

The dependent variable of this research is the Risk Level, which measures the possible effect of risks that have been identified on precast construction projects.

6.0 Data Collection and Analysis

6.1 Data collection

In order to gain a well-rounded understanding of the risks associated with precast concrete construction, a systematic three-step data collection procedure was used. By ensuring the study was based on both current knowledge and actual industry experience, this approach resulted in a balanced risk assessment. The process of data collection entailed a thorough literature review, in-depth interviews with experts, and a guided questionnaire survey to quantify the likelihood and impact of different risks.

Literature review: developing a knowledge base: The initial data gathering step was undertaking a comprehensive review of literature. This included review of academic papers, industry studies, case histories, and governmental regulations pertaining to precast concrete construction. The key purpose behind this review was to ascertain predominant risks in all three phases: casting, transport, and placing. Moreover, it also brought out current countermeasures existing in the marketplace and their suitability.

Interviews with industry experts: uncovering practical insights: Interviewees comprised engineers, construction managers, project developers, contractors, and safety officers. Each of these experts contributed different insights based on their actual experiences. The interview design was semi-structured, so responses could provide descriptive insights with responses to certain prominent issues. All data gained during these interviews became instrumental in better defining our study focus, enhancing the qualitative details gained via questionnaires.

Questionnaire survey: Quantifying risk probabilities: The questionnaire was divided into three sections, each focusing on one phase of precast construction: casting, transportation, and installation. Respondents were asked to evaluate the probability of different risk factors occurring based on their professional observations. In total, 54 industry experts participated in the survey, including Structural Engineer. Project managers and contractor. The questionnaire was made comprehensive and easy to use, with the inclusion of multiple-choice and Likert scale questions to measure risk probability. The respondents were required to score each of the risks that were identified on a scale of 1 to 5, where 1 indicated a low chance of occurrence and 5 indicated a high chance of occurrence.

Integration of data sources: Having compiled the data from the literature review, interviews, and survey, the next task was to synthesize these data to form a holistic risk assessment. This method ensured that the research was based on theoretical as well as practical knowledge. Risks that were most often mentioned in literature and survey returns were labelled as high-priority risks.

$$\text{Risk Level} = \text{Probability of Occurrence} \times \text{Severity}$$

Key findings from data collection: In casting, most significant issues in casting were mis measured concrete mix ratios, defects in curing, and errors in reinforcement. For transportation, the risks were structural damage and unstable loads, while logistics coordination and driver expertise were crucial. Risks during installation were equipment failures, misplacing supports, and hazards to workers.

6.2 Data analysis

Casting stage correlation matrix: This correlation matrix shows relations among different risk factors during the casting phase of precast structures. The darker red colours reflect stronger correlations, and lighter or blue colours reflect weaker or opposite correlations. “Improper Concrete Mix Proportions” highly correlate with more than one risk, including “Defects from Curing Conditions” and “Insufficient Concrete Vibration,” indicating material properties highly affect the quality of casting. Likewise, “Environmental Factors” and “Equipment Malfunctions” are strongly associated, pointing to external dependencies.

Transportation stage analysis: Structural damage and inadequate inspections exhibit the strongest correlation, emphasizing the need for rigorous quality checks before transport.

Installation stage analysis: Foundation issues and equipment breakdowns are highly correlated, highlighting the importance of proper site preparation and reliable machinery.

Risk Matrix: Risk mitigation in precast construction is essential to prevent delays, quality issues, and safety hazards.

Just like the casting stage, the transportation and installation stages of precast concrete construction come with their own set of risks that must be carefully managed. Transportation risks include structural damage, equipment breakdowns, and compliance issues, while installation risks involve foundation problems, incorrect levelling, and inadequate safety

Table 1: Casting Stage Risk Level and Mitigation Strategies

Risk Factor	Severity Rating (1-5)	Probability	Risk Level	Risk Ownership	Best Possible Mitigation Strategies	Predicted Reduction in Severity	Predicted Reduction in Likelihood	Cost Associated with Mitigation Strategy (₹)
Improper Concrete Mix Proportions	5	3	15	Contractor	1. Conduct strict quality control checks. 2. Use standardized mix design and trial mixes. 3. Regularly calibrate batching equipment.	5 → 3	3 → 2	₹50,000 - ₹1,00,000
Environmental Factors (Temperature and Humidity Fluctuation)	4	3	12	Contractor	1. Use climate-controlled casting areas. 2. Apply curing compounds or insulation blankets. 3. Monitor weather and adjust casting schedules.	4 → 3	3 → 2	₹30,000 - ₹80,000
Equipment Malfunction	4	3	12	Contractor	1. Regular maintenance and servicing of equipment. 2. Keep backup machinery available. 3. Train operators for troubleshooting.	4 → 3	3 → 2	₹1,00,000 - ₹2,50,000
Formwork Setup and Stability Issues	4	3	12	Contractor	1. Use high-quality formwork materials. 2. Conduct stability checks before casting. 3. Ensure proper bracing and support.	4 → 2	3 → 2	₹75,000 - ₹1,50,000
Reinforcement Placement Errors	5	3	15	Contractor	1. Use skilled labour and supervision. 2. Conduct pre-pour inspections.	5 → 3	3 → 2	₹40,000 - ₹1,20,000
Defects from Curing Conditions	5	3	15	Contractor	1. Maintain adequate moisture levels. 2. Use curing compounds and water retention blankets. 3. Monitor temperature variations during curing.	5 → 3	3 → 2	₹60,000 - ₹1,50,000
Insufficient Concrete Vibration	4	3	12	Contractor	1. Use high-frequency vibrators. 2. Train workers on vibration techniques. 3. Ensure sufficient vibration time for each pour.	4 → 2	3 → 2	₹50,000 - ₹1,00,000

Contamination in Mixing Materials	3	3	9	Contractor	1. Use certified raw materials. 2. Store materials in dry, covered areas. 3. Implement strict quality control checks.	3 → 2	3 → 1	₹25,000 - ₹60,000
Inconsistent Formwork Release Agents	3	3	9	Contractor	1. Use standardized release agents. 2. Conduct pre-use testing of agents. 3. Apply agents uniformly and in correct quantities.	3 → 2	3 → 1	₹20,000 - ₹50,000
Delays in Material Supply	2	3	6	Client	1. Pre-plan and schedule material deliveries. 2. Maintain buffer stock. 3. Have alternative suppliers in case of delays.	2 → 1	3 → 1	₹50,000 - ₹2,00,000

7.0 Conclusion

This study investigates the risks of casting, transporting, and installing pre-stressed concrete structures, identifies key hazards, and outlines measures to mitigate them in order to improve safety and efficiency. Risks during casting, like improper concrete mix, misplaced reinforcement, curing defects, and equipment malfunction, can jeopardize structural longevity and project scheduling. Failure to exercise proper quality control, have standardized mix designs, and maintain equipment can cause these risks. During transit, mishandling, bad weather, road conditions, and instability in the load cause structural damage. Proper loading, route planning, and live GPS tracking reduce such risks to a minimum. Installation is marred by issues of safety hazards, equipment malfunctioning, improper temporary supports, and misalignment, impacting both stability and safety for workers. Utilizing skilled personnel, advanced lifting equipment, and constant monitoring results in a safer installation.

References

- Alani, A. M., & Aboutalebi, M. (2012). Risk management on concrete structures as a tool for the control of construction efficiency. *Construction Management Journal*, 28(4), 455–472.
- Al-Mayah, A., & Sennah, K. (2013). Analysis of prestressing in precast prestressed concrete beams. *Structural Engineering Review*, 12(2), 159–176.
- American Concrete Institute. (2018). State-of-the-art report on partially prestressed concrete earthquake-resistant building structures for highly seismic regions. *ACI Structural Journal*, 115(6), 1298–1312.

Chou, J. S., & Wu, H. Y. (2015). A probabilistic approach for safety risk analysis in metro construction. *Safety Science*, 79, 260–273.

Cueva, E. L., & Jiménez, P. M. (2019). Monitoring of long-term prestress losses in prestressed concrete structures using fibre optic sensors. *Journal of Structural Engineering*, 145(3), 04019012.

Eisenhower, J., & Park, R. (2017). Managing risks of precast concrete supply chain: A case study. *International Journal of Construction Supply Chain Management*, 5(2), 137–153.

Farooq, M., & Chen, Y. (2020). Assessment of prestressed concrete bridges – Challenges. *Journal of Bridge Engineering*, 26(1), 98–113.

Fazlur, K., & Lee, C. (2019). The quality management in precast concrete production and delivery processes supported by association analysis. *Journal of Construction Materials*, 32(4), 201–221.

Fischer, M., & Kunz, J. (2021). Case studies of BIM adoption for precast concrete design by mid-sized structural engineering firms. *Automation in Construction*, 121, 103436.

Garcia, L., & Torres, J. (2020). Contribution of prefabricated constructions to reduce the risk of project management. *Journal of Engineering and Project Management*, 45(3), 410–429.

Gonzalez, R., & Martinez, H. (2017). Case study of failure of a long prestressed precast concrete girder during lifting. *Structural Safety*, 79, 243–259.

Hassan, R., & Ali, F. (2018). Mitigating schedule overruns in pre-stressed girder bridge construction: Assessing risks and proposing mitigation strategies. *Construction Management and Economics*, 36(2), 95–115.

Holm, M., & Jansson, A. (2020). Managing risks of precast concrete supply chain. *Supply Chain Management Review*, 29(3), 112–126.

Hu, X., & Wang, T. (2019). Time-dependent prestress losses in pretensioned concrete construction. *Journal of Structural Engineering*, 145(9), 04019122.

Jain, K., & Mehta, R. (2017). Tarrant Regional Water District's risk management plan for prestressed concrete cylinder pipe. *Water Resources Management*, 31(5), 1721–1736.

Johnson, P., & Lee, D. (2019). Prestressed concrete bridge tested to failure: The Alveo Vecchio viaduct case study. *Journal of Bridge Engineering*, 24(3), 92–107.

Kang, Y., & Lee, C. (2020). Strengthening of prestressed concrete girders with composites: Installation, design, and inspection. *Composite Structures*, 235, 111767.

Kumar, S., & Sharma, P. (2018). Risk in structural engineering. *Structural Engineering and Mechanics*, 66(4), 521–537.

Liu, X., & Zhang, W. (2019). Enhanced synergic identification of prestress force and moving force in prestressed concrete bridges. *Engineering Structures*, 197, 109217.

Mahmoud, A., & Salama, A. (2017). Time-dependent prestress losses in prestressed concrete girders built of high-performance concrete. *Construction and Building Materials*, 156, 1205–1215.

Mansour, T., & Said, H. (2021). A new risk-based approach to evaluating the performance of precast concrete installations. *Journal of Construction Engineering and Management*, 147(8), 04021078.

Megaproject success: Hoover Dam construction and pre-construction management ingenuity. (2019). *Engineering History Review*, 34(5), 87–102.

Pan, Y., & Yuan, C. (2018). The impact of transportation risks on the structural integrity of precast concrete elements. *Journal of Civil Engineering*, 27(3), 298–312.

Patel, M., & Kumar, R. (2019). Safety hazards in precast concrete construction: A review. *International Journal of Safety Science*, 53(7), 243–258.

Tan, B., & Zhang, X. (2021). The impact of curing conditions on precast concrete strength development. *Journal of Materials in Civil Engineering*, 33(1), 05020002.

CHAPTER 120

Road Safety Rating using iRAP

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ABSTRACT

India ranks among the highest in the world for road accident fatalities, with over 150,000 deaths and millions of injuries recorded annually. Road accidents account for 13% of global road traffic deaths, posing a significant public health and economic challenge. Contributing factors include poor road infrastructure, lack of pedestrian and cyclist facilities, unsafe driving behaviours, and inadequate enforcement of traffic laws. Despite technological advancements, road safety remains a critical issue, with vulnerable road users such as pedestrians, motorcyclists, and cyclists disproportionately affected. This project addresses these challenges through the application of the International Road Assessment Programme (iRAP) methodology. Using iRAP, the study identifies hazardous sections of a selected national highway, evaluates its safety performance, and prioritizes safety improvements. The methodology includes the development of actionable countermeasures based on star ratings for safety. The expected outcomes include the development of a safer road network, reduced accident rates, and enhanced safety for diverse road user categories. By employing data-driven strategies and aligning with global best practices, this research aims to support the broader goal of achieving higher safety rating for national highways in India, promoting sustainable and secure road environments.

Keywords: iRAP; Road safety; Star rating.

1.0 Introduction

1.1 Introduction to road condition

Every day, millions of people travel, run errands, and commute on roadways, but these routes can be hazardous due to a lack of proper safety precautions. Road accidents continue to be a major source of death and injury globally despite technological advancements because of things like speeding, inebriated or distracted driving, human error, inadequate infrastructure, and defective vehicles. Every year, 150,785 persons in India lose their lives in traffic accidents, which cost the country's economy over \$75 billion, or 4% of GDP. According to IndiaRAP's analysis of 17,600 km of high-risk roads, 99% of them do not have bike lanes. There are no pathways on 95% of routes.

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Motorcycle facilities are absent from 99 percent of heavy motorcycle traffic routes. Fifty-five percent of routes that are 80 km/h or faster are undivided. Roadside hazards are present on 89% of curves at 80 km/h or faster. Roundabouts, turn lanes, and interchanges are absent from 87% of high-speed intersections. Over 7.6 million lives could be saved and serious injuries might be avoided in the next 20 years if 10% of India's most hazardous roads were upgraded to three stars or better.

1.2 International road assessment programme (iRAP)

By offering unbiased evaluations and suggestions, the International Road Assessment Programme (iRAP) is committed to enhancing road safety on a global scale. Its main goal is to create a “safe system” by analyzing driving behavior, routes, and automobiles. Over 70 countries, including 10 Indian states, have participated in iRAP's assessments, which are carried out in partnership with institutions such as the World Bank's GRSF. According to inspections conducted between 2010 and 2014, the majority of roads in states including Uttar Pradesh, Telangana, Rajasthan, Kerala, Tamil Nadu, Haryana, and Andhra Pradesh were rated as low safety (one or two stars). iRAP assists in directing investments and influencing driving behavior to lower the number of fatalities and injuries globally by identifying high-risk regions.

1.3 Objectives of the study

- To analyze road characteristics of 5KM stretch from Bhujbal Vasti Chowk to Sus Road Baner.
- To conduct safety performance assessment using iRAP VIDA Software.
- To recommend safety measures for good ratings.

2.0 Literature Review

Table 1: Summary of Literature Review

No.	Title	Authors	Key Findings
1	Roadway Safety Assessment and Star Rating using iRAP	Sunil, Abhishek Sharma	Assesses SH-11A (Jind-Kaithal) using iRAP to improve safety and achieve a minimum 3-star rating.
2	BIM & Road Safety	Emidio Sabatoa, Fabrizio D'Amicoa, Antonino Tripodi, Paola Tiberi	Integrates BIM with iRAP for automated safety assessments, improving efficiency in road design and asset management.
3	Road Infrastructure Inspection & iRAP	Lauragrazia Daidone <i>et al.</i>	Highlights EuroRAP/iRAP methodologies for road safety, emphasizing Safe System approaches and collaborative improvements.

4	Road Safety and iRAP in Bangladesh	Hoque M, Smith G, Rahman M	iRAP reveals low safety ratings on highways, stressing cost-effective countermeasures for vulnerable road users.
5	Road Safety Audit & Black Spot Identification in India	Sadguna Nuli, Katkam Rohan, Chenreddy Joshnavi	Emphasizes RSA and black spot identification to reduce accident-prone areas and enhance road safety.
6	Road Safety Evidence & Gap Map	Dinesh Mohan <i>et al.</i>	Identifies global road safety challenges, advocating evidence-based interventions to reduce traffic injuries.
7	Safety Factors on Two-Lane Highways in India	Sudipa Chatterjee <i>et al.</i>	RSA highlights poor road design and user behavior risks, recommending infrastructure upgrades and speed management.
8	COVID-19 Impact on Driving Behaviour & Safety	Eva Michelaraki <i>et al.</i>	Lockdowns led to higher speeds and increased risky driving behavior, requiring new safety regulations.
9	Road Safety in India: A Public Health Concern	Shradha S Parsekar <i>et al.</i>	Human negligence is a key factor in accidents; education, enforcement, and infrastructure improvements are crucial.
10	Road Safety Challenges in Nepal & India	Om Prakash Giri <i>et al.</i>	Advocates multi-stakeholder collaboration for road safety improvements in diverse geographical terrains.
11	Exposure & Speed in Road Safety	Xin PEI <i>et al.</i>	Speed increases crash severity; time spent driving also affects crash risks, requiring balanced analysis.

3.0 Methodology

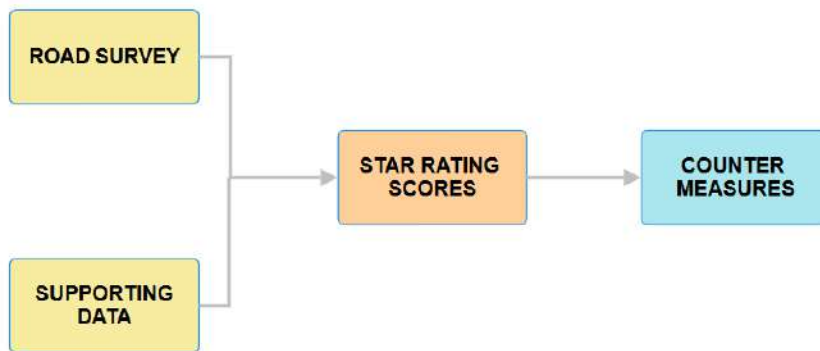
Roads are surveyed, data is gathered, and a safety rating indicating crash risk is assigned as part of a framework for improving road safety. To lessen the chance of a collision, several countermeasures are suggested based on the rating, such as putting rumble strips, adding shoulders, or upgrading signage.

3.1 Framework

The framework represents a structured approach to road safety assessment with a focus on star rating and road improvement recommendations. Below is a detailed breakdown of the process:

3.1.1 Data collection and initial assessment

- *Road survey*: Collects real-world data on existing road conditions.
- *Road coding*: Categorizes and encodes the collected data for further analysis.
- *Supporting data*: Additional relevant data such as traffic volume, and road geometry.

Figure 1: iRAP Methodology Framework

3.1.2 Evaluation and condition analysis

- *Star rating scores:* A systematic way to assess road safety using iRAP. Assigns a safety rating (typically 1-5 stars) based on road conditions and risk factors.

3.1.3 Safety recommendation

- *Countermeasure generation:* Identifies possible safety improvements (e.g., better road markings, pedestrian crossings, barriers).

3.2 Steps involved iRAP Vida road safety assessment process

Data collection on road infrastructure, traffic dynamics, and operational factors is the initial step in the assessment process. Road alignment, surface quality, paved shoulders, safety barriers, rumble strips, and speed control techniques are important components. Additionally taken into account are traffic statistics such as pedestrian flows and Annual Average Daily Traffic (AADT).

3.3 Categorization into safety modules

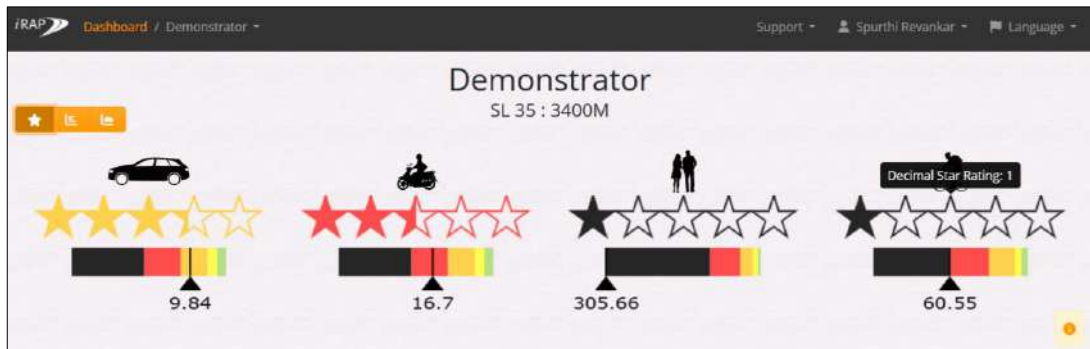
The collected data is then classified into distinct safety modules to enable a structured evaluation. The Roadside Hazard Assessment examines the proximity of fixed objects, such as safety barriers placed within a 1–5-meter range. Shoulder conditions, including narrow paved shoulders and the presence of rumble strips, are also evaluated.

3.4 Risk scoring and weighting

Based on crash data and the severity of injuries, iRAP provides weighted risk scores to road elements, producing star ratings (1–5) for cyclists, motorcyclists, pedestrians, and car occupants. International injury-prevention databases are the source of these scores.

Table 2: Categorization into Safety Modules

Roadside Attributes	
Roadside severity driver-side distance	1 to<5m
Roadside severity - driver-side object	Safety barrier - metal
Roadside severity - passenger-side distance	1 to<5m
Roadside severity. Passenger-side Object	Safety barrier metal
Shoulder rumble strips	Not present
Paved shoulder - driver-side	Narrow (≥ 0 m to < 1m)
Midblock Attributes	
Carriageway label	Carriageway A Of a divided carriageway road
Upgrade cost	Medium
Median type	Physical median width ≥ 0 m to < 1 m
Centerline rumble strips	Not present
Number of lanes	Three
Lane width	Medium (≥ 2.75 m to < 3.25m)
Intersection Attributes	
Intersection type	None
Intersection channelization	Not present
Intersecting road volume	None
Intersection quality	Not applicable
Property access points	None
Flow Attributes	
Vehicle flow (AADT)	36332
Motorcyclist %	41%-60%
Pedestrian peak hour flows across the road	6 to 25
Pedestrian peak hour flow along the road driver-side	6 to 25
Pedestrian peak hour flows along the road passenger-side	6 to 25
VRU Facilities and land use Attributes	
Land use - driver-side	Commercial
Land use - passenger-side	Commercial
Area type	Urban rural town or village
Pedestrian crossing facilities inspected road	No facility
Pedestrian crossing quality	Not applicable
Pedestrian crossing facilities - intersecting road	No facility
Speeds Attributes	
Speed limit	80km/h
Differential speed limits	Not present
Speed management I traffic calming	Not present
Operating Speed (85th percentile)	70km/h

Figure 2: Demonstrator Rating

4.0 Data Analysis and Findings

Figure 3: Selection of Study Area

4.1 Selection of study area

A 5 km road segment from Bhujbal Vasti Chowk to Sus Road Baner was surveyed using photo imagery and iRAP VIDA software. Historical speed data analysis showed no pace or warning signs, and vehicles didn't slow at junctions. The road was divided into 100-meter segments for consistent evaluation. The Star Rating Demonstrator assessed features like roadside conditions, intersections, vulnerable road user facilities, land use, and speed data. A 5

km road segment from Bhujbal Vasti Chowk to Sus Road Baner was surveyed using photo imagery and iRAP VIDA software. Historical speed data analysis showed no pace or warning signs, and vehicles didn't slow at junctions. The road was divided into 100-meter segments for consistent evaluation. The Star Rating Demonstrator assessed features like roadside conditions, intersections, vulnerable road user facilities, land use, and speed data.

4.2 iRAP star rating of 5km stretch from Bhujbal Vasti chowk to Sus road Baner

Table 3: iRAP Star Rating of 5 KM stretch from Bhujbal Vasti Chowk to Sus Road

SL NO.	DISTANCE	BEFORE - CAR	BEFORE - BIKE	BEFORE - PEDESTRIAN	BEFORE - BICYCLIST	AFTER - CAR	AFTER - BIKE	AFTER - PEDESTRIAN	AFTER - BICYCLIST
1	0 m	3.9	3.6	1	2.9	4.6	3.4	3	5
2	100 m	3.5	3.6	1	2.2	5	4.6	3	5
3	200 m	3.4	3.4	1	1	5	4.2	3	5
4	300 m	3.5	3.4	1	1	3.9	2.8	3	5
5	400 m	3.4	2.8	1	1	3.8	3.5	2.8	5
6	500 m	3.1	2.7	1	1	3.8	3.5	2.8	5
7	600 m	3.1	2.7	1	1	3.5	3.5	2.8	5
8	700 m	4.9	4.4	2	3.3	5	4.5	3.6	5
9	800 m	3.3	2.5	1	1	3.5	2.5	2.5	4.9
10	900 m	3.3	2.5	1	1	3.5	2.9	2.6	4.9
11	1000 m	2.9	2.3	1	1	3.7	2.6	2.9	5
12	1100 m	2.9	2.3	1	1	3.3	3	2.9	5
13	1200 m	2.9	2.4	1	1	3.3	3	2.9	5
14	1300 m	2.9	2.4	1	1	3.3	3	2.9	5
15	1400 m	3.3	2.6	1	1	3.3	3.3	2.9	5
16	1500 m	3.5	2.6	1	1	3.7	3.3	2.7	5
17	1600 m	3.5	2.6	1	1	3.7	3.3	2.7	5
18	1700 m	3.5	2.6	1	1	3.7	3.3	2.9	5
19	1800 m	3.5	2.6	1	1	3.7	3.3	2.9	5
20	1900 m	3.5	2.6	1	1	3.4	3.3	2.9	5
21	2000 m	2.7	2.1	1	1	3.4	3.3	4.5	5
22	2100 m	3.5	2.6	1	1	3.7	3.4	3.2	5
23	2200 m	3	2.4	1	1	3.7	3.4	3.2	5
24	2300 m	3	2.4	1	1	3.7	3.4	3.2	5
25	2400 m	3.5	2.7	1	1	3.7	3.4	3.2	5
26	2500 m	3.5	2.7	1	1	3.7	3.5	3.2	5
27	2600 m	3.3	2.6	1	1	3.7	3.5	3.2	5
28	2700 m	3.3	2.5	1	1	3.7	3.4	3	5
29	2800 m	2.8	2.2	1	1	3.4	3.2	2.9	5
30	2900 m	3.3	2.6	1	1	3.7	3.4	2.9	5
31	3000 m	3.4	2.8	1	1	3.7	3.4	3	5
32	3100 m	3.3	2.6	1	1	3.7	3.4	3	5
...	...	...	...	...	...	...	...	...	...
51	5000 m	2.8	2.2	1	1	3.5	3.1	3.1	5
AVERAGE RATING		3.4	2.7	1	1.5	3.8	3.4	3.1	5

4.3 Star rating analysis iRAP Vida road analysis

4.3.1 Star rating table (raw) –present road condition

Table shows clearly that only 88 % of the roads for vehicle occupants, 12% for motorcyclists, is rated 3 star or above, rest is below 3 Star.

Table 4: Star Rating Table – Present Road Condition

Star Rating	Vehicle Occupant		Motorcyclist		Pedestrian		Bicycle	
	Length (Km)	Percent %	Length (Km)	Percent %			Length (Km)	Percent %
5 STARS	0.3	6%	0	0%	0	0%	0	0%
4 STARS	0.1	2%	0.1	2%	0	0%	0	0%
3 STARS	4	80%	0.5	10%	0	0%	0.1	2%
2 STARS	0.6	12%	4.4	88%	0.1	2%	1.9	38%
1 STAR	0	0%	0	0%	4.9	98%	3	60%
TOTALS	5	100%	5	100%	5	100%	5	100%

4.4 Star rating table (Raw) – After recommendation's from iRAP Vida

This table clearly shows that around 100 % of the roads for vehicle occupants are rated 3-star or above, and about 100% of the roads for motorcyclists are rated safe after implementing the countermeasures into the iRAP VIDA Software. There is a significant increase in the safety characteristics of the roads in comparison to the existing situation.

Table 5: Star Rating Table- After Recommendation's from iRAP Vida

Star Rating	Vehicle Occupant		Motorcyclist		Pedestrian		Bicycle	
	Length (Km)	Percent %	Length (Km)	Percent %			Length (Km)	Percent %
5 STARS	0.5	10%	0	0%	0	0%	4.8	96%
4 STARS	0	0%	0.5	10%	0.1	2%	0.2	4%
3 STARS	4.5	90%	4.5	90%	2.9	58%	0	0%
2 STARS	0	0%	0	0%	2	40%	0	0%
1 STAR	0	0%	0	0%	0	0%	0	0%
TOTALS	5	100%	5	100%	5	100%	5	100%

4.5 Results and observations in general

Recommendations include widening shoulders and installing speed-calming measures. Safety performance is evaluated by calculating Star Rating Scores for every 100-meter segment for four user groups: Vehicle occupants, Motorcyclists, Pedestrians, and Bicyclists.

4.6 Strategic implications and safety enhancements

- *Narrow/No Shoulder:* Adding rumble strips, using wide medians, and providing designated shoulders on both sides can improve safety and enforce correct lane discipline. Narrow or missing shoulders on expressways, particularly in ghat sections, reduce emergency stopping space.

- *Poor/ineffective road signage:* Clear road markings and signage are essential for guiding drivers and ensuring timely decisions. Issues include poor visibility, incorrect placement, and lack of multilingual information. Signs should be installed at least 1 km before action points, using clear symbols or multilingual text (Marathi, Hindi, English). Repeating signs at least three times improves effectiveness.
- *Damaged curb stones:* Black and yellow curb stones along the borders of motorways can seriously damage cars in collisions, putting them at risk of rollovers.
- *Infrastructure for pedestrians and cyclists:* By reducing collisions with cars, crossings, walkways, and bike lanes increase safety for non-motorized users.
- *Road markings & speed control:* Safety and compliance are improved by clear markings, signage, and speed control devices like bumps and cameras.
- *Physical safety interventions:* Improved lighting, rumble strips, and guardrails lower collision rates and increase visibility at night.
- *Modifications to traffic flow:* Improving traffic flow and safety can be achieved by adding median barriers and widening lanes.
- *Projected safety outcomes:* With focused interventions, iRAP ratings can rise from 1-2 stars to 3 stars.
- *Crash reduction:* Actions could result in a 50% decrease in crashes that cause fatalities and major injuries.

5.0 Conclusion

The Star Rating system assesses road safety based on user protection rather than the number of crashes or fatalities. This study evaluated road safety from Bhujbal Vasti Chowk to Sus Road, Baner, dividing the corridor into 100-meter segments for accurate analysis using the Star Rating Demonstrator. Key factors assessed included roadside features, traffic flow, VRU infrastructure, and speed data. Recommended countermeasures aim to achieve a minimum 3-star rating for all users, focusing on improved road markings, pedestrian crossings, barriers, speed control, and visibility. Continuous monitoring with data analytics is emphasized for long-term effectiveness.

References

BIYIK, C. (2021, November 24). *Vehicular communications for road safety applications*. AURUM Journal of Engineering Systems and Architecture.

Chatterjee, S., Bandyopadhyaya, P. S., & Mitra, S. (2020). Identifying critical safety issues on two-lane national highways in India – A case study from NH 117 and NH 60. *Transportation Research Procedia*, 48, 3908–3923.

Daidone, L., Pagliari, E., Pennisi, L., Caporali, E., Mazzia, E., & Tiberi, P. (2023). Road infrastructure inspections to assess the road network according to the iRAP/EuroRAP methodology. *Transportation Research Procedia*, 69, 743–750.

Ellison, A. B., Greaves, S. P., & Bliemer, M. C. (2015). Driver behaviour profiles for road safety analysis. *Accident Analysis & Prevention*, 76, 118–132.

Hoque, M. M., Smith, G., Rahman, M. A., & Uddin, M. H. M. A. (2012, October 4–6). iRAP and road infrastructure safety assessment in Bangladesh. *Australasian Road Safety Research, Policing and Education Conference*, Wellington, New Zealand.

iRAP. (2023, December 5). *iRAP - International Road Assessment Programme*. <https://irap.org/>

iRAP. (2023, September 7). *iRAP methodology fact sheets*. iRAP.

Ktrakazas, C., Michelaraki, E., Sekadakis, M., & Yannis, G. (2020). A descriptive analysis of the effect of the COVID-19 pandemic on driving behaviour and road safety. *Transportation Research Interdisciplinary Perspectives*, 7, 100186.

Ministry of Road Transport & Highways, Government of India. (n.d.). *Ministry of Road Transport & Highways*. <https://morth.nic.in/>

Mohan, D., Tiwari, G., Varghese, M., Bhalla, K., John, D., Saran, A., & White, H. (2020). Protocol: Effectiveness of road safety interventions: An evidence and gap map. *Campbell Systematic Reviews*, 16(1).

Nuli, S., Rohan, K., & Joshnavi, C. (2022, September 1). A study on road safety audit and black spot identification. *IOP Conference Series: Earth and Environmental Science*, 1086(1), 012028.

CHAPTER 121

Root Cause Analysis in Adaption of Prefabrication Technology in Construction Industry

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ABSTRACT

Prefabrication technologies are increasingly being adopted in the building industry due to their time, cost, and quality benefits. However, there are challenges that hinder their widespread adoption. This study focuses on identifying the root causes (RCA) behind the failure to adopt prefabrication technology. Issues such as enforceability of digital signatures, volatile supply chains, legal exceptions, industry resistance, and incompetent designers are among the problems identified. By combining qualitative and quantitative techniques, the study evaluates the scope of these issues and suggests strategies to address them. The findings show that improving workforce training, legislative support, and supply chain management can significantly enhance the use of prefabrication methods. The research aims to assist in developing frameworks and guidelines to promote the adoption of prefabrication technologies in the construction industry.

Keywords: Prefabrication; Root cause analysis; Workforce training; Average index method.

1.0 Introduction

Prefabricated construction not only promotes better quality control, flexibility, and easier construction, but it also revolutionizes traditional construction site methods—where buildings are often made by hand, without proper planning or foresight. These older methods face challenges like poor weather conditions and other unpredictable factors, which can lead to costly mistakes and inefficiencies.

- *Modular construction:* All building sections of the house are precast and installed on site, suitable for home hotels and student housing.
- *Panelized construction:* Prefabricated wall, floor, and roof panels offer design flexibility.
- *Precast concrete:* Durable concrete elements like walls and beams are cast off-site and transported.
- *Structural steel framing:* Off-site fabricated steel components enable large spans and open spaces.

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- *Prefabricated timber construction:* Sustainable timber elements provide cost-effectiveness and insulation.

1.1 Research objectives

- To identify major barriers to prefabrication technology adoption.
- To analyze the root causes of these challenges using RCA.
- To propose strategic solutions for overcoming these barriers.

2.0 Literature Review

Construction prefabrication is cost-saving, sustainable, and efficient but also presents issues. Beulah (2022) presents serious issues of high cost and change resistance. Palanisamy (2021) focuses on factors and innovation in prefabricated building. Ibrahim *et al.* (2023) employ a Fuzzy-SEM model to present financial, policy, and technological issues to prefabrication. Prefabrication productivity benefits in Tamil Nadu are identified by Murali and K (2020) with flexibility and training concerns. Nor & Azman (2012) contrast traditional and prefabrication practice, with higher use of precast systems. Palcis (n.d.) illustrates the effect of prefabrication on speed, safety, and sustainability. Rocha *et al.* (2022) discuss the effect of prefabrication on environmental and economic sustainability. These studies altogether indicate the potentialities and constraints of prefabrication in various fields and applications.

3.0 Methodology

3.1 Research approach

A mixed-method approach was used, incorporating both qualitative and quantitative data collection methods. Literature reviews and surveys were conducted to gather insights.

3.2 Data collection

- *Primary data:* Surveys and interviews with industry professionals, contractors, and suppliers. The survey focused on identifying the most pressing challenges and possible solutions from industry practitioners.
- *Secondary data:* Review of academic papers, industry reports, and case studies related to prefabrication technology. The secondary data helped in understanding global best practices and comparing prefabrication adoption in different regions.

We have done a survey to identify and rank the factors that are the Root cause in adaption of prefabrication technology in construction industry.

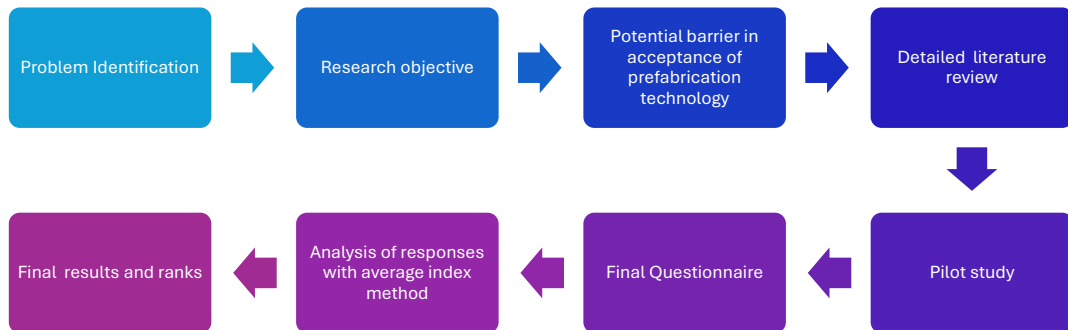
3.3 Research questions and rating scale

Instructions: Please rate the following questions based on their impact on prefabrication adoption.

Scale: (Option for each question)

1. Not Important
2. Slightly Important
3. Moderately Important
4. Important
5. Very Important

Figure 1: Research Methodology.



3.3.1 Transportation and logistics

- Do transportation restrictions (e.g., road width, weight limits) hinder prefabricated component delivery?
- Do high transportation setup costs discourage prefabrication adoption?
- Does the requirement for large-capacity cranes increase logistical challenges?
- Do complex permit requirements for large, prefabricated components delay projects?

3.3.2 Cost & financial constraints

- Does the high initial investment make prefabrication less attractive than conventional methods?
- Do transportation and handling costs of prefabricated components outweigh their benefits?
- Does the lack of government incentives slow prefabrication adoption?

3.3.3 Design & construction challenges

- Does inflexibility in design modifications limit prefabrication adoption?
- Do long lead times for prefabrication components affect project efficiency?
- Does the lack of recognized quality control organizations impact trust in prefabrication?

3.3.4 R&D & innovation

- Does limited investment in research and development hinder prefabrication improvements?
- Does difficulty in integrating prefabrication with traditional methods slow its adoption?

- Does the lack of advanced digital tools/software create challenges in prefabrication planning and execution?

3.3.5 Regulatory & policy constraints

- Do government policies and regulations fail to support prefabrication adoption?
- Do complex permitting processes for prefabricated components cause project delays and cost overruns?

Figure 2: Pie Chart Showing Roles of the Responders

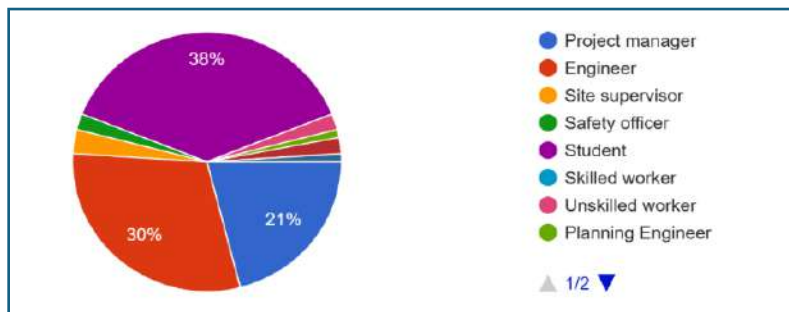
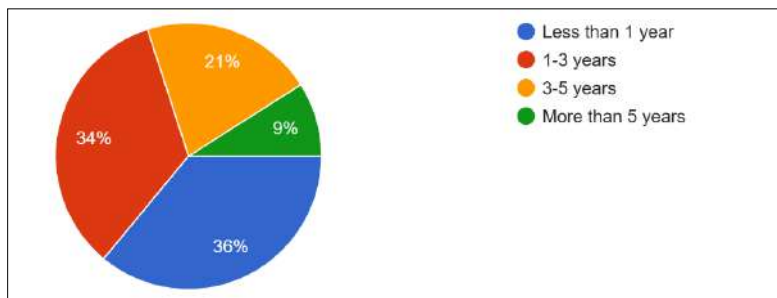


Figure 3: Pie Chart Years of Experience of the Responders



3.4 Data analysis

3.4.1 Average index method

The Average Index Method is a valuable tool in root cause analysis, utilized to identify the key contributing factors of a problem through the analysis of survey or operational data. This method assists in ranking issues based on their significance or frequency.

$$\text{Average Index} = \left[\frac{\sum_{i=1}^5 a_i x_i}{5 \sum_{i=1}^5 x_i} \right] \quad \dots 1$$

Where, a_i represents a constant that indicates the weight assigned to i , while X_i denotes a variable that reflects the frequency of the response.

Table 1: Survey Response Sheet

Survey questions in short	No. of Response as 1	No. of Response as 2	No. of Response as 3	No. of Response as 4	No. of Response as 5
Lack of experienced designers?	5	7	27	40	21
Lack of qualified contractors?	5	8	26	36	25
Shortage of prefabricated component suppliers?	3	9	31	29	28
Investors reluctant to invest?	2	12	23	36	27
Industry resistance to innovation?	3	9	31	35	22
Limited skilled labor for assembly?	3	15	28	33	21
High cost of prefabrication contractors?	2	11	21	41	25
High transportation expenses?	3	7	26	41	23
Lack of government regulations?	3	14	25	38	20
Insufficient training programs?	5	7	29	35	24
Restrictions on transportation?	5	8	26	39	22
High start-up costs for prefabrication?	3	8	24	38	27
Low research & development in prefabrication?	2	9	24	37	28
Complexity in obtaining permits?	2	7	31	32	28
Poor stakeholder collaboration?	3	5	32	34	26

3.4.2 Relative Importance Index (RII)

In the present study, the Relative Importance Index (RII) method was employed to rank the significance of factors influencing the adoption of prefabrication technology within the construction industry. The RII technique is frequently utilized in construction management research to determine the relative weight of responses gathered using a Likert scale. The RII approach is helpful in determining the most important factors affecting decision-making procedures by transforming ordinal data into normalized scale.

$$RII = (5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1) / 5N \quad \dots 2$$

where, n_1 = Number of respondents for Not Important

n_2 = Number of respondents for Less Important

n_3 = Number of respondents for Moderately Important

n_4 = Number of respondents for Important

n_5 = Number of respondents for Very Important

N = Total number of respondents

Using this formula, the RII values of each factor were calculated and the factors ranked in decreasing order according to their relative importance. The greater the value of RII, the more important the factor is in relation to the issue being researched. This analysis offers a structured and metric approach to determining the most important factors, assisting in more informed decision-making and targeting corrective measures.

Table 2: Data Analysis Sheet

Survey questions in short	Relative importance index score (RII)	Average index method score (AI)	Rank on the basis of RII	Rank on the basis of AI
Lack of experienced designers?	0.73	3.65	11	11
Lack of qualified contractors?	0.736	3.68	9	9
Shortage of prefabricated component suppliers?	0.74	3.7	8	8
Investors reluctant to invest?	0.748	3.74	6	6
Industry resistance to innovation?	0.728	3.64	13	13
Limited skilled labor for assembly?	0.708	3.54	15	15
High cost of prefabrication contractors?	0.752	3.76	4	4
High transportation expenses?	0.748	3.74	6	6
Lack of government regulations?	0.716	3.58	14	14
Insufficient training programs?	0.732	3.66	10	10
Restrictions on transportation?	0.73	3.65	11	11
High start-up costs for prefabrication?	0.756	3.78	2	2
Low research & development in prefabrication?	0.76	3.8	1	1
Complexity in obtaining permits?	0.754	3.77	3	3
Poor stakeholder collaboration?	0.75	3.75	5	5

4.0 Research Findings and Results

4.1 Findings

4.1.1 Key barriers to prefabrication adoption

- The most significant challenge identified is low research & development (R&D) in prefabrication, which ranked highest based on both the Relative Importance Index (RII) = 0.76 and the Average Index Method (AI) = 3.8.
- High start-up costs for prefabrication (RII = 0.756, AI = 3.78) are another major factor preventing the adoption of prefabrication in construction.
- Complexity in obtaining permits (RII = 0.754, AI = 3.77) is a major regulatory barrier affecting the smooth implementation of prefabrication.

4.1.2 Financial and logistical constraints

- High cost of prefabrication contractors (RII = 0.752, AI = 3.76) and high transportation expenses (RII = 0.748, AI = 3.74) are significant cost-related concerns that discourage prefabrication use.
- Investors' reluctance to invest (RII = 0.748, AI = 3.74) indicates financial hesitancy from stakeholders due to uncertainties in return on investment and market viability.

4.1.3 Skilled labor and industry readiness

- The shortage of prefabricated component suppliers (RII = 0.74, AI = 3.7) and lack of qualified contractors (RII = 0.736, AI = 3.68) highlight a gap in industry expertise.
- The lack of experienced designers (RII = 0.73, AI = 3.65) and insufficient training programs (RII = 0.732, AI = 3.66) indicate the need for better educational frameworks and training initiatives.

4.1.4 Regulatory and structural challenges

- Lack of government regulations (RII = 0.716, AI = 3.58) and industry resistance to innovation (RII = 0.728, AI = 3.64) suggest that policy support and industry mindset shifts are necessary.
- The lowest-ranked factor is limited skilled labor for assembly (RII = 0.708, AI = 3.54), which suggests that while labor shortages exist, they may not be the most critical issue compared to financial and regulatory barriers.

4.2 Results

- The most critical barriers are related to financial feasibility (high start-up costs), lack of R&D, and regulatory complexity.
- The industry is hesitant to invest in prefabrication due to high costs, lack of government incentives, and supply chain constraints.
- Stakeholder collaboration needs improvement, as it ranked among the top challenges (RII = 0.75, AI = 3.75), showing that better coordination among designers, contractors, and suppliers is crucial.
- Addressing skill shortages through training programs and contractor qualification improvements can help mitigate industry readiness challenges.

5.0 Conclusion

The analysis highlights that financial constraints, regulatory hurdles, and insufficient research & development are the most significant barriers to prefabrication technology adoption in the construction industry. Addressing these issues through increased investment in R&D, policy interventions, and improved collaboration between stakeholders can help accelerate the adoption of prefabrication. Additionally, reducing costs, improving supply chain efficiency, and providing industry training will further support widespread implementation.

Reference

Beulah, F. (2022). Challenges faced in prefabrication or modular construction. *International Journal for Research in Applied Science and Engineering Technology*, 10(1), 168–178.

Chandrasekaran, P. (2021). *Prefabricated structures and its components—Advances in civil engineering* (S. Sathish, Ed.). AkiNik Publications. <https://doi.org/10.22271/ed.book.1130>

Ibrahim, A., Hamdy, K., & Badawy, M. (2023). Overall barriers to the prefabricated construction industry: A fuzzy-SEM approach. *Research Square*. <https://doi.org/10.21203/rs.3.rs-3487126/v1>

K, M., & K, S. (2020). Prefabrication as a solution to improve productivity of construction industry, Tamilnadu, India. *International Journal of Scientific and Research Publications*, 10(4), 10068. <https://doi.org/10.29322/ijsrp.10.04.2020.p10068>

Nor, M., & Azman, A. (2012). *Comparative study on prefabrication construction process*. <https://www.researchgate.net/publication/260202475>

Pelitones Palcis, R. J. (n.d.). *Examining the advantages of prefabrication and modular construction techniques for enhancing speed, efficiency, and sustainability in construction projects*. <https://doi.org/10.13140/RG.2.2.25678.54081>

Rocha, P. F., Ferreira, N. O., Pimenta, F., & Pereira, N. B. (2022). Impacts of prefabrication in the building construction industry. *Encyclopedia*, 3(1), 28–45. <https://doi.org/10.3390/encyclopedia3010003>

Wu, Z., Luo, L., Li, H., Wang, Y., Bi, G., & Antwi-Afari, M. F. (2021). An analysis on promoting prefabrication implementation in construction industry towards sustainability. *International Journal of Environmental Research and Public Health*, 18(21), 11493. <https://doi.org/10.3390/ijerph182111493>

Yuan, Z., Ni, G., Wang, L., Qiao, Y., Sun, C., Xu, N., & Wang, W. (2020). Research on the barrier analysis and strength measurement of a prefabricated building design. *Sustainability*, 12(7), 2994. <https://doi.org/10.3390/su12072994>

CHAPTER 122

Selection of Construction Contractors using Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Fuzzy TOPSIS)

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ABSTRACT

The success of construction projects hinges on selecting the right contractor, but traditional methods often struggle due to the subjective nature and complexity of evaluating contractors. This study proposes an integrated approach combining the Fuzzy Analytical Hierarchy Process (AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to improve contractor selection. Fuzzy AHP addresses subjectivity in expert opinions by assigning relative weights to key contractor selection criteria, such as project quality, experience, safety records, cost estimation accuracy, and adherence to timelines. (Tafazzoli, 1861). These weighted criteria are subsequently applied in the Fuzzy TOPSIS algorithm, which ranks contractors by evaluating their performance relative to an ideal (optimal) and a negative (least desirable) solution. The most suitable contractor is determined by minimizing their distance from the ideal solution while maximizing their distance from the negative solution. (Y *et al.*, 2024) The result is a more accurate and reliable contractor selection process that can enhance project outcomes. By using Fuzzy AHP and Fuzzy TOPSIS, the study demonstrates how this approach streamlines contractor selection, ultimately contributing to the overall success of construction projects. (Wang, 2023).

Keywords: Fuzzy analytical hierarchy process (Fuzzy AHP); Fuzzy technique for order preference by similarity to ideal solution (Fuzzy TOPSIS); Contractor selection; Subjectivity.

1.0 Introduction

1.1 What do you mean by MCDM?

Contractor selection is most important in the construction business. Traditional contractor selection methods are usually faced with the problem of ambiguity and subjectivity. The MCDM provides a model-based process for selection that increases the probability of success. This is done based on various criteria like cost, quality, experience, safety, and financial stability.

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1.2 Problems in construction contractor selection

Traditional contractor selection methods are usually faced with the problem of ambiguity and subjectivity. The MCDM provides model-based structured selection processes that increase the likelihood of a better selection decision. (Sahoo, 2023)

- Subjectivity in Assessment
- Multiple Criteria Complexity
- Inconsistent Weighting of Criteria
- External Factors Affecting Performance
- Risk of Poor Outcomes

1.3 Role of MCDM in construction contractor selection

MCDM techniques help address contractor selection challenges by:

- Establishing evaluation criteria
 - Defining weights for each criterion
 - Gathering and analyzing data
 - Ranking contractors based on an objective methodology
- Common criteria in contractor selection include:
- *Technical Competence*: Experience, past project success, and workforce expertise.
 - *Financial Stability*: Cash flow, credit rating, and financial reserves.
 - *Project Management Ability*: Planning, risk management, and adherence to deadlines.
 - *Safety Records*: Compliance with safety standards and historical performance.
 - *Quality Assurance*: Past work quality and customer satisfaction.

2.0 Literature Review

2.1 Problems in construction contract selection

This research compilation underscores the necessity of robust contractor selection, moving beyond the traditional lowest-bid approach. Multi-criteria decision-making (MCDM) methods like AHP, ANP, and TOPSIS are advocated, emphasizing key factors such as safety, financial stability, technical expertise, and past performance. (Aghajan, 2025) The studies highlight the importance of integrating both quantitative and qualitative data, recognizing contextual differences between public and private sectors, and regional variations. Tailored selection frameworks, accounting for specific project requirements and stakeholder preferences, are crucial. (Yang, 2014) Furthermore, the research emphasizes understanding causal relationships between selection criteria and project outcomes. This necessitates comprehensive pre-qualification standards and refined decision-making processes to mitigate risks and ensure project success. (Amireh, 2022)

2.2 Criteria for selecting construction contractors

Here the various options of the choice of the contractor are considered, as the reference being made to the fact that the basic criterion was only the cost, and currently, the evaluation is extensive, including many indicators (Jaskowski, 2010). The key factors defining the quality of the contractor are safety, sustainability, financial resources, professionalism of work, and management abilities. Such methodologies as AHP, TOPSIS, and Sustainability are growing in importance with research focusing on green building practices and CO2 emissions. Trust, past performance, and quality control are also important. Research examines main contractor and subcontractor selection, revealing regional differences and industry-specific priorities. (Y *et al.*, 2024) The studies argue in favor of structured evaluation frameworks which integrate stakeholder input and quantifiable metrics, to enhance project success rate and lower the risk and the uncertainty. Also, they criticize the preference for the lowest-bidder approach and emphasize the necessity for data-driven, comprehensive selection processes.

2.3 Multi-criteria decision-making (MCDM) methods for contractor selection

This research synthesizes findings from numerous studies, emphasizing the evolution of contractor selection methodologies. Traditional approaches, often reliant on lowest-bid awards, are increasingly challenged by multi-criteria decision-making (MCDM) methods like AHP, ANP, TOPSIS, and PROMETHEE. Key studies such as (A., M.Z.X., & C., 2022) on green building criteria, (A.R., A.M., S.H., N.I.A.B., & N.A., 2021) on safety, and (Tafazzoli, 1861) on subcontractor selection, alongside others, highlight the shift towards comprehensive evaluations encompassing safety, financial stability, technical expertise, and past performance. These works collectively advocate for tailored frameworks and data-driven processes, recognizing contextual variations and the importance of understanding causal relationships for project success.

2.4 Application of fuzzy analytical process in contractor selection

This section examines diverse contractor selection methodologies, including Fuzzy AHP, VIKOR, and ANP, addressing multi-criteria decision-making (MCDM) complexities. Studies like the 2020 Operational Research in Engineering Sciences publication, (X *et al.*, 2024) ANP study and research introducing BWM and SIR methods are highlighted. These approaches, incorporating fuzzy logic and quantified SWOT analysis, aim to mitigate subjectivity and enhance project outcomes by considering factors beyond bid prices, such as financial strength and technical expertise.

2.5 Application for fuzzy technique for order preference by similarity to ideal solution

This section highlights the shift towards multi-faceted contractor selection, emphasizing non-price factors and utilizing MCDM methods like TOPSIS and Fuzzy AHP. Studies, including Alptekin's work on Turkish public procurement, research on South Kerman Electricity Company's SWOT analysis, and (Izadi, 2013) Fuzzy TOPSIS application

demonstrates the importance of considering financial stability, risk assessment, and quality control. These papers collectively advocate data-driven decisions that integrate subjective and objective criteria to enhance project success.

3.0 Methodology

The study employs a systematic approach integrating Fuzzy AHP and Fuzzy TOPSIS for contractor selection.

3.1 Questionnaire development

A Fuzzy AHP-TOPSIS questionnaire was developed for contractor evaluation. It collected expert assessments on the importance of criteria and contractor performance. A pilot test on Google Forms was conducted to refine the questionnaire. Ten respondents of diverse backgrounds provided feedback so that the wording was improved, questions that were duplicates were eliminated, and the layout was improved.

3.2 Fuzzy AHP analysis

- Step 1: Define Hierarchical Structure: Clearly define a goal (object of ranking criteria for selection of a contractor) and create a hierarchical model. Identify and group relevant criteria (for example, financial stability, technical excellence, safety) in a structured framework. (Ebrahim Jokar, 2020)
- Step 2: Develop Fuzzy Pairwise Comparison Matrices: Design questionnaires with linguistic scales, like equally important to collecting expert opinions. Transform language terms into triangular fuzzy numbers.

Figure 1: Creating a Fuzzy Pairwise Comparison Matrix

	Sustainable Practices implemented in similar projects	Client Testimonials	Creditworthiness and Rating
Sustainable Practices implemented in similar projects	(1,1,1)	(1,2,3)	(2,3,4)
Client Testimonials	(0.4,0.5,0.6)	(1,1,1)	(0.6,0.667,0.7)
Creditworthiness and Rating	(0.3,0.33,0.4)	(1.4,1.5,1.6)	(1,1,1)

- Step 3: Fuzzy Synthesis, Consistency Check: Aggregate the fuzzy matrices by the geometric mean or other methods to derive overall fuzzy weights. Calculate the Consistency Ratio (CR) to ensure expert judgments are consistent. De-fuzzify the comparison matrix, compute the consistency index (CI), and compare it to the random consistency index (RI).
- Step 4: Defuzzification: This involves converting fuzzy weights into crisp numbers.
- Step 5: Normalize and Rank: Normalize the De-Fuzzified weights. This makes them sum to one, showing the relative importance of each criterion. Rank the criteria in descending order. Use their normalized weights, with the highest weight indicating the most critical factor. (Osman Taylan, 2014)

Figure 2: Computing the Fuzzy Geometric Weight r_i and the Fuzzy Weights w_i

Criteria	Fuzzy Geometric mean r_i	Fuzzy Weights w_i
Sustainable Practices implemented in similar projects	(6.096,7.177,6.89)	(0.22,0.313,0.376)
Client Testimonials	(0.22,0.291,0.427)	(0.0081,0.012,0.023)
Creditworthiness and Rating	(0.288,0.3637,0.432)	(0.010,0.015,0.023)
References from previous clients	(0.381,0.470,0.548)	(0.014,0.020,0.029)

Figure 3: Computing the Normalized Fuzzy Weights W_i

Criteria	Fuzzy Weights w_i	Weights W_i	Normalized Weights W_i
Sustainable Practices implemented in similar projects	(0.22,0.313,0.376)	0.303	0.295667447
Client Testimonials	(0.0081,0.012,0.023)	0.014	0.013661202
Creditworthiness and Rating	(0.010,0.015,0.023)	0.016	0.015612802

3.3 Fuzzy TOPSIS analysis

Step 1: Alternatives ratings by decision makers: A 5-point scale rating is a simple and structured way to evaluate contractors in construction projects, ranging from very low (1) to very high (5). It helps assess key factors like experience, financial stability, past performance, and compliance, making the selection process fair and data driven. The Contractors are rated by different decision makers to get a fair rating, and these ratings will be combined further for ease of calculations.

Figure 4: Information Collected from the Decision-makers

	Sustainable Practices Implemented in similar projects	Client Testimonials	Creditworthiness and Rating	References from previous clients	Project Management experience on similar projects
Contractor 1	Very low	Very High	High	Very High	High
Contractor 2	Average	Very low	Low	Very low	Low
Contractor 3	Very High	Very High	Very High	Very High	Very High

Step 2: Converting linguistic rankings to fuzzy numbers using triangular membership function: This helps turn vague ratings (like “good” or “excellent”) into precise numerical values. Apply normalization techniques suitable for fuzzy data (e.g., triangular fuzzy number normalization) to ensure all criteria are on a comparable scale, regardless of their original units or scales of measurement. (Osman Taylan, 2014)

Step 3: Calculate the weighted fuzzy normalized decision matrix: Multiply each normalized fuzzy rating by the corresponding criterion weight, obtained from a previous Fuzzy AHP analysis, to reflect the relative importance of each criterion.

Table 1: Conversion of 5-point Linguistic Rating to Fuzzy Numbers

Term	Fuzzy Numbers
Very Low	(1,1,3)
Low	(1,3,5)
Average	(3,5,7)
High	(5,7,9)
Very High	(7,9,9)

Figure 5: Conversion of Linguistic Rating to Fuzzy Numbers

	Sustainable Practices implemented in similar projects	Client Testimonials	Creditworthiness and Rating	References from previous clients
Contractor 1	(1,1,1)	(5,7,67,9)	(5,7,9)	(7,9,9)
Contractor 2	(3,5,7)	(1,1,3)	(1,3,67,7)	(1,1,3)
Contractor 3	(1,7,9)	(7,9,9)	(7,9,9)	(5,5,9)

Step 4: Determine fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS): Identify the FPIS, representing the best possible performance for each criterion, and the FNIS, representing the worst possible performance. These are defined based on the maximum and minimum fuzzy values in the weighted normalized decision matrix. (Fang Wang, 2016)

Figure 6: Calculating the Weighted Normalized Decision Matrix

Weightage	(0.22,0.313,0.376)	(0.0081,0.012,0.023)	(0.010,0.015,0.023)	(0.014,0.020,0.029)	(0.018,0.025,0.035)
	Sustainable Practices implemented in similar projects	Client Testimonials	Creditworthiness and Rating	References from previous clients	Project Management experience on similar projects
Contractor 1	(1,1,1)	(5,7,67,9)	(5,7,9)	(7,9,9)	(5,7,9)
Contractor 2	(3,5,7)	(1,1,3)	(1,3,67,7)	(1,1,3)	(1,3,5)
Contractor 3	(1,7,9)	(7,9,9)	(7,9,9)	(5,5,9)	(7,9,9)

Figure 7: Calculation of FPIS and FNIS

Weightage	(0.22,0.313,0.376)	(0.0081,0.012,0.023)
	Sustainable Practices implemented in similar projects	Client Testimonials
Contractor 1	(0.022,0.034,0.041)	(0.004,0.0102,0.023)
Contractor 2	(0.072,0.175,0.29)	(0.0008,0.0013,0.007)
Contractor 3	(0.024,0.244,0.376)	(0.006,0.012,0.023)
A+	(0.024,0.244,0.376)	(0.006,0.012,0.023)
A-	(0.022,0.034,0.041)	(0.0008,0.0013,0.007)

Figure 8: Calculating the Distance from FPIS and FNIS

Weightage	(0.22,0.313,0.376)	(0.0081,0.012,0.023)
	Sustainable Practices implemented in similar projects	Client Testimonials
Contractor 1	(0.022,0.034,0.041)	(0.004,0.0102,0.023)
Contractor 2	(0.072,0.175,0.29)	(0.0008,0.0013,0.007)
Contractor 3	(0.024,0.244,0.376)	(0.006,0.012,0.023)
A+	(0.024,0.244,0.376)	(0.006,0.012,0.023)
A-	(0.022,0.034,0.041)	(0.0008,0.0013,0.007)
Contractor 1	0.1132	0.0015
Contractor 2	0.414	0.0115
Contractor 3	0	0
Contractor 1	0	0.0107
Contractor 2	0.1677	0
Contractor 3	0.1132	0.0115

Step 5: Compute Distances from FPIS and FNIS: Calculate the distance of each contractor's performance from both the FPIS and FNIS using the vertex method or another suitable distance measure for fuzzy numbers (Fang Wang, 2016).

Step 6: Calculate Closeness Coefficients and Rank Contractors: Determine the closeness coefficient for each contractor, representing its relative proximity to the FPIS and distance from the FNIS. Rank the contractors in descending order based on their closeness coefficients, with the highest coefficient indicating the most suitable contractor.

Figure 9: Calculation of Closeness Coefficient and Ranking

	Di+	Di-	CCi	Rank
Contractor 1	0.5461	0.2527	0.316349524	3
Contractor 2	0.7119	0.5301	0.426811594	2
Contractor 3	0.8721	1.3203	0.602216749	1

4.0 Results and Findings

Fuzzy AHP ranks contractors by integrating literature criteria, expert opinions, and project needs. Linguistic ratings are converted into fuzzy numbers, averaged to mitigate bias, and compiled into a pairwise comparison matrix. Fuzzy geometric means, such as (6.096, 7.177, 6.89) for “Sustainable Practices,” and de-fuzzified scores like 3.9696 for “Risk Management capacity,” provide data-driven insights. Utilizing a fuzzy scale, like (1,1,1) for “Equal” and (9,9,9) for “Extremely strong,” ensures representative judgments. This approach emphasizes risk and safety in contractor selection. Fuzzy TOPSIS provides a structured ranking method using a 5-point rating scale and triangular membership functions, enhancing objectivity. A combined decision matrix, incorporating experience, financial health, and performance, enables equitable comparisons via normalized fuzzy scores. Weighting factors reflect criterion importance, leading to holistic evaluations. Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) serve as benchmarks, with closeness coefficients determining contractor rankings. These methods collectively enhance decision-making accuracy and fairness in contractor selection.

5.0 Conclusion

In conclusion, the integration of Fuzzy AHP and Fuzzy TOPSIS offers a robust and comprehensive framework for contractor selection, addressing the inherent complexities and uncertainties of the construction industry. Fuzzy AHP systematically translates subjective linguistic opinions into numerical fuzzy values, minimizing personal bias and providing a data-driven evaluation based on critical criteria like sustainability, financial health, and safety. By constructing a pairwise comparison matrix and employing the geometric mean, this method ensures a holistic and informed decision-making process, emphasizing risk management and

safety procedures. Complementarily, Fuzzy TOPSIS facilitates fair and objective contractor ranking. Through the conversion of linguistic assessments into fuzzy numbers and the creation of normalized and weighted decision matrices, it enable equitable comparisons. Utilizing Fuzzy Positive-Ideal Solution (FPIS) and Fuzzy Negative-Ideal Solution (FNIS) as benchmarks, the closeness coefficient provides a clear ranking, guiding contractor selection. This combined methodology enhances the transparency and reliability of contractor evaluations, ultimately contributing to improved project outcomes and mitigating potential risks.

References

A. Oben Sabuncuoglu, A. G. (2016). Decision Making Through the Fuzzy TOPSIS Method . *International Journal of research in Bussiness and Social Science*, 2147-4475.

A., E., E., P., F., A., M., N., & A., H. (2021). Quantifying contractors' qualifications using pairwise comparison in best value procurement method. *Procedings of international Sturctural Engineering and construction*. Virtual.

A., F., M., R., & E., S. (2020). An integrated organizational system for project source selection in the major Iranian construction companies. *Buildings*, 10(12), 1-22.

A., O., M.Z.X., B., & C., P. (2022). Establishment of pre-qualification criteria for the selection of subcontractors by the prime constructors for building projects. *Journal of Building engineering*, 45.

A.E., K., & K., S. (2022). Effect of Sub-Contractor Selection on Construction Project Success in Turkey. *Technicak journal of Turkish Chamber of civil Engineers*, 33(4), 12105 - 12118.

A.P., G., & K., K. (2020). Contractor prequalification for green buildings—evidence from Turkey. *Engineering, Construction and Architectural Management*, 27(6), 1377 - 1400.

A.R., K., A.M., Y., S.H., K., N.I.A.B., A., & N.A., M. (2021). Automated two-stage continuous decision support model using exploratory factor analysis-MACBETH-SMART: an application of contractor selection in public sector construction. *Journal of Ambient Intelligence and Humanized computing*.

A.S., A., M., A., O.S., A., & M.E., S. (2023). Evaluating construction contractors in the pre-tendering stage through an integrated based model. *Alexandria Engineering Journal*, 82, 437-445.

Abteen Ijadi Maghsoodi, M. K. (2018). Identification and Evaluation of Construction Projects' Critical Success Factors Employing Fuzzy-TOPSIS Approach. *KSCE Journal of Civil Engineering*, 1593–1605.

Agnieszka Lesnaik, D. K. (2018). Fuzzy AHP Application for Supporting Contractors' Bidding Decision. *Fuzzy Techniques for Decision Making*.

Alptekin, O. A. (n.d.). Analysis of Criteria Influencing Contractor Selection Using TOPSIS Method. *IOP Conference Series: Materials*, 245.

Alptekin2, O. A. (2017). Analysis of Criteria Influencing Contractor., (p. IOP Conference Series: Materials).

Amireh, F. (2022). *A study on the impact of contractor selection method and contractors' pre-qualifications on delays in Jordanian public construction projects*.

Cristóball, J. R. (2012). Contractor Selection Using Multicriteria Decision-Making Methods. *Journal of Construction Engineering and Management*, 679-789.

D.M.D.U., P., & P.A., P. (2020). Decision support system selection of tender winners project development building of STMIK STIKOM Indonesia with TOPSIS method. *Journal of Physics: Conference Series*.

Daniel Nii Ayeh Ayettey1, H. D. (2018). Contractor Selection Criteria in Ghanaian. *Journal of Building Construction and Planning Research*, , 278-297.

DOLOI, H. (2009). Analysis of pre-qualification criteria in contractor selection and their impacts on project success. *Construction Management and Economics*, 1245–1263.

Ebrahim Jokar, B. A. (2020). Risk prioritization and selection of contractors participating in PublicPrivate Partnership (PPP) infrastructure projects using Hybrid Fuzzy AHP and Fuzzy TOPSIS (Case Study: Saveh-Salafchegan Freeway Project). *Journal of Construction Engineering, Management & Innovation*, 16.

Ebrahim Jokar1, B. A. (2020). Risk prioritization and selection of contractor participating in PublicPrivate Partnership (PPP) infrastructure project using Hybrid Fuzzy. *Journal of Construction Engineering, Management & Innovation*, 1-16\.

Edmundas Kazimieras Zavadskas, T. V. (2010). Contractor selection for construction works by. *Journal of Business Economics and Management*.

F., A., & G., A. (2018). A multi-criteria decision-making support system for choice of method of compensation for highway construction contractors in Greece. *International journal of construction management*, 19(6), 492-508.

F.D., A., & A.C., P. (2020). Selection of subcontractor vendor using analytic hierarchy process (AHP) method in construction company. *IOP Conference series: Earth and environmental sciences*.

Faikcan Cog, H. Y. (2014). A Meta Classification and Analysis of Contractor Selection and Prequalification. *Creative Construction Conference*.

Fang Wang, ., S.-w. (2016). Outcome-based Contractors Selection using the Integrated Fuzzy AHP and Fuzzy TOPSIS Method. *International Journal of Hybrid Information Technology*, 83-92.

Ibayasid Bintoro, R. M. (n.d.). Modelling of contractor selection using fuzzy-TOPSIS. *International Conference on Electrical, Electronics and Information Engineering*. 2017.

Izadi, M. A. (2013). Contractor Selection Based on Swot Analysis with Vikor and Topsis Methods in Fuzzy Environment. *World Applied Sciences Journal*, 540-549.

Ke Wang, Z. Y. (2023). Investigating the Role of Artificial Intelligence Technologies in the Construction Industry Using a Delphi-ANP-TOPSIS Hybrid MCDM Concept under a Fuzzy Environment. *Sustainability* .

M.-Y., C., S.-H., Y., & W.-C., C. (2020). Multi-criteria decision making of contractor selection in mass rapid transit station development using bayesian fuzzy prospect model. *Sustainability*, 12(11).

N., A. R., O., E., P., F., K., O., B., D., & F., M.-S. (2021). Identification of health and safety prequalification criteria for contractor selection in construction projects: A systematic review. *Energies*, 14(21).

Osman Taylan, A. O. (2014). Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. *Applied Soft Computing*, 105-116.

P.Z., R., N.I., R., M.I., A., & P.J., R. (2020). Selection of Contractor by Using Analytical Hierarchy Process (AHP). *IOP Conference series*.

Piotr Jaskowski, S. B. (2010). Assessing contractor selection criteria weights with fuzzy AHP method application in group decision environment. *Automation in Construction*, 120-126.

Pour Aghajan, M. (2025). Supporting Early Decision-Making Between Precast and In-Situ Concrete in Construction Industry. *PhD by Publication, Queensland University of Technology*.

Q., C., M.O., E., S., B., & C.O., E. (2019). Grey SWARA-FUCOM weighting method for contractor selection MCDM problem: A case study of floating solar panel energy system installation. *Energies*.

R., L., J., Z., C., W., Z., S., & X., W. (2019). Joint-Venture Contractor Selection Using Competitive and Collaborative Criteria with Uncertainty. *Journal of Construction Engineering and Management*.

S., K., S.M., M., & J., A. (2023). Enhancing Contractor Selection Process by a New Interval-Valued Fuzzy Decision-Making Model Based on SWARA and CoCoSo Methods. *Axioms*, 12(8).

S., S., R., R., A., D., N., K., & S., P. (2024). A novel hybrid grey-fuzzy optimization model for assessment of solar technologies considering different scenarios of the Indian market. *Energy reports*, 2023-2034.

S., T., B., S., L., Z., & X., C. (2024). An approach of multi-criteria group decision making with incomplete information based on formal concept analysis and rough set. *Expert systems with applications*.

S.M., A., & N., K. (2024). Evaluation and ranking of fuzzy sets under equivalence fuzzy relations as α -certainty and β -possibility[Formula presented]. *Evaluation systems with applications*, 248.

S.M., E.-S., M., B., A., H. A., & N., Z. (2019). Key contractor selection criteria for green construction projects in the UAE. *International Journal of Construction Management*, 21(12), 1240-1250 .

Sameh M El-Sayegh, M. B. (2019). Key contractor selection criteria for green construction projects in the UAE. *Taylor ans Francis online*, 21(12), 1240-1250.

Skitmore, Z. H. (2010). Criteria for contractor selection. *Construction Management adn economics*.

Sushil Kumar Sahoo, S. S. (2023). A Comprehensive Review of Multiple Criteria Decision-Making (MCDM) Methods: Advancements, Applications, and Future Directions. *Decision making advances.*, & I., N. (2020). Selecting and evaluating suppliers in the Czech construction sector. *Periodica Polytechnica Social and Management Sciences*, 28(2), 155–161.

Tafazzoli, M. (1861). Enhancing contractor selection through Fuzzy TOPSIS and Fuzzy SAW Techniques. *Buildings* 14(6).

Tiong2, D. S. (2006). Contractor Selection Criteria: Investigation of Opinionsof Singapore Construction Practitioners. *Journal of Construction Engineering and Management*.

X., L., C., Y., L., L., Y., D., J., X., J., H., . . . L., L. (2024). Configurational paths to turnover intention among primary public health workers in Liaoning Province, China: a fuzzy-set qualitative comparative analysis. *BMC Public Health*.

Y., S., G.J.L., M., & E., C. (2022). Supplier selection and supply chain configuration in the projects environment. *Production Planning and Control*, 33(12), 1155 - 1172.

Y., W., J., D., H., L., S., G., X., L., & X., D. (2024). Interpretable classifier design by axiomatic fuzzy sets theory and derivative-free optimization. *Expert systems with applications*.

Yang, R. J. (2014). An investigation of stakeholder analysis in urban development projects: Empirical or rationalistic perspectives. *International Journal of Project Management*, 838-849.

Annexures

For further reference to the Data collection, and analysis and decision making for criteria as well as contractor selection please refer to the documents provided below.

Data Collection: https://docs.google.com/forms/d/e/1FAIpQLSdlJkJEg_7ArpI_ln_5bGE6_k6wuPWLu_G9oF0Y_T-0guZx42g/viewform

Fuzzy AHP Analysis for ranking of Selection Criteria: Fuzzy AHP.xlsx

Ranking of Contractor Using Fuzzy TOPSIS: Fuzzy TOPSIS Analysis.xlsx

CHAPTER 123

Share Pledging and Real Estate Prices: An Exploratory Study

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Joshi Sushrut Sanjay², Vaibhav Taori² and Rajni Kant Rajhans²*

ABSTRACT

This study investigates the potential relationship between share pledge and real estate prices. Share pledging means using a company's shares as collateral for loans. The high real estate liabilities can indicate financial pressures that can affect investor confidence in the industry and ultimately affect real estate values. The analysis is done through multifaceted approach. First, looking at historical data on pledge levels for real estate stocks and compare them with real estate price indexes. Statistical methods are used to identify correlations between these variables. Secondly, we conduct case studies analysis of available properties that have made significant contributions in real estate. This requires a complete financial analysis to understand the reasons for the pledge and find their potential impact on the company's financial position and future development projects. Combining these methods, the study aims to highlight on the potential impact of the stock and in property prices. The results can be valuable to real estate investors, lenders and promoters, enabling them to make more informed decisions in a complex and interconnected market.

Keywords: Share pledging; Real estate prices; Listed firms; Equity pledging.

1.0 Introduction

A share-pledging transaction occurs when administrative officers or directors consign their stock equity to secure personal financing. Personal loans originating from shareholders serve two purposes: consumption and investment purposes. (Puleo *et al.*, 2020, Lia *et al.*, 2023). Promoters of listed firms frequently make use of funding practice share pledging to borrow money against their own company shares. Directors pledge their shareholding stakes with lending institutions to obtain financial loans. The facility enables promoters to obtain financing resources through it. Business expansion, acquisitions, and even personal investment at times. Although it is an important tool for raising capital, especially in industries such as infrastructure and Real Estate, share pledging contains fundamental risks which generate substantial losses affecting both investors together with market stability (Madasu, 2019).

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Share pledging is a traditional financial instrument in the markets. The occurrence of share pledging together with market interest has noticeably increased during recent years despite remaining stable. Market volatility during the past years together with the entry of new financial participants such as Non-Banking Financial Companies (NBFCs) and mutual funds has led to intensified pledging activity. Non-Banking Financial Companies (NBFCs) and mutual funds. Share pledging is still a common practice in India and China, among other countries. It is very prevalent in the emerging markets in which promoters use this instrument to raise capital without sacrificing their equity stakes (Rajhans, 2022).

Share pledging is a valuable instrument for controlling shareholders and promoters to access capital without watering down their stakes. Through share pledging as collateral, promoters can borrow money to finance business growth, acquisitions, and even individual investments, thus increasing liquidity and financial flexibility (Madasu, 2019; Rajhans, 2022). The significance of share pledging also transcends the individual company to the overall financial system. Share pledging enables firms, especially those in such capital-intensive industries as infrastructure and Real Estate, to obtain much-needed funds for development and operational improvement (Madasu, 2019). It can also attract lenders and institutional investors through discipline imposed on borrowers by supervision by lenders that possibly enhances corporate governance (Rajhans, 2022). In addition, share pledging is an essential proxy for a company's liquidity requirement and financial position. It reflects important information to multiple stakeholders, such as regulators, fund managers, lenders, and individual investors. The realization of the extent of share pledging in a company helps indicate potential threats, including forced selling in times of market downturn, which results in high stock price volatility and firm instability (Rajhans, 2022).

In the previous times, share pledging was mostly viewed as a convenient option for promoters for raising finance for business growth, acquisitions, and personal requirements. But when the practice gained prevalence, it did catch regulatory attention because it has the potential to influence market stability as well as corporate governance. Some prominent financial scandals, like the Indian Satyam Computer Services meltdown, exposed the dangers of over-share pledging, which range from mismanagement of finances to heightened susceptibility to stock price volatility (Rajhans, 2022). The rapid expansion of this practice has prompted regulatory scrutiny worldwide, as seen in the US and China, with efforts to mitigate risks through measures like limiting pledge amounts and revising regulations. The recent surge in defaults, exemplified by cases like Green Mountain Coffee Roasters, Luckin Coffees, Letv, underscores the vulnerability of this practice to share price volatility and pledgor solvency (Wang (2023). At the international level, the practice has varied. In advanced economies, share pledging has declined as a result of more stringent rules and risk exposure concerns. Emerging economies, by contrast, still see high-activity pledging resulting from capital needs and the prevalence of promoter-led ownership structures (Li, 2022; Fengchao, 2021). Lu & Zhu (2021) examined the influence of share pledge transactions on investor sentiment and stock market

volatility in China from 2014 to 2018 and report that share pledge transactions amplify emotional bias, leading to increased stock market volatility driven by both optimistic and pessimistic sentiments. The repetitive nature of stock prices becomes more intense while market instability increases during negative market periods. According to Han (2023) the results indicate that controlling shareholders who pledge their stocks demonstrate a link to future corporate fraud. Stock pledge risks lead controlling shareholders to increase their fraud efforts out of concern for losing control over their companies. Intense media and investor monitoring may reduce the effect that pledged stock contributes toward fraudulent corporate practices. The research results provide insights about stock pledging practices while outlining the way external monitoring affects corporate fraudulent activities. Share pledging history demonstrates its essential role as a vital financial tool together with its potential to cause market-wide problems.

2.0 Literature Review

Share pledging, which is the use of one's own shares as collateral to obtain financing, has been an increasing topic of interest in the financial literature (Li, 2021). This paper aims to review the existing literature on share pledging and present potential future directions for research. The Review starts with examining the motivations behind share pledging. Share pledging can be the last resort for controlling shareholders to meet their liquidity needs, hence reflecting important information about the firm's financial constraints and borrowing constraints. Share pledging also allows shareholders to raise further finance while allowing them to retain control over the firm, which is especially useful for those firms with limited access to debt markets. (Damodaran, 2011)

However, extant literature has also focused on the possible drawbacks of share pledging. Share pledging exposes the firm to more severe shocks in negative stock price declines, as it might cause margin calls and thereby further worsen the downward pressure on the stock price. Further, the increased cost of capital arising from share pledging could force firms to forego positive net present value risky projects and thereby reduce the firm's value. (Li *et al.*, 2021). This share pledging practice has elicited increased attentions from both regulators and stake holders in Indian stock market of late, seeing the volume pledged by promoters rises significantly in previous years. (Madasu, n.d.)

The practice of share pledging can offer short-term liquidity to a company, but this also carries with it risks (Damodaran, 2011). Most specifically, if the pledged shares are utilized for long-term operations instead of for meeting short-term working capital requirements, it can be problematic for market regulators. (Madasu, n.d.) Moreover, research has indicated that capital expenditure growth and potential dividends can have substantial impacts on the returns of a stock, and thus, it is possible that pledged shares use may affect a company's financial performance. (Damodaran, 2011) (Sharma, 2013) This paper aims to provide a comprehensive review of the existing literature on share pledging, identifying key research issues and potential

avenues for future investigation. (Wang & Xiao, 2023). The reviewed studies shed light on some important insights. First, controlling shareholders may pledge shares to raise personal loans and maintain control of the firm but expose themselves to margin calls and the loss of control. (DeJong *et al.*, 2018) Controlling shareholders of firms pledged their shares, and are more likely to manipulate accounting numbers to avoid such margin call risks, exhibit more positive discretionary accruals, income-increasing real earnings management, and higher propensity to use nonrecurring items to avoid losses. (DeJong *et al.*, 2018).

It is found that the relationship between share pledging, and earnings management is more pronounced in non-state-owned enterprises (non-SOEs) and firms with a weaker balance of control rights, which suggests that the institutional environment and governance mechanisms are important in determining the incentives and behaviours of controlling shareholders (DeJong *et al.*, 2018) (Deren & LIAO, 2018). This paper synthesizes what literature exists on the relationship between share pledging and firm behaviour as well as performance under a variety of measurements. An increasingly large body of research has investigated the financial constraints and incentives that may lead insiders to engage in share pledging (Cheng *et al.*, 2020). Organizations with greater financial limitations tend to commit shares as an alternative funding method that intensifies their funding challenges. The existence of share pledging proves to be a more important concern for investors than the extent of pledged shares leading to worse financing conditions for the company.

The literature explores how stakeholder share pledges affect a company's operational conduct together with its organizational performance. Share pledging leads to less erratic earnings and fewer research and development expenses which shows that control rights through share pledging control risk-taking behaviours. When controlling shareholders pledge their shares, accounting manipulations may increase because they use artificial methods to boost financial performance to prevent margin calls (DeJong *et al.*, 2018). Higher financial constraints lead firms to utilize share pledging instead of alternative funding methods resulting in more severe financing challenges. The existence of share pledging itself represents a more critical problem for investors and ultimately leads to worse financing conditions for the firm. Research investigates the effects share pledging has on corporate actions while studying its impact on business performance. The findings show that shares pledged for borrowing purposes are linked with reduced earnings volatility as well as limited R&D spending thus demonstrating share pledging acts to curb risky corporate behavior. Controlled shareholders who pledge their shares might use accounting manipulations to boost financial performance because this protects them from margin calls. (DeJong *et al.*, 2018)

3.0 Case Study Analysis

Each case that is chosen is examined using a before-and-after methodology, looking at stock prices prior to and subsequent to share pledging-distress. The examination also measures

changes in property valuations brought about by involuntary sales and analyzes market sentiment and investor response to such transactions. The objective is to analyse actual cases in which share pledging affected real estate asset values. The cases are divided into two categories: Category A, companies in which share pledging led to distress sales and falling real estate asset values, and Category B, companies in which the leveraging of real estate assets increased valuations.

3.1 Companies where share pledging led to real estate values decline

3.1.1 Kingfisher airlines

Kingfisher Airlines, once a premium airline in India, faced severe financial distress due to mismanagement, high operational costs, and regulatory challenges. To sustain operations, its promoter, Vijay Mallya, pledged a significant portion of his shares in United Breweries and United Spirits. As the stock prices of these companies declined, lenders invoked margin calls, triggering asset liquidations. This financial crisis not only led to the collapse of Kingfisher Airlines but also resulted in the distress sale of Mallya's prime real estate assets.

3.1.2 Background and share pledging details

To secure loans for Kingfisher Airlines, Mallya pledged his holdings in United Breweries, United Spirits, and other group companies. However, as Kingfisher Airlines continued to incur losses and eventually ceased operations in 2012, the lenders started liquidating his pledged shares. In June 2021, lenders recovered ₹5,824.5 crore by selling these pledged shares (Singh, n.d.)

3.1.3 Impact on real estate holdings

As a result of the financial crisis, multiple high-value properties owned by Mallya were put up for auction to recover outstanding debts. The most notable among them were:

Kingfisher House (Mumbai, 17,000 sq. ft.): Kingfisher House, once the headquarters of Kingfisher Airlines, was originally valued at ₹150 crore. However, due to a lack of buyers, the reserve price had to be revised multiple times. Initially set at ₹135 crore in 2016, it was reduced to ₹93.5 crore in 2017 and then further lowered to ₹82 crore. After eight failed auctions, the property was finally sold in 2021 for ₹52.25 crore, reflecting a 65% depreciation in value (Rebello, n.d.)

3.1.4 Goa beachfront villas & other properties

Several luxury properties owned by Mallya, including his beachfront villas in Goa, were seized by lenders but struggled to find buyers. In 2017, the High Court of Karnataka permitted banks to begin the auction process, but these properties remained unsold for years due to ongoing legal disputes and a lack of investor interest at high reserve prices. By 2023, banks

had taken control of assets worth ₹14,000 crore, including the Goa villas, but many properties were yet to be liquidated due to prolonged litigation and concerns over ownership.

3.1.5 Impact on the broader real estate market

The distress sale of Kingfisher House and other assets negatively impacted investor sentiment in premium commercial real estate markets, particularly in Mumbai and Goa. The repeated failure to secure buyers at earlier reserve prices signaled financial instability, reducing investor confidence in corporate-owned properties. Similar cases, such as Unitech's stalled projects and Reliance Infrastructure's asset sales, further heightened risk perception in the sector (Rebello, n.d.) Additionally, reduced liquidity in high-end commercial real estate became evident, as distress sales like Kingfisher House set new valuation benchmarks. The 65% depreciation in its final sale price influenced expectations for other distressed asset sales, forcing sellers to offer deeper discounts. This fire-sale pricing effect contributed to price stagnation in the luxury commercial real estate segment between 2017 and 2022, particularly in major metros (Chandola, n.d.)

3.1.6 Analysis

The case of Kingfisher Airlines and Vijay Mallya exemplifies the cascading effect of share pledging, financial distress, and forced asset liquidation on real estate valuations. The significant depreciation of Kingfisher House and the unsold properties in Goa highlight the challenges associated with distress sales in the real estate market. The broader impact included reduced investor confidence and lower liquidity in the high-end property sector. This case reinforces the direct relationship between corporate financial health, share pledging practices, and real estate price stability.

3.1.7 Unitech Ltd and its real estate collapse

Unitech Ltd., once India's second-largest real estate developer, experienced a significant financial collapse due to heavy share pledging by its promoters, regulatory actions over fraud allegations, and severe project delays. The company's inability to complete projects and repay debts led to distress sales of its real estate assets, affecting both its valuation and broader investor sentiment in the commercial and residential real estate markets (Babar, n.d.)

3.1.8 Background and share pledging details

Unitech's financial troubles intensified post-2008 as the company took on excessive leverage while pledging shares to raise capital. By 2009, Unitech's promoters had pledged approximately 49.48% of their holdings, leading to margin calls when stock prices collapsed. Investigations by the Enforcement Directorate (ED) and the Supreme Court further exacerbated the situation, resulting in asset freezes and delayed resolution of pending projects (ET Bureau, 2009, n.d.)

3.1.9 Impact on real estate holdings

Unitech's financial distress led to several prime properties being affected through distress sales, stalled projects, or declining valuations: Large-scale Unfinished Projects across NCR and Bengaluru: Unitech's residential and commercial projects across Noida, Gurugram, and Bengaluru stalled as liquidity dried up. More than 16,000 homebuyers were left in limbo, with projects such as Unitech Grande (Noida), Unitech Golf & Country Club (Noida), and Uniworld City (Gurugram) facing indefinite delays. Due to the funding crunch, lenders liquidated pledged shares and forced asset sales, but legal disputes prevented quick resolutions (Menon & Kamath, n.d.) Office Spaces in Gurugram and Noida: Unitech's commercial properties in Gurugram and Noida suffered valuation declines due to investor uncertainty and financial instability. Prime Unitech office spaces saw a 10-20% depreciation between 2017 and 2022, as buyers and tenants became hesitant to engage with a financially distressed developer. Several office buildings, including Signature Towers and Cyber Park (Gurugram), struggled with occupancy due to negative market sentiment. (Babar, n.d.)

3.1.10 Impact on the broader real estate market

The collapse of Unitech had wider repercussions on India's real estate sector, particularly in Delhi-NCR and Bengaluru, where the company had extensive operations. The stagnation in commercial and residential property pricing became evident as investor confidence weakened. Buyers became more risk-averse, leading to a higher default risk premium on loans issued to real estate companies. Financial institutions also tightened lending norms for developers with significant share pledging exposure, making it harder for other real estate firms to raise funds. (Unitech Case – Delays and Legal Challenges, n.d.)

Furthermore, distress sales of Unitech's prime properties influenced market pricing benchmarks. As investors anticipated fire-sale pricing, it became challenging for developers with financial stress to sell assets at fair market value. This effect was observed in stalled residential projects in Noida, Gurugram, and Bengaluru, where resale values dropped due to prolonged legal battles and uncertainty over project completion. (Unitech Case – Delays and Legal Challenges, n.d.)

4.0 Analysis

Unitech's downfall exemplifies how excessive share pledging, financial mismanagement, and regulatory actions can trigger real estate market disruptions. The forced asset liquidations and project delays resulted in severe valuation declines, leaving thousands of homebuyers stranded and shaking investor confidence in commercial and residential property markets. This case underscores the importance of financial discipline among real estate developers, as reliance on share pledging for funding can have long-term negative consequences on asset valuation and market stability.

5.0 Conclusion

This research establishes definitive proof of a high degree of correlation among share pledging, decision-making by corporates, and property prices in the Indian Real Estate Industry. Pledging has emerged as a common method of financing, mostly for real estate companies that require large amounts of capital to finance long-term, capital-driven projects. Promoters often turn to pledging shares as security to raise finance without giving up control or equity. This practice carries financial risks that can directly and indirectly influence corporate decision-making and property valuations.

In this study we investigate the effect of share pledging on real estate prices. As seen by instances such as Kingfisher Airlines and Unitech Ltd., the study emphasizes that excessive share pledging can result in financial hardship, forced asset sales, and deteriorating property prices. To minimize the risks associated with share pledging, the research highlights the importance of alternative sources of funding, regulatory oversight, and sound financial planning. Long-term development in the Real Estate Industry can be facilitated by sustainable financial methods such as Institutional Investments and Structured Debt Instruments, which can enhance market confidence.

This research reflects that overly excessive share pledging results in pressure on Promoters to undertake forceful corporate actions, for stabilizing share prices and ensuring control. Short-term measures include taking cost-cutting steps or quickly disposing of critical assets, which may destroy the long-term efficacy of a project and breach compliance with governance provisions. The study also shows that distressed share pledging is often accompanied by margin calls, compelled sale of real estate assets, and adverse investor sentiments, resulting in a fall in property prices as well as investor confidence in the market.

Conversely, research shows that disciplined and strategic pledging in line with cautious financial planning can influence property prices favourably by enabling real estate companies to acquire financing for new projects, increase value in their asset base, and attract institutional investment. Lastly, share pledging is a significant financing mechanism for real estate companies but simultaneously has a dual impact on corporate decisions and property values. The outcome is highly dependent on the level of commitment, the financial health of the company, and the applicable regulatory framework. Effective regulation of share pledging practices and transparent corporate governance are critical to ensuring stability in property values and investor confidence in the industry.

References

Chaney, T. S. (2012). The collateral channel: How real estate shocks affect corporate investment. *American Economic Review*, 102(6), 2381–2409.

Chang, J. (2022). A tale of riskiness: The real effects of share pledging on the Chinese stock market. *Pacific-Basin Finance Journal*, 73, 101738.

Gurgaon, B. P. (n.d.). *Buy property in Gurgaon by India's top builders - Unitech Builders in Gurgaon*.

Han, H. Z. (2023). The effect of stock pledge on corporate fraudulence: Evidence from China. *Finance Research Letters*, 57, 104624.

Investors - Publications - Embassy REIT. (n.d.). Retrieved from <https://www.embassyofficeparks.com/investors/publications/>

Khatwani, R. R. (2023). Impact of change in promoters' shareholding pattern on the performance of small-cap-value equity stocks in the National Stock Exchange of India. *Journal of Risk and Financial Management*, 16(3), 160.

Li, F. Z. (2021). Linkages between share pledging, stock price risk and profitability: Evidence from the P.R. China. *PLOS ONE*, 16(6), e0253143.

Li, W. H. (2022). Does share pledging promote or impede corporate social responsibility? An examination of Chinese listed firms. *Economic Research-Ekonomska Istraživanja*, 35(1), 1133–1151.

Lu, H. Z. (2021). Share pledge transactions as an investor sentiment indicator: Evidence from China. *Quarterly Review of Economics and Finance*, 82, 1–13.

Madasu, M. P. (2019). Promoters share pledging: An emerging concern for Indian stock market regulator. *Gavesana Journal of Management*, 11(1), 1–8.

Rajhans, R. K. (2022). Pledging and firm performance: Evidence from Indian firms. *Asia Pacific Management Review*, 27(3), 198–207.

Realty, L. (n.d.). *Envy is a beautiful emotion*. Retrieved from <https://www.lntrealty.com>

Ren, G. M. (2022). Equity pledge of controlling shareholders, property right structure and enterprise innovation efficiency: Evidence from Chinese firms. *Economic Research-Ekonomska Istraživanja*, 35(1), 1235–1256.

Stereńczak, S. K. (2023). The choice of external financing source: The role of company size and stock liquidity. *Economics and Business Review*, 9(1), 60–72.

Times, E. (2013, April 16). Kingfisher Airlines lenders stumped as value of pledged properties crashes. *The Economic Times*.

Wang, L. S. (2023). A study on optimal share pledge rate based on bilateral risk-CVaR of pledgee. *Heliyon*, 9(4), e14150.

Xie, Y. W. (2023). Does controlling shareholders' share pledge exacerbate excessive financialization of enterprises? Evidence from performance pressure perspective. *PLOS ONE*, 18(3), e0282157.

Zhong, X. W. (2021). Controlling shareholders' stock pledges and strategic change: The moderating effects of corporate governance. *Baltic Journal of Management*, 16(2), 244–263.

CHAPTER 124

Six Sigma in Linear Project Delivery

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ABSTRACT

This study seeks to understand the implementation of Six Sigma in linear projects delivery such as roads and railways. It explores the potential of Six Sigma methodology applied to Garage repairing operations. The garage project selected for the study undertakes massive vehicle repairing activities, which are essentially linear activities. Thus, we undertaken a case study of Garage repairing operations for process improvement using six sigma. The current operations of the garage facility before application of six sigma were evaluated. We measured operations such as service delays, diagnostic errors, inventory shortages, customer complaints. The garage processes were found to be operating at 3 sigma levels. We suggested process improvements to attain 6 sigma levels. We collected vehicle repair data for process improvement. The activities were ranked in the descending order of six sigma potential (1. Inventory shortages, 2. Diagnostic errors, 3. Unorganized workplace, 4. Undefined repair protocol and scrutiny). By adapting data driven approach the research identifies key inefficiency through root cause analysis, process capability indices and pare to analysis. The garage is currently operating at Sigma Level 3 which leads to various delays and errors. To overcome those challenges a structured Six Sigma framework is proposed focusing on workflow optimization, inventory management, and standardized operations. Adapting these strategies can reduce defects and enhance reliability. This study shows the importance of adapting Six Sigma into linear projects for the continuous improvement by data driven approach.

Keywords: Six sigma; Process improvement; Inventory shortage; Vehicle repairing activities; Workflow optimization; Standardized process.

1.0 Introduction

1.1 Linear p0rojects

Linear projects are defined by their extensive scope and involve constructing, expanding, or maintaining infrastructure that stretches over long distances such as roadways, railways and pipelines.

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However, linear projects present unique challenges for quality and performance management due to their size, complexity and the dynamic nature of the environments in which they operate. The recent studies show how quality and process optimization can be increased by applying six sigma methodology in construction projects as construction projects are considered as linear projects due to the repetitive nature of the activity and sequential workflow. Past studies focus on improving the quality and process optimization. In this paper the study area author chooses Garage Operation for the quality improvement and process optimization to achieve Six sigma in the operation of the Garage. 1. In Garage operation Sequential flow of activities takes place such as vehicle check-in, Diagnostics, Repair, Quality check and Delivery, each step cannot begin until the previous one is completed. 2. Each vehicle has a clear entry point and exit point; in that much time only a vehicle needs to be delivered to the customer. 3. For different vehicles operations are repeated which follows the same linear path making it repetitive linear project. 4. The output of one process becomes input for the next process, like diagnostics reports are essential for deciding whether parts need to be replaced or not. 5. Resource management is one of the important tasks in garage operation as it impacts vehicle delivery and also reduces the service time. This makes garage operation act as linear project which can be improved by applying six sigma in the operation to improve its quality and process optimization.

1.1.1 Key challenges in linear projects include

Linear projects often encompass a variety of geographic landscapes & each location presents a variety of challenges. Managing resources along a linear project corridor becomes difficult. Coordinating the on-time delivery of resources to different locations requires careful logistical planning and supply chain coordination. Acquiring land rights and permits required for linear projects can be a long and complex process that requires negotiations with different entities. Linear projects are exposed to weather-related interruption. Linear projects often involve multiple stakeholders & maintaining consistent quality standards throughout a large linear project presents serious challenges. Robust quality management processes and inspection procedures are required to ensure that construction activities meet design specifications.

1.1.2 Need for effective methodologies

This project focuses on applying Six Sigma principles to garage operations to identify inefficiencies and optimise processes. By analysing repetitive activities within garage operations and measuring their impact on overall productivity, this study aims to introduce Six Sigma improvements that enhance operational efficiency. The study also aims to demonstrate how Six Sigma can be leveraged to standardise operations, streamline workflows, and achieve higher service quality. By implementing Six Sigma improvements, this project seeks to provide practical solutions that enhance garage operations and contribute to long-term efficiency and sustainability in the automotive service industry.

1.2 Six Sigma

Six Sigma is a data-driven methodology aimed at improving business processes by identifying and eliminating defects, reducing process variability, and enhancing overall efficiency. Developed by Motorola in the 1980s, Six Sigma has since been widely adopted across various industries, including manufacturing, healthcare, IT, finance, and service. The term “Six Sigma” refers to a statistical measure of process capability, where a process operating at a Six Sigma level produces only 3.4 defects per million opportunities (DPMO). This signifies near-perfection in business operations and results in higher customer satisfaction, reduced waste, and improved profitability. Overall, Six Sigma provides a systematic approach to process improvement and variation reduction, which is well suited to linear projects.

1.3 Objectives

- Review garage repair operations and inefficiencies.
- Measure the sigma level and process metrics.
- Identify and categorise defects in the process.
- Propose Six Sigma changes to reduce defects and increase efficiency.

1.4 Scope

This study covers a garage that does routine and complex vehicle repairs. Scope includes: Six Sigma can lead to measurable improvements in service, accuracy and inventory. Businesses will have shorter service times, fewer errors and more inventory available. These improvements will increase customer satisfaction and profitability. Review workflows, inventory management and service protocols. Identify the root causes of defects and inefficiencies. Use Six Sigma tools like DMAIC (Define, Measure, Analyse, Improve, Control), Pareto Analysis and Root Cause Analysis.

1.5 Need for the study

High Defect Rate in Linear Projects, Process Standardization and Efficiency Enhancement, Cost Optimization through Waste Reduction, Improving Quality, Data Driven Decision Making, Achieving Higher Sigma Levels and Reducing Defects.

2.0 Methodology

2.1 Methods of six sigma

- DMAIC (Define, Measure, Analyse, Improve, Control) (Mast Jeroen de, 2012)
- Define: - Clearly define the problem, project scope, and objectives.
- Measure: - Gather data to understand the current process performance.
- Analyse: - Find the root causes of defects, delays, or inefficiencies.
- Improve: - Develop and implement solutions to eliminate inefficiencies.
- Control: - Maintain the improved process and prevent regression.

2.2 Data collection process

- *Direct Observation*: Observing the time taken for each repair activity and identifying any unnecessary delays. Checking for recurring service delays due to staff inefficiency, lack of resources, or unavailability of spare parts.
- *Workforce Interviews*: Interviewing mechanics, supervisors, inventory managers and service advisors. (Garages employee).
- *Customer Feedback Logs*: Overall experience with the service provided. Waiting time before and during the service process.
- *Time Motion Studies*: Segmenting repair tasks into categories such as diagnostics, disassembly, repair, reassembly, and final inspection.
- *Defect Tracking Logs*: Every defect was categorized based on its nature to prioritize urgent repairs. Root cause analysis was conducted for major defects to determine whether they were due to manufacturing issues, improper servicing, or customer mishandling.
- *Benchmarking*: Measuring key performance indicators (KPIs) such as service completion time, defect rates, and customer satisfaction scores.

2.3 Segregation of non-conformities

- *Service delays*: Inefficient workflow due to lack of automation in tracking and scheduling. Absence of well-defined repair protocols leading to inconsistencies. Unorganized workspace causes delays in locating tools and parts.
- *Diagnostic delays*: Lack of structured diagnostic checklists resulting in misdiagnosis. Inconsistent skill levels among mechanics causing repair inefficiencies. Limited training on modern vehicle technologies affecting service accuracy.
- *Inventory shortages*: Inadequate forecasting of spare part requirements leading to frequent stock-outs. Reactive ordering instead of proactive inventory planning. Supplier delays cause extended vehicle servicing time.
- *Customer complaints*: Extended waiting times due to inefficiencies in scheduling and execution. Frequent callbacks due to incomplete or faulty repairs. Unavailability of critical spare parts leading to service delays.

2.4 Quantitative data collection

Table 1: Quantitative Data

Problem Area	Root Cause	No. of Unconformities	Total units Inspected	Delay due to Unconformities (Hrs.)
Service Delays	inefficient workflow	2	350	5
	lack of defined protocols	2	350	3
	unorganized workplace	2	350	1

Diagnostic Errors	Inconsistent Skills	2	350	3
	Lack of Checklist	2	350	2
	Limited Training	3	350	1
Inventory Shortages	Long Wait Times	3	350	2
	Reactive Ordering	2	350	5
	Supplier Delays	4	350	15
Customer Complaints	Long Wait Times	3	350	6
	Frequent Callbacks	1	350	2
	Parts Unavailability	3	350	8
Total		29		55

2.5 Problem areas and the observation

- *Service delays*: Total 6 unconformities occurred out of 350 units which were inspected, which leads to delay in the operation of garage.
- *Diagnostic delays*: Total 7 unconformities occurred out of 350 units which were inspected, which leads to delay in operation of garage.
- *Inventory shortage*: Total 9 unconformities occurred out of 350 units which were inspected, which leads to delay in operation of garage.
- *Customer complaints*: Total 7 unconformities occurred out of 350 units which were inspected, which leads to delay in operation of garage.

By taking all the observation from different activities and by segregating it into 4 different problem areas a total of 29 unconformities occurred out of 350 total units inspected. Further based on data we collected sigma level is being calculated.

2.6 Sigma level calculations

Defects Per Million Opportunities:

$$\begin{aligned} \text{DPMO} &= \frac{\text{Total no. of Defects}}{\text{Total no. of Units Inspected}} \times 1000000 \\ &= \frac{29}{350} \times 1000000 \\ &= 82,857 \text{ defects.} \end{aligned}$$

By comparing the DPMO value with the standard Six Sigma conversion table, we see that this corresponds to a Sigma Level of approximately 3.

Table 2: Standard Six Sigma Conversion Table

DPMO	Sigma Level
6,90,000.00	1
3,08,537.00	2
66,807.00	3
6,210.00	4
233.00	5
3.40	6

$$\begin{aligned}\text{Mean } (\mu) &= \frac{\text{Total Defects}}{\text{Total Inspected}} \\ &= \frac{29}{350} \\ &= 0.082\end{aligned}$$

Mean (μ) is equal to 0.082.

$$\begin{aligned}\text{Standard Deviation } (\sigma) &= \sqrt{\mu} \\ &= \sqrt{0.082} \\ &= 0.286\end{aligned}$$

Standard Deviation (σ) is equal to 0.286.

Process Capabilities Index (Cp): process's ability to operate within specification limits.

$$\begin{aligned}(\text{Cp}) &= \frac{USL - LSL}{6\sigma} \\ &= \frac{1 - 0}{6 \times 0.286} \\ &= 0.582\end{aligned}$$

Process Capabilities Index (Cp) is equal to 0.582.

Process Capabilities performance index (Cpk): Process Capability Performance Index (Cpk) determines if the process is centered within the acceptable limits.

$$\begin{aligned}\text{Cpk} &= \text{Min}\left(\frac{USL - \mu}{3\sigma} \text{ or } \frac{\mu - LSL}{3\sigma}\right) \\ &= \text{Min}\left(\frac{1 - 0.082}{3 \times 0.286} \text{ or } \frac{0.082 - 0}{3 \times 0.286}\right) \\ &= \text{Min}(1.06, 0.095) \\ \text{Cpk} &= 0.095\end{aligned}$$

Process capability performance index (Cpk) is 0.095.

3.0 Statistical analysis

3.1 Pareto analysis

Pareto Analysis is based on the 80/20 rule, which suggests that 80% of problems arise from 20% of causes. By identifying and addressing these high-impact defects first, efficiency can be significantly improved. A Pareto Chart was created using defect data collected over a month. The findings were: Inventory shortages accounted for 42% of total service delays. Customer complaints (long wait times) contributed 30%. Service delays due to workflow inefficiencies contributed 17%. Diagnostic errors led to 11% of rework cases. By focusing on inventory shortages and customer complaints first, the garage could eliminate 72% of overall inefficiencies in a targeted manner. A frequent complaint involved delayed vehicle service due to unavailable spare parts.

3.2 Root Cause Analysis (RCA)

Root Cause Analysis (RCA) is a problem-solving method used to determine the underlying causes of defects or inefficiencies, rather than just addressing symptoms. An

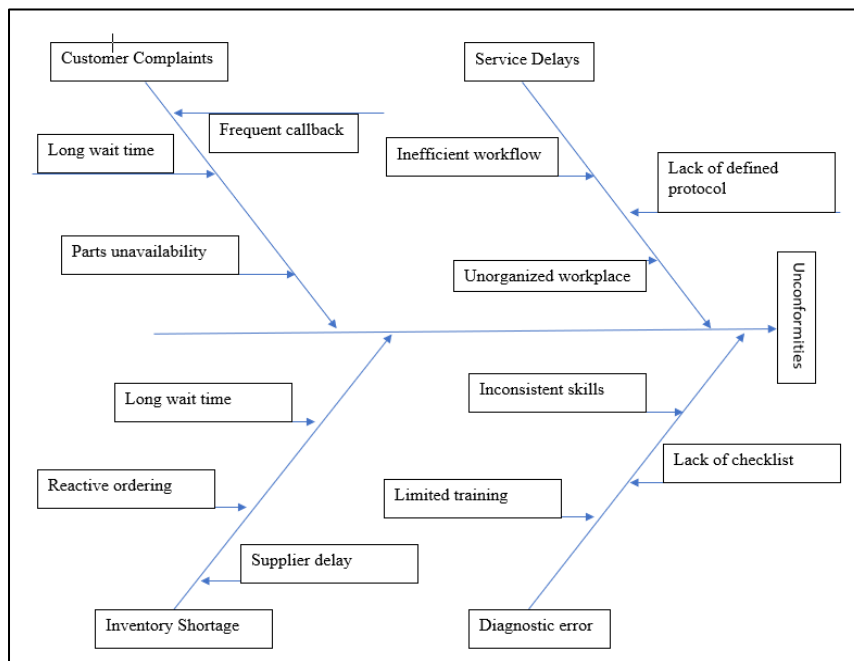
Ishikawa (Fishbone) Diagram was used to visually map the root causes of delays and inefficiencies. The major contributing factors identified were: Service delays were due to unorganized workspaces, Inventory shortages stemmed from poor supplier relationships, Diagnostic errors were linked to inconsistent training, long wait times were caused by inefficient scheduling and lack of real-time job tracking. A root cause analysis on frequent part shortages found that delays stemmed from reactive ordering rather than proactive inventory management. By shifting to predictive demand forecasting, inventory stock-outs decreased by 50%, ensuring continuous service operations.

4.0 Findings and Discussions

4.1 Findings

- Process Performance and Defect Rate:** A total of 350 vehicle inspections were conducted, out of which 29 defects were recorded. The Defects Per Million Opportunities (DPMO) were calculated as 82,857, corresponding to a Sigma Level of approximately 3. A 3 Sigma process implies that defects occur in approximately 6.7% of all operations, which is higher than the industry standard of 4 Sigma or above. The current defect rate is too high, leading to inefficiencies in service execution. To achieve a higher sigma level, defects must be reduced by at least 50%, ensuring a more stable and capable process.

Figure 1: Fishbone Diagram



- *Process Capability (Cp and Cpk) Findings:* The Process Capability Index (Cp) was calculated as 0.579, indicating high process variability. The Process Capability Performance Index (Cpk) was 0.096, showing that the process is not centered within acceptable limits. $Cp < 1$ means that the process does not meet specifications consistently and is highly variable. $Cpk < 1$ suggests that the process is off-center, leading to frequent defects. Without reducing variation and improving process alignment, defects will continue to persist at an unacceptably high rate.
- *Common Defect Types and Root Causes:* From the Pareto Analysis, the major defect categories contributing to inefficiencies were identified: Inventory shortages are the leading cause of service inefficiencies, causing over 40% of delays. Diagnostic errors contribute to 24% of issues, indicating inconsistent troubleshooting practices. Customer complaints are closely linked to delays, highlighting the need for improved scheduling and process coordination

Table 3: Pareto Analysis Observation

Defect types	Occurrence (%)	Impacts
Inventory Shortages	40%	Delayed service times, increased downtime
Customer Complaints	24%	Reduced customer satisfaction, repeat service requests
Diagnostic Errors	24%	Misdiagnosed issues, unnecessary part replacements
Service Workflow Delays	12%	Extended turnaround times, bottlenecks in service execution

- *Root Cause Analysis (RCA) Insights:* A Fishbone (Ishikawa) Diagram was used to map out the primary root causes of inefficiencies. The following key factors were identified:

Table 4: Root Cause Analysis (RCA)

Category	Root Causes
Manpower	Lack of structured training, inconsistent skill levels
Materials	Frequent stockouts, delayed supplier deliveries
Methods	No standard operating procedures (SOPs), inconsistent service execution
Machines	Unmaintained tools, inefficient workspace layout
Measurement	Inconsistent quality checks, lack of performance tracking

Process inconsistencies are largely due to inadequate training and missing SOPs. Inventory mismanagement is a significant issue, leading to delays and incomplete repairs. Poor quality control and lack of standardized inspection methods contribute to recurring defects.

4.2 Discussions and suggestions

- *Service Delays*
 - *Improve workflow efficiency:* Implement standardized work procedures; Eliminate waste and unnecessary steps; Assign tasks based on worker expertise

- *Define protocols for standardization:* Create standard operating procedures for each service; Conduct regular training sessions for workers; Use process flow diagrams and visual aids
- *Organize the Workplace (5S Methodology):* (Mazur Magdalena, 2024)

Sort: Remove unnecessary tools and items from the workspace, 2. *Set in Order:* Arrange tools and materials in a logical order for easy access, 3. *Shine:* Keep workstations clean to ensure smooth operations, 4. *Standardize:* Implement best practices for maintaining workplace efficiency, 5. *Sustain:* Conduct audits and provide regular training to reinforce these principles.

- *Diagnostic delays*
 - *Enhance worker skills:* Conduct technical training programs; Implement mentorship programs for new employees.
 - *Implement checklists for diagnosis:* Develop step-by-step diagnostic checklists; Introduce digital checklists for automated issue identification; Ensure technicians cross-check diagnoses.
 - *Provide continuous training:* Offer monthly training sessions on new diagnostic tools; Introduce certification programs for technicians to meet industry standards.
- *Inventory shortage*
 - *Reduce waiting time for parts:* Maintain buffer stock for frequently used parts; Implement automated inventory management system; Set minimum reorder points to avoid shortages.
 - *Implement Just-in-Time (JIT) Ordering or Two Bin system:*
 - *Just-in-time system:* Use demand forecasting techniques to predict parts requirements based on historical data. Coordinate with suppliers to ensure faster turnaround times for critical parts. Develop a vendor performance tracking system to monitor reliability. (Fullerton, 2001)
 - *Two Bin system:* It is an inventory system where stock is divided into two bins where, first bin is used for daily operations and the second bin is act as backup for the first bin which triggers replenishment when the first bin is empty. This will maintain the stock and ensure the continuous supply, reduce stockout and simplifies inventory management. (Tang Yuanjie, 2014)
 - *Improve supplier coordination:* Establish long-term contracts with suppliers; Develop a multi-supplier network; Use logistic tracking tools for real-time monitoring.
- *Customer complaints*
 - *Reduce wait times:* Implement real-time scheduling and queue management; Update customers on service progress via digital tools (e.g., text messages); Offer priority servicing for regular or urgent repairs.
 - *Minimize call-backs:* Train technicians to diagnose and resolve potential secondary issues; Improve first-time fix rate through inspection; Use quality control checklists before vehicle handover.

- *Ensure parts availability:* Analyse customer demand trends; Implement automated inventory tracking to prevent stockouts.

5.0 Conclusion

The application of six sigma in garage operation is being studied which identifies key inefficiency including service delay, diagnostic delays, inventory shortage, customer complaints. Before applying six sigma methodology garages in operating at sigma level 3 which shows that improvement was needed to improve operation efficiency and reduce defects.

- Average number of defects per unit inspected is 0.082
- Degree of variation in the defect occurrence is calculated 0.286
- Process capabilities index is calculated 0.582
- Process capabilities Performance index is calculated 0.095

To address these issues the following are the recommendations. The use of 5S and Just-In-Time (JIT) alongside Six Sigma contributes to a comprehensive quality improvement system. 5S establishes workplace organization and discipline, reducing clutter and ensuring efficient workflows. Workflow management by implementing 5S principles at workplace and by adopting standardized procedures. Providing regular training to mechanics and developing structured checklist for accurate diagnostic. JIT eliminates waste by ensuring parts and processes occur precisely when needed, minimizing delays. Implementing Two-Bin system or Just-In-Time system to avoid inventory shortage and by strengthening supplier relationship. By adopting real time scheduling, reducing waiting time which will enhance customer experience. Both tools support Six Sigma's focus on reducing variation and improving process consistency. This study shows the importance of data driven decision making to create smoother and more reliable operation.

6.0 References

- Antony, J., & Banuelas, R. (2002). Key ingredients for the effective implementation of Six Sigma programs. *Measuring Business Excellence*, 6(4), 20–27.
- Brailsford, S. C., Potts, C. N., & Smith, B. M. (1998). Constraint satisfaction problems: Algorithms and applications. *European Journal of Operational Research*, 107(1), 1–2.
- Bröchner, J., & Badenfelt, U. (2011). Changes and change management in construction and IT projects. *Chalmers University of Technology*.
- De Mast, J., & Lokkerbol, J. (2012). A foundation for understanding the limitations of DMAIC. *International Journal of Production Research*, 50(1), 1–12.

- Fullerton, R. R., & McWatters, C. S. (2001). The production performance benefits from JIT implementation. *Journal of Operations Management*, 19(1), 81–96.
- Georgy, M. E. (2007). Evolutionary resource scheduler for linear projects. *Automation in Construction*, 16(5), 664–676.
- Gijo, E. V., & Sarkar, A. (2011). Application of Six Sigma to improve the quality of the road for wind turbine installation. *The TQM Journal*, 23(1), 105–122.
- Goh, T. N., & Xie, M. (2004). Improving on the Six Sigma paradigm. *The TQM Magazine*, 16(4), 235–240.
- Hasib, M. (2006). Six Sigma in the automobile industry: A study on the implementation of Six Sigma in the Garland Assembly Plant (GAP). *Master's thesis, University of Skövde*.
- Heon, S., Chae, M. J., Im, K. S., & Dong, H. (2009). Six Sigma-based approach to improve performance in construction operations. *KSCE Journal of Civil Engineering*, 13(4), 241–248.
- Hsieh, T. Y., Lu, S. T., & Wu, C. H. (2004). Statistical analysis of causes for change orders in metropolitan public works. *International Journal of Project Management*, 22(8), 679–686.
- Jou, Y.-T., Silitonga, R. M., Sukwadi, R., & Rivaldo, J. (2022). Application of Six Sigma methodology in an automotive manufacturing company: A case study. *IOP Conference Series: Materials Science and Engineering*, 1249(1), 012052.
- Kumar, S., & Sosnoski, M. (2009). Using Six Sigma DMAIC to improve production quality and reduce costs in a tooling manufacturing environment: A case study. *Journal of Manufacturing Technology Management*, 20(7), 992–1007.
- Mazur, M., Korenko, M., Zitnak, M., & Shchur, T. (2024). A case study on the implementation of the 5S method in workplace organisation. *Operations Management Research*.
- Motawa, I. A., Anumba, C. J., Lee, S., & Peña-Mora, F. (2007). An integrated system for change management in construction. *Automation in Construction*, 16(3), 368–377.
- Nandakumara, N., Saleeshya, P. G., & Harikumarc, P. (2020). Application of Lean Six Sigma DMAIC methodology in a food processing industry in South India. *Materials Today: Proceedings*, 33, 550–555.

Park, M., Peña-Mora, F., & Yi, J.-S. (2005). Dynamic change management for construction: Introducing the change blueprint model. *Journal of Computing in Civil Engineering*, 19(4), 369–378.

Ponsiglione, A. M., Ricciardi, C., Improta, G., Dell'Aversana Orabona, G., Sorrentino, A., Amato, F., & Romano, M. (2021). The integration of Six Sigma's DMAIC methodology into health technology assessment (HTA). *International Journal of Environmental Research and Public Health*, 18(7), 3457.

Sharma, R. K., & Chetiya, R. (2010). Application of Six Sigma in real estate and construction sector: A conceptual study. *International Journal of Engineering Science and Technology*, 2(4), 577–586.

Tang, Y., Liu, R., & Sun, Q. (2014). Schedule control model for linear projects based on linear scheduling method and constraint programming. *Automation in Construction*, 44, 132–142.

Tang, Y., Liu, R., & Sun, Q. (2014). Two-stage scheduling model for resource leveling of linear projects. *Automation in Construction*, 40, 1–10.

Teng, Z., Hu, Z., & Tang, Y. (2017). Resource levelling optimisation for linear projects using linear scheduling method (LSM). *KSCE Journal of Civil Engineering*, 21(7), 2696–2706.

Wang, H., Chang, G., Deng, J., Zheng, J., & Zhao, Y. (2013). Comprehensive Six Sigma quality management in highway engineering. *Applied Mechanics and Materials*, 361–363, 1009–1012.

Wang, Z. T., Hu, Z., & Tang, Y. (2007). Float-based resource leveling optimization of linear projects. *Tsinghua Science and Technology*, 12(3), 305–310.

Yüksel, H. (2012). The success of Six Sigma projects using data envelopment analysis (DEA). *International Journal of Lean Six Sigma*, 3(1), 74–87.

CHAPTER 125

Spatio-Temporal Analysis of Urban Flooding in Industrial Towns: A Case Study of Gurugram

Dhaarna¹ and Bhumit Ahlawat²

ABSTRACT

Urban flooding has become a major environmental and economic problem in industrial cities, facing rapid urbanisation and land use changes. Gurugram, being one of the top industrial and commercial hubs of India, has seen a rise in the number of floods mainly due to uncontrolled urbanisation, inadequate drainage systems and environmental degradation. This research does a spatio-temporal analysis of urban flooding in Gurugram to identify the main contributing factors, community perception of flood risk and the existing flood management strategies. Data was collected through a structured survey of residents from different sectors and industrial areas of Gurugram. The total sample size is 193. The survey asked about public perception of urban flooding, its impact on daily life and the perceived effectiveness of planning and infrastructure in reducing or increasing flood risk. Results show that most of the respondents viewed urban flooding as a big issue, especially during the monsoon months of July and August. Respondents identified inadequate drainage systems, encroachment on water bodies, deforestation and unplanned urbanisation as the top three factors contributing to the frequency and severity of floods. Apart from environmental and infrastructural concerns, respondents reported significant socio-economic impacts like property damage, mobility disruption, loss of work hours and vulnerability to waterborne diseases. Results also show a gap between community needs and existing mitigation strategies. Most of the respondents rated maintenance of drainage systems, emergency response services and enforcement of land use regulations as inadequate. While some initiatives, like awareness campaigns and the creation of green spaces, got more positive responses, they are not enough to address the scale of the issue. The study suggests the need for comprehensive urban flood management strategies that integrate infrastructure improvement, enforcement of land use regulations and active community engagement.

Keywords: Urban flooding; Spatio-temporal analysis; Industrial towns; Gurugram; drainage infrastructure.

1.0 Introduction

Urban flooding is a serious concern in industrialised areas where urbanization, climate

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variability and poor infrastructure collide to create regular disasters (Gupta & Nair, 2021; Yasmin & Das, 2019). Gurugram, one of India's fastest industrial and commercial hubs in NCR, has been experiencing urban flooding for the last two decades (NIDM & Amity University, 2021). The city has transformed from a small town to an industrial and IT centre, which has resulted in significant land use changes, shrinkage of water bodies and an overloaded drainage network (Gupta & Nair, 2021; Suriya & Mudgal, 2012). Monsoon floods have become a regular phenomenon, causing economic loss, public health concerns and severe disruption in business, transportation and residential life (Sahana *et al.*, 2019).

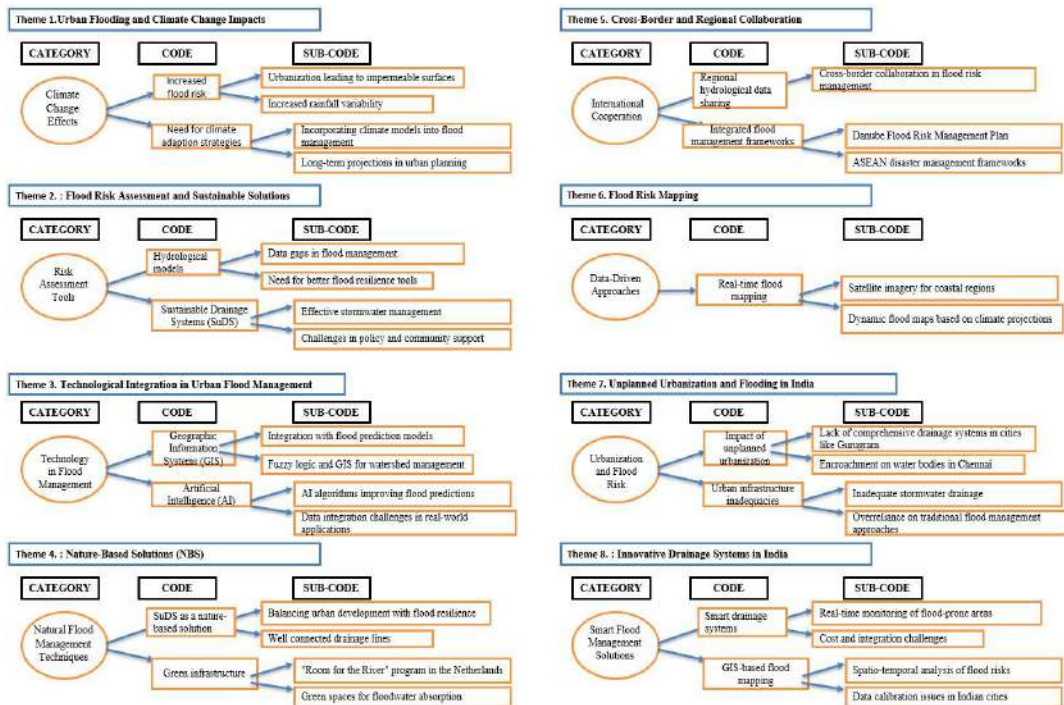
The motivation behind this study is to address Gurugram's increasing vulnerability to urban flooding; despite being an industrial hub, it lacks robust and adaptive flood management systems (Lavanya, 2012). While efforts are being made to modernise infrastructure, the combination of rapid industrialization and limited green infrastructure has made the city more flood-prone (Harsha & Sridharan, 2020). Since Gurugram is a model for other emerging industrial towns, a spatio-temporal analysis of its flooding pattern is needed to understand how urbanization and climate factors interact to increase flood risk (Patra & Kant, 2014). This study aims to investigate the spatial and temporal dynamics of urban flooding in Gurugram, identifying key factors like land use and land cover (LULC) changes, drainage network efficiency and socio-economic vulnerabilities. This study will use GIS and remote sensing to map flood-prone areas, identify infrastructure gaps and evaluate existing flood mitigation measures (Wang & Zhang, 2018).

This research will look into Ward 32 of Gurugram, a flood prone area which is a microcosm of the city's overall urban flooding problem. The study will look into historical flood data, LULC trends and performance of natural and man-made drainage systems over a defined period. It will also explore the scope of nature based solutions and integrated urban planning frameworks to enhance flood resilience. The limitations of this study are that it is limited to one industrial city (Gurugram) and may not apply to other urban contexts with different geography and socio-political conditions. Also, the study is based on secondary data and community level surveys, which may have data gaps or response bias. However, the study will give insight into the evolving problem of urban flooding in industrial areas.

This review aims to critically analyse the spatio-temporal methods used to assess urban flooding in industrial towns with special reference to Gurugram. Through this review, the gaps in research, methodologies and findings will be highlighted, which will contribute to our understanding of urban flood risk in industrial areas. Urban flooding is a growing phenomenon in cities the world over due to rapid urbanization and climate change (Suriya & Mudgal, 2012; Gupta & Nair, 2021). Industrial towns like Gurugram have multiple challenges due to haphazard growth, conversion of natural landscape to impervious surfaces and inadequate stormwater management (Patra *et al.*, 2018). This chapter will review the literature on urban flooding with special reference to industrial cities, spatio-temporal analysis and sustainable flood management. A systematic review of 150 articles was done, out of which 30 articles were

selected for the review. The themes determined by the systematic literature review are showcased in Figure 1. The themes are Urban flooding and Climate change impacts, Flood risk assessment and Sustainable Solutions, Technological Integration in urban flood management, NBS etc.

Figure 1: Themes Identified through Systematic Literature Review



Source: By authors

Globally, urban flooding is linked to increased rainfall variability, sea level rise and land use change. Cities like Rotterdam, New York and Copenhagen have seen major pluvial and fluvial flooding due to these changes (Schreider *et al.*, 2000; Sandink, 2013). It's made worse by the increase in impervious surfaces and ageing or poorly designed drainage infrastructure (Miller, 2018). To tackle these, cities have adopted Sustainable Drainage Systems (SuDS) and green infrastructure to be more resilient (Guptha, 2020). For instance, Rotterdam's water squares and Copenhagen's cloudburst management plan combine grey and green infrastructure to reduce flood impact (Armenakis, 2019).

Technological advancements like artificial intelligence (AI) and Geographic Information Systems (GIS) have enabled flood prediction and early warning systems globally (Chew Ze, 2021; Wang, 2012). AI models have improved flood forecasting in urban Malaysia,

while fuzzy logic combined with GIS has improved urban watershed management in other areas (Wang, 2012). In India, cities like Mumbai, Chennai and Gurugram have faced repeated urban flooding due to unplanned urbanisation, encroachment of natural floodplains and poor stormwater infrastructure (Sahana *et al.*, 2019). The problem is further compounded by high population density and a lack of coordination between municipal bodies and environmental agencies (Yasmoon & Saud, 2016). For instance, Gurugram has lost its water bodies and wetlands and has reduced its natural stormwater absorption capacity (Guhathakurta & Marathe, 2022). NIDM and Amity University (2021) say urban flooding in India has socio-economic impacts like disruption to transportation, damage to property and health impacts.

Lavanya (2012) also says there is no policy integration between urban planners and the environment department, hence poor implementation of land use regulation and increased vulnerability to flooding. Gurugram is an industrial and commercial hub of Haryana and is a perfect example of the challenges faced by Indian industrial towns on urban flooding. The city has been facing frequent and severe flooding, especially in sectors like Ward 32, NH-8 and Golf Course Road (Patra *et al.*, 2018). The rapid transformation of Gurugram into an economic centre has resulted in widespread land cover changes, notably the conversion of agricultural and open spaces into built-up areas (Gupta & Nair, 2021). Suriya and Mudgal (2012) report that Gurugram's stormwater drainage system is inadequate for its current rate of urbanization, with many natural drains encroached upon or completely obstructed. This leads to frequent waterlogging, traffic congestion, and economic losses during the monsoon season. While infrastructural upgrades have been initiated, they have been largely fragmented and insufficiently integrated with environmental planning efforts (NIDM & Amity University, 2021). The global discourse on urban flood management is increasingly advocating for Nature-Based Solutions (NBS) as a complementary or alternative strategy to traditional grey infrastructure (Guptha, 2020).

Green infrastructure elements such as bioswales, rain gardens, green roofs, and permeable pavements have been successfully implemented in cities like Singapore and Amsterdam (Armenakis, 2019; IPCC, 2021). These interventions enhance water infiltration, reduce surface runoff, and restore ecological functions within urban settings. In India, Harahap *et al.* (2021) show that combining traditional practices like rainwater harvesting with modern technology can create cost-effective and community-driven flood mitigation measures. Given Gurugram's wetland heritage, there is a huge scope to integrate NBS, like wetland restoration and green-blue corridors, in its flood management plans. Though there is a lot of research on urban flooding globally and in India, research on industrial towns like Gurugram is limited.

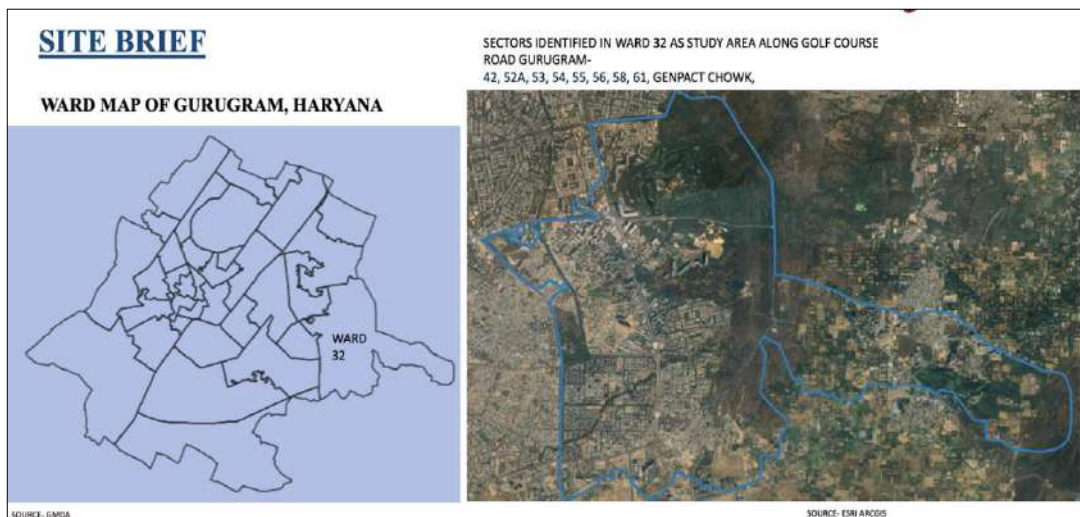
Most available research tends to either focus narrowly on hydrological modelling or socio-economic vulnerabilities (Sahana *et al.*, 2019). There is a lack of comprehensive studies that integrate spatio-temporal data with community-based insights to analyse urban flooding holistically. Furthermore, while the role of NBS in flood mitigation has been studied extensively

in global north contexts, its application and effectiveness in fast-growing Indian industrial towns are yet to be fully explored.

2.0 Methodology

This research employs a mixed-methods approach to comprehensively investigate the spatio-temporal dynamics of urban flooding in Gurugram, with a particular focus on Ward 32, a flood-prone area within the city. The methodology is designed to integrate both geospatial analysis and field-based qualitative insights, ensuring that both the physical patterns of flooding and the socio-economic dimensions of vulnerability are adequately addressed.

Figure 2: Site Brief of the Study Area



Source: By authors

The study area, Ward 32, was selected due to its recurring history of urban flooding, rapid land use transitions, and its representation of the broader infrastructural and environmental challenges faced by Gurugram (see Figure 2). The research combines primary data collection through field surveys and interviews with secondary data analysis derived from satellite imagery, municipal records, and census data. This combination ensures a holistic understanding of flood risk patterns and their underlying drivers. The primary data component includes household surveys conducted with 50 residents in Ward 32 (see Figure 3). The surveys were structured to gather information on residents' experiences with flooding, perceptions of the adequacy of drainage systems, awareness of government interventions, and coping mechanisms during flood events.

Figure 3: Ward Boundary of the Selected Study Area Ward -32



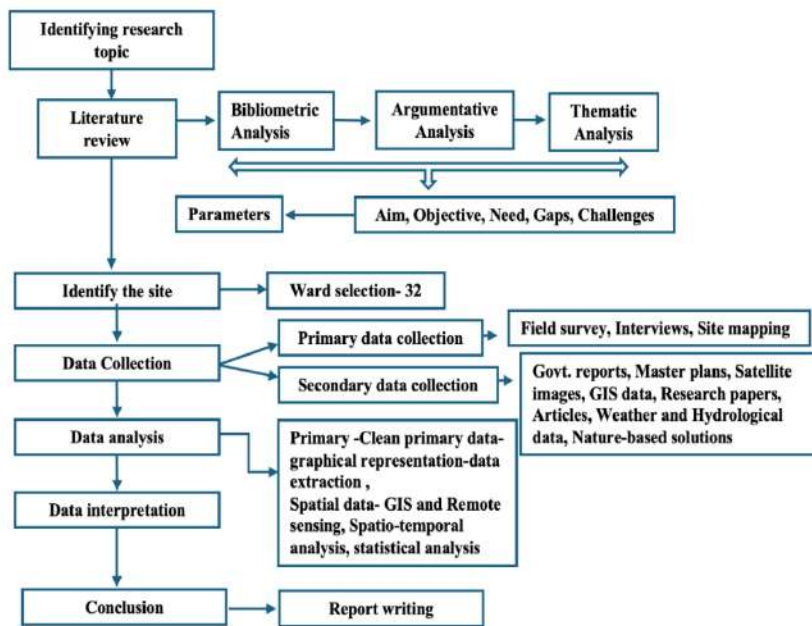
Source: By authors

The survey responses provide critical insights into the socio-economic impacts of urban flooding at the community level. In addition to household surveys, key informant interviews were conducted with officials from the Municipal Corporation of Gurugram (MCG) and the Haryana Urban Development Authority (HUDA). These interviews were instrumental in understanding institutional efforts, planning gaps, and challenges related to flood management within Gurugram. The secondary data includes a multi-temporal dataset of Landsat 8 (30-meter resolution) and Sentinel-2 (10-meter resolution) satellite images for the years 2010, 2015, and 2023, which were used to perform land use/land cover (LULC) change detection. The study area has witnessed extensive land conversion, particularly from open spaces and agricultural land to built-up areas, which has altered its hydrological behaviour and drainage patterns, helping to identify natural flow patterns and low-lying areas prone to waterlogging. For the assessment of community-level vulnerabilities and responses, survey data was processed using Microsoft Excel and SPSS.

Descriptive statistics such as frequencies and percentages were used to interpret patterns in household perceptions regarding the frequency, causes, and impacts of flooding in Ward 32. These insights were further corroborated with flood incident reports and municipal data sourced from the MCG and the Indian Meteorological Department (IMD). Despite the comprehensive nature of the methodology, the research does acknowledge certain limitations. The use of medium-resolution satellite data restricts the fine-scale detection of micro-level urban features such as narrow drains or small green spaces that could influence localized flooding patterns. Additionally, the household survey sample size is relatively modest due to time and logistical constraints, which may affect the generalizability of socio-economic findings beyond Ward 32. Finally, while the study provides a detailed assessment of Gurugram, it is

context-specific and may not fully capture the complexities of urban flooding in cities with significantly different geomorphological or institutional frameworks.

Figure 4: Methodology of the Study



Source: By authors

To understand the causes and impacts of urban flooding in Gurgaon, a total of 193 surveys were conducted with residents of Ward 32. The survey aimed to capture the public's perception of flooding-related issues, its frequency, and its consequences. Respondents highlighted urban flooding as a critical problem, exacerbated during the monsoon season, with 90% agreeing that it disrupts daily activities such as commuting, work, and accessing basic services. A significant number reported property damage and financial loss caused by waterlogging, emphasizing the role of inadequate drainage infrastructure and rapid urbanization. Additionally, the responses shed light on the community's preference for nature-based solutions, including the creation of green spaces, water retention areas, and improved urban planning practices, as effective mitigation strategies. These insights underscore the urgent need for implementing a Sponge Park in low-lying areas of Ward 32 to manage stormwater, reduce runoff, and enhance resilience against flooding. Overall, the methodology offers an integrated lens to understand both the physical landscape transformations and the lived experiences of urban residents in Gurugram, providing a solid foundation for developing targeted recommendations for flood risk reduction (see Figure 4).

3.0 Results and Discussion

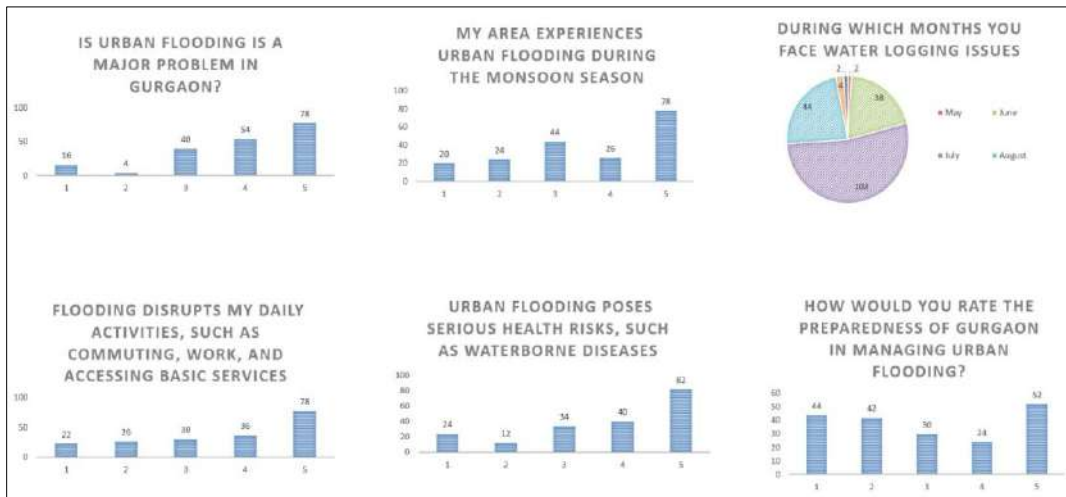
The following section outlines the key findings from the survey conducted to assess urban flooding issues in Gurugram. The survey focused on understanding the public's perception of urban flooding as a major issue, the contributing factors, the socio-economic and health impacts, and the effectiveness of flood management measures implemented in the area. The responses were gathered from a sample representing both residential and industrial areas of Gurugram, reflecting the broader challenges faced in an industrial town undergoing rapid urbanisation. The data indicates that a significant portion of respondents perceive urban flooding as a severe issue in Gurugram. Specifically, 78 participants strongly agreed that urban flooding is a major problem, while 54 participants rated it as a significant concern (scale 4 out of 5).

A similar trend emerged regarding seasonal flooding, where 78 respondents reported frequent occurrences of urban flooding during the monsoon season. The pie chart depicting the months most associated with waterlogging issues highlights that July is the most critical period, with 102 responses identifying it as the peak month for waterlogging, followed by August (44 responses) and June (38 responses). The data suggests a clear monsoon-related vulnerability to urban flooding, which coincides with heavy rainfall months typical of the region's climate pattern. Urban flooding has had significant socio-economic and health-related impacts on the surveyed population. A majority of respondents (78) strongly agreed that urban flooding disrupts their daily activities such as commuting, attending work, and accessing basic services. Moreover, 82 respondents strongly believed that flooding poses serious health risks, particularly in the form of waterborne diseases such as cholera and diarrhoea, which are prevalent during the flood season. Financial repercussions were also prominent, with 112 respondents confirming that either they or someone in their family had experienced property damage or financial losses as a direct consequence of urban flooding. This highlights the urgent need for improved urban flood management strategies in Gurugram (Figure 4).

The survey also evaluated public perceptions of the factors contributing to urban flooding. Poor drainage infrastructure was identified as the leading contributor, with 68 respondents strongly agreeing and 40 moderately agreeing (scale 5 and 4 respectively) that inadequate drainage exacerbates flood risks in the city. Encroachment on natural water bodies ranked second, with 64 respondents moderately agreeing and another 40 strongly agreeing that it has significantly contributed to flooding.

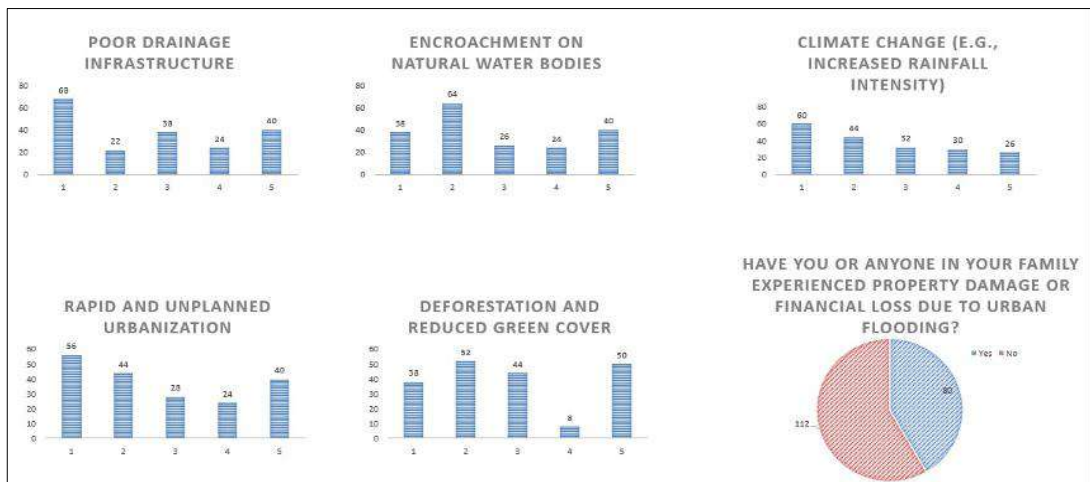
Rapid and unplanned urbanization was another major concern, as 56 respondents strongly agreed that unregulated growth has worsened flooding conditions. Additionally, deforestation and reduced green cover were also seen as contributing factors, with 50 respondents strongly agreeing that the loss of natural vegetation has increased surface runoff and waterlogging incidents. Climate change, specifically the increased intensity and frequency of rainfall, was acknowledged by 60 respondents who strongly agreed that it plays a role in the rising urban flood risk (as seen in Figure 5).

Figure 5: Respondents Perception about Urban Flooding in Study Area



Source: By authors

Figure 6: Factors Contributing to Urban Flooding in the Study Area

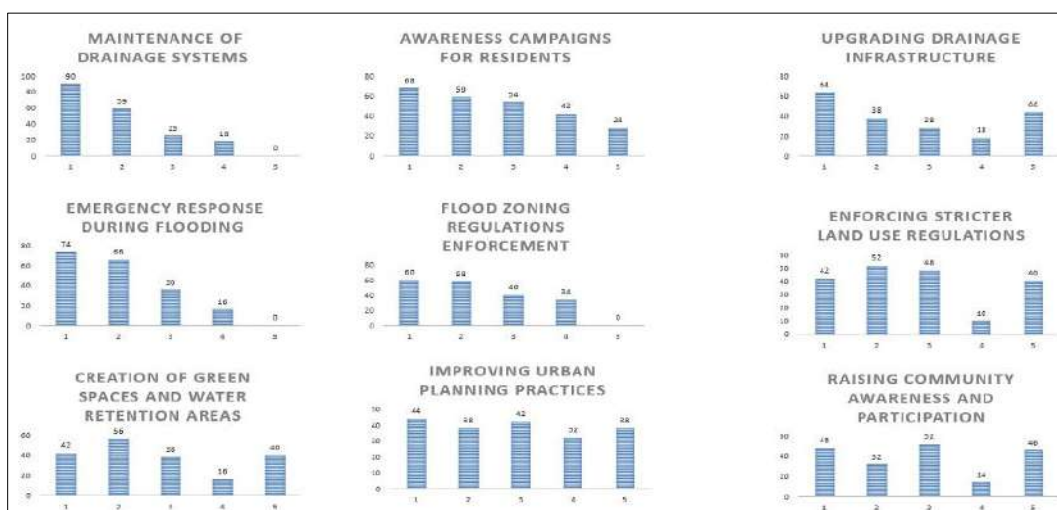


Source: By authors

Respondents were asked to evaluate the effectiveness of existing flood management measures in their local areas on a scale from 1 (very ineffective) to 5 (very effective). The results reveal a general dissatisfaction with current interventions. For instance, maintenance of drainage systems was rated as very ineffective by 90 respondents, highlighting major issues in

the upkeep and capacity of existing infrastructure. Similarly, emergency response during flooding was deemed ineffective, with 74 respondents giving it the lowest possible rating. The awareness campaigns for residents were slightly better rated but still concerning, with 68 participants marking them as largely ineffective. Flood zoning regulations and land use regulations enforcement also received mixed feedback, with a noticeable number of respondents rating them as moderately ineffective (60 and 58 respondents, respectively).

**Figure 7: Effective Measures Implemented in the Study
Area as per Respondents' Perception**



Source: By authors

However, some positive feedback was recorded for upgrading drainage infrastructure and the creation of green spaces and water retention areas, where a segment of respondents (44 and 40 respectively) rated these measures as effective. Notably, raising community awareness and participation and improving urban planning practices showed relatively balanced opinions. Around 46 respondents viewed community participation as effective, whereas urban planning improvements were seen as moderately effective by 38 respondents. Lastly, when asked to rate the overall preparedness of Gurugram in managing urban flooding, the responses were divided. While 52 respondents rated the preparedness as effective (score of 5), a substantial portion—44 and 42 respondents—rated it as poor (scores of 1 and 2). This polarization reflects the inconsistency in the implementation and perceived success of urban flood management strategies across different parts of the city. The major parameters emerging from this analysis include the lack of proper drainage infrastructure, encroachment on water bodies, unplanned urban growth, and weak enforcement of planning regulations. Additionally, health risks,

economic damages, and disruptions to daily life were consistently reported as critical consequences of urban flooding. While some measures such as the creation of green spaces show moderate success, there remains a critical gap in community preparedness and systemic responses to urban flood risks in Gurugram (as seen in Figure 7).

Interviews with key informants, including officials from MCG, the Haryana Urban Development Authority (HUDA), and local elected representatives, provided critical institutional perspectives on urban flood management challenges in Ward 32. Officials acknowledged that while the city's Drainage Master Plan exists, ward-level implementation is fragmented due to budgetary limitations, bureaucratic delays, and the lack of an integrated drainage and land-use plan. There was also recognition of the difficulties posed by rampant encroachment on natural water bodies and drains, which has disrupted the natural flow of stormwater. While some short-term measures have been initiated, such as localized drain cleaning and the raising of road levels in selected streets, there has been limited movement toward systemic and sustainable solutions. Officials cited limited land availability, legal disputes over land ownership, and a lack of technical expertise in green infrastructure as major barriers to implementing large-scale Nature-Based Solutions in Gurugram. Nevertheless, municipal officials expressed interest in piloting NBS projects, including sponge parks and bioswales, particularly in flood-prone areas where conventional infrastructure has failed to address the problem adequately. However, there is currently no formal mechanism in place for engaging the community in these efforts.

Figure 8: Classification of Nature-Based Solutions and their Usage in Gurugram

Name of NBS	Case Study	Where It Can Be Used in Gurugram Ward 32	
Sponge Parks	Qunli National Urban Wetland Park in Harbin, China: Restored wetlands to mitigate flooding and improve biodiversity.	Designating low-lying open spaces near NH-48 and residential areas in Ward 32 as sponge parks to capture and store stormwater.	
Rain Gardens	Diverse projects in Portland, USA: Small-scale green spaces used to absorb and filter stormwater.	Installing rain gardens along sidewalks and medians of MG Road and Galleria Market area to slow down runoff and reduce waterlogging.	
Urban Wetlands	East Kolkata Wetlands, India: A natural wetland system treating wastewater while reducing flood risks.	Restoring natural depressions and low-lying areas near Wazirabad Drain , converting them into wetlands to manage flood overflow.	
Green Roofs	Singapore's Green Roof Program: Rooftop vegetation to reduce runoff and urban heat.	Encouraging commercial and residential buildings near DLF Phase IV to install green roofs to manage rainwater at its source.	
Permeable Pavements	Palava Smart City, Mumbai: Introduced permeable concrete for sidewalks and parking areas.	Replacing impervious concrete in residential lanes and parking spaces in Ward 32 with permeable pavements to reduce surface runoff.	
Bioswales	High Line, New York: Vegetated channels designed to manage stormwater runoff.	Creating bioswales along internal roads in Ward 32, particularly near schools and community centers, to filter and channel water.	
Retention Ponds	Bhopal's Upper Lake Revitalization: Used as a stormwater reservoir to	Building small retention ponds in underutilized parks or open areas near Ward 32 to temporarily store stormwater during peak rainfall.	

Source: By authors

Nature-based solutions (NBS) offer a promising alternative to traditional flood control infrastructure. By working with natural processes, NBS can help mitigate flood risks, enhance urban resilience, and provide co-benefits such as improved biodiversity, air quality, and recreational spaces for residents. Some of the most relevant NBS types for Ward 32 include Permeable pavements, Bioswales, Rain Gardens, Green Roofs, Sponge Parks etc. (as mentioned in Figure 8). The survey revealed that while direct knowledge of these solutions was low, there is broad support for the idea of green infrastructure if framed as a way to reduce flooding and improve local living conditions. 84% of respondents expressed that they would support or help maintain green spaces that could also serve to manage stormwater effectively. Based on both community feedback and physical site observations, Saraswati Kunj has been identified as a potential site for developing a Sponge Park (see Figure 9). This study area was consistently mentioned by respondents during the survey as an area prone to chronic waterlogging during monsoons. The selected site is strategically located at a topographic low point within Ward 32, making it ideal for intercepting and storing runoff during heavy rain events. The site, currently covered with degraded grass and informal dumping of solid waste, presents an opportunity to be transformed into a multi-functional green space.

Figure 9: Site Selected for NBS (Sponge Park) to Mitigate Urban flooding



Source: By authors

A well-designed sponge park here could achieve several objectives, such as Retention of stormwater (reducing flood peaks), Groundwater recharge (supporting local water security),

Provision of recreational space (contributing to community well-being), and Improvement of local biodiversity by introducing native vegetation. Community feedback indicated that 55% of residents would be willing to participate in tree planting, park maintenance, and other related activities that could help in mitigating the issue, provided that the initiative is championed by the municipal authorities and supported with basic resources. The combined results of the community survey and key informant interviews highlight a clear need for integrated flood management strategies in Ward 32 that go beyond conventional infrastructure solutions. The lack of awareness about NBS among residents contrasts with their strong willingness to engage in community-based projects if properly mobilized. Institutional gaps, particularly in terms of cross-agency coordination and public participation, continue to hinder progress. However, the identification of a viable sponge park site near the Saraswati Kunj presents a concrete opportunity to pilot nature-based interventions within a highly vulnerable urban area.

4.0 Conclusion

Based on the survey findings, it is evident that urban flooding poses a persistent and severe challenge for Gurugram, particularly during the monsoon season, leading to significant disruptions in daily life, health risks, and financial losses for residents. The study highlights key contributing factors such as poor drainage infrastructure, rapid and unplanned urbanization, encroachment on natural water bodies, and reduced green cover, all of which are exacerbated by climate change-induced rainfall variability. While some flood mitigation efforts, including awareness campaigns and the creation of green spaces, show marginal effectiveness, the overall perception of Gurugram's flood preparedness remains low.

These findings underscore the urgent need for integrated urban planning strategies, stricter land use enforcement, and enhanced community participation to build resilience against urban flooding in this rapidly industrializing city.

References

- Armenakis, C. (2019). Regional hydrological data integration for transboundary flood management. *International Journal of River Basin Management*, 17(1), 1-12.
- Chew Ze, R. (2021). AI-enhanced flood prediction models for Malaysian urban areas. *Journal of Hydrology*, 603, 126989.
- Guhathakurta, S., & Marathe, A. (2022). Urban sprawl and flood vulnerability in Indian cities. *Environment and Urbanization Asia*, 13(2), 251-268.
- Gupta, K., & Nair, S. (2021). Urban flooding and drainage challenges in Gurugram. *Journal of Infrastructure Development*, 13(1), 45-62.

Guptha, R. (2020). The role of Sustainable Drainage Systems (SuDS) in Indian urban planning. *Urban Water Journal*, 17(3), 243-255.

Harahap, M., Satria, M., & Yuliana, R. (2021). Indigenous practices and modern technology integration for flood management. *Water Resources Management*, 35(4), 1125-1140.

IPCC. (2021). *Climate Change 2021: Impacts, Adaptation, and Vulnerability*. Cambridge University Press.

Lavanya, K. (2012). Encroachment and flood management challenges in Chennai. *Indian Journal of Urban Affairs*, 11(2), 99-115.

Miller, J. (2018). Urban impermeability and its role in flood intensification. *International Journal of Urban Sciences*, 22(4), 520-537.

NIDM & Amity University. (2021). *Urban flood risks and disaster management in Gurugram*. National Institute of Disaster Management.

Patra, A., Sharma, P., & Mishra, R. (2018). Traffic disruptions due to urban flooding in India. *Transportation Research Record*, 2672(1), 71-79.

Sahana, M., Sajjad, H., & Ahmed, R. (2019). Pluvial flooding trends in Indian metropolitan cities. *Natural Hazards*, 98(3), 1051-1071.

Sandink, D. (2013). Public engagement and adaptive planning in Canadian flood management. *Canadian Water Resources Journal*, 38(3), 253-262.

Schreider, S., Smith, D., & Jakeman, A. (2000). Climate models and flood risk. *Climatic Change*, 45(3-4), 499-522.

Suriya, S., & Mudgal, B. V. (2012). Urban flooding in Indian industrial cities. *Hydrology Journal*, 35(4), 361-372.

Wang, X. (2012). GIS and fuzzy logic for urban watershed management. *Water Resources Management*, 26(12), 3489-3504.

Yasmoon, N., & Saud, M. (2016). Coordination challenges in urban flood management in India. *Disaster Prevention and Management*, 25(5), 675-690.

CHAPTER 126

Stakeholder Identification and Management in Small Scale Real-Estate Projects

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ABSTRACT

Objectives: The purpose of this study is to create a process for the identification and management of stakeholders in small-scale real-estate projects in India, where such mechanisms are often lacking. The absence of structured stakeholder engagement leads to increased project costs, extended durations, and reduced efficiency. By addressing this gap, this research aims to propose effective strategies to enhance stakeholder management and project outcomes. *Methodology:* The study employs an exploratory approach combining quantitative survey of selective stakeholders using standardized questionnaire and qualitative interviews of relevant stakeholders working in the construction sector. *Findings:* The research is expected to identify the stakeholder management approaches adopted for real estate projects in India. These findings will encompass the identification of stakeholders, their management and engagement strategies, along with their benefits. In specific, the study suggests advancements in several different features, i.e. cost, time optimization, improved processes, and efficient collaboration with diverse stakeholders across different levels. *Practical implications:* This study will be useful in providing insights for creating practical tools and guidelines that may be useful for the organizations towards managing stakeholders better in small-scale real-estate projects, this can further help the companies organize their projects in a better way. This study will contribute to the timely and successful completion of the projects, ultimately promoting economic growth and social development.

Keywords: Stakeholder management; Small scale; Real-estate; India.

1.0 Introduction

This research offers a theoretical basis for stakeholder management practices in small-scale real estate development projects and seeks to formulate strategies that improve the efficiency of the project and involve stakeholders. Stakeholder management is essential in real estate development as it helps in reducing conflicts, facilitating effective communication, and enhancing the success of the project.

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Effective stakeholder management not only assists in avoiding risks but also ensures timely project completion and cost-effectiveness. But small-scale real estate developments usually do not have formal stakeholder management strategies, resulting in communication failures, project delays, and cost inefficiencies. Successful stakeholder management entails the identification of critical stakeholders, their interests and power, and the formulation of systematic engagement strategies. Most studies emphasize that the lack of systematic stakeholder management leads to ineffective project coordination and more legal conflicts. This research aims to fill this gap by examining existing stakeholder management practices, determining the most critical challenges, and suggesting a systematic framework to enhance stakeholder engagement.

1.1 Objectives

- To assess the approaches employed to deal with stakeholders in small-scale real estate projects.
- To identify problems in the identification and engagement of stakeholders.
- To examine how stakeholder management influences the success of a project.
- Providing suggestions for improving the engagement of stakeholders in small-scale real estate projects.

1.2 Scope

This research aims to examine current practices, identifying challenges, and provide suggestions to enhance stakeholder engagement and management in small-scale real estate projects. Using a mixed-methodology approach, the research provides findings that can guide policymakers, developers, and project managers in applying better stakeholder initiatives. The scope of work includes the following elements:

- Focus on Small-Scale Real Estate Projects
- Importance of Stakeholder Identification and Management
- Recommendations for Enhanced Stakeholder Management
- Contribution to Research and Practice

1.3 Limitations

- The research focuses on small-scale real estate projects in a single geographic area, resulting in limited potential for extending the findings beyond that specific region, that is, the West Region.
- The quality and availability of data pertaining to small scale real-estate projects presented serious difficulties as there has been limited availability of data in the context of small-scale real-estate projects.
- Security concerns about data privacy led project-specific informants to refuse participating in the study.

- The time limitations of academic studies along with extended stakeholder involvement made it impossible to conduct long-term studies to evaluate research results.

2.0 Literature Review

Effective stakeholder management determines the success rate of construction projects specifically within the real estate context. Small-scale real estate projects have risen in complexity, which demands elaborate stakeholder engagement understandings. Many small-scale real estate companies operate without formal structures to identify stakeholders while also analyzing their needs and managing their expectations. The lack of structured research in stakeholder management demands new approaches to deal with small-scale real estate projects throughout India.

2.1 Stakeholder management in construction projects

Organizations experience challenges with implementing stakeholder management for project success because they lack clear guidelines and have inconsistent engagement strategies according to Jepsen & Eskerod (2009). Managers experience difficulties both in recognizing important stakeholders along with placing their needs in priority sequences resulting in compromised project performance. Major construction projects require strong relationships between internal and external stakeholders as per Mazur & Pisarski (2015). It also states that, to develop and maintain these relationships, significantly impacts project outcomes. The authors found three essential elements, which determine the effectiveness of stakeholder management, are Internal stakeholder relationship quality, stakeholder relationship development, and stakeholder relationship effectiveness. Large-scale infrastructure projects have multiple stakeholders with varying interests for this, Aaltonen and Kujala (2016) proposed a framework based on complexity, uncertainty and dynamism for stakeholder engagement strategies.

2.2 Stakeholder management in real estate projects

Real estate sector management requires exceptional stakeholder management because multiple groups possess opposing demands. Real Estate organisations should maintain equilibrium between what investors, employees, clients, vendors, and regulatory institutions want according to Norsa & Pedeliento (2010). Real estate projects operate with much dynamism than industrial and service-based companies because their project timelines and market conditions, alongside regulatory requirements, keep changing. Small-scale construction enterprises require effective stakeholder management practices according to Klaus-Rosińska & Iwko (2021). The study discovered large firms maintain special stakeholder management groups but small enterprises mostly utilize outdated practices which fail to satisfy stakeholders properly. It also states that small enterprises should develop ordered approaches for stakeholder communication to ensure project sustainability and financial success in the long run.

2.3 Stakeholder management in the Indian construction industry

The Indian construction market proves highly fragmented because small and medium-sized enterprises (SMEs) dominate its operations. Projects in India achieve successful completion through effective stakeholder management according to Ramakrishnan (2010) because of the intricate regulatory framework and diverse stakeholders involved. The Indian construction sector contains several essential stakeholder groups, including clients, investors, contractors, regulatory bodies, and local communities. Yang & Shen (2015) indicate that Indian construction firms operate without established stakeholder engagement frameworks, which produces higher project delays and expense growth and fights between project stakeholders. Multiple Indian firms face problems maintaining efficient stakeholder management because they experience dispersed communication channels and undefined stakeholder duties.

3.0 Methodology

The research conducted for the thesis was a Literature Review, which covers the topic of stakeholder identification & management on different levels. It focuses on Stakeholder Management in the context of small-scale real-estate projects. It also includes a mix of both, Quantitative Analysis & Qualitative Analysis. We have adopted a mix of two types, Purposive & Convenient Sampling.

3.1 Method of data collection for quantitative analysis

The data for the present study was collected through a survey of the relevant industry personnel. The survey was conducted through circulating a questionnaire designed to appropriately record the responses of the people and taking interviews of relevant stakeholders by incorporating the important indicators of their management criteria and the effect on the firm's performance.

3.2 Method of data collection for qualitative analysis

After this, we did interviews with some of the stakeholders from small-scale real-estate projects to find out the reason for the results that we found in the quantitative study. We took a total of 12 interviews, out of which 03 were not up to mark & hence we had to discard them. The questions we asked them are all present in the appendix 02.

3.3 Questionnaire design

We have adopted a mix of Purposive & Convenient Sampling. We have done so because we needed individuals only from the construction industry & that too from the small-scale real-estate sector & it was easier & more practical to approach our contacts working in the same sector. The standardized questionnaire was adopted from a paper (Klaus-Rosinka & Iwko, 2021). This study was done in Poland on small-scale companies to see whether Stakeholder

Management was understood by them & how important they thought it was. We thought that the same kind of study would be relevant in the Indian context, as Stakeholder Management is not very popular among small-scale companies & there is a need that they understand how important Stakeholder Management is & how significantly it can improve the performance of their projects. The research process included getting consent from the respondents to use their responses for research & letting them know their identity will be kept confidential. We approached nearly 10 different small-scale real-estate companies & asked different stakeholders within each to fill a particularly designed questionnaire. We received 60-65 responses & after rejection of the responses because insufficient data & the information provided, we have selected 50 responses that can be used for the study. The questionnaire consisted of 05 introductory questions that helped us confirm their sector of work, size of their company, revenue, etc. Whereas, in the second part of the questionnaire, the respondents answered 13 questions regarding their knowledge of stakeholder management & their company's behaviour & strategies about stakeholder management. The questionnaire was published in simple & standard English language which can be understood by everyone & avoid any type of ambiguity in the questions. The respondents answered 11 of those 13 questions in the second part of the questionnaire, using a 7-point Likert scale (ranging from 1-“definitely no”, 2-“almost no”, 3-“slightly”, 4-“to a moderate extent”, 5-“pretty much”, 6-“basically yes”& 7-“definitely yes”). All the questions of the questionnaire are presented in Appendix 1 & 2 at the end.

3.4 Sample profile

The questionnaire is designed to collect the organisational information of all the respondents, such as revenue generated, number of employees, and work experience in the industry. As each individual might have different perceptions about their organization's performance in the market based on their ESG initiatives, it becomes imperative to capture the responses from people of all age groups, gender, and years of work experience. A brief profile of respondents is listed in Table 1.

Table 1: Organisational Profile

Revenue	Number	%
Under 10 Cr	53	86.9
10 to 20 Cr	4	6.6
Above 20 Cr	4	6.6
No. of Employees		
Under 50	30	49.2
Between 50-250	22	36.1
Above 250	9	14.8
Operating Since		
Before 1990	6	9.8
After 1990	55	90.3

4.0 Analysis

A research investigation denotes stakeholder management stands as a vital element for small-scale real estate projects across India. Research findings demonstrate that small businesses lack systematized methods although stakeholder management remains essential even for them. Organizations tend to choose between nonexistence of stakeholder analysis and random methods instead of using established systematic approaches. The practice leads to communication problems, project scheduling problems, and operational inefficiency affecting final project success rates. By going through the data extracted from the questionnaire and the interviews, we identified various themes that were mentioned by almost every person we interacted with, based on which we identified the challenges in the Implementation of Stakeholder Management practices, and came up with some recommendations.

4.1 Key themes identified

4.1.1 Lack of communication & engagement

The successful implementation of projects requires effective communication, but organizations struggle predominantly with unclear information flow, together with inadequate stakeholder engagement, and a reactive approach to crises. When communication emerges spontaneously, there develop misunderstandings which create alignment challenges that result in stakeholder dissatisfaction, thus increasing project risks. Such communication weaknesses typically produce project delays alongside various issues such as expense growth and stakeholder disagreements. Organizations need to create formal communication plans combined with technology-based collaboration systems and periodic meetings with stakeholders to solve this issue. The implementation of proactive communication leads organizations to greater transparency and boosts stakeholder trust, thus producing project-wide success.

4.1.2 Absence of a formal stakeholder management framework

A standardized framework for stakeholder management within small and medium enterprises produces inadequate stakeholder interactions together with hasty decision-making and non-existent accountability. Standardized processes are absent, which leads stakeholders to go unidentified and engagement plans to be unclear while problems are addressed only after incidents happen. Project uncertainties arise with fewer opportunities for collaboration as well as ineffective conflict resolution. Organizations can reduce these issues by using a systematic approach for stakeholder management, and by appointing specific staff members for engagement and by conducting regular stakeholder evaluations. When organizations take proactive measures, their projects become more effective while reducing the potential risks and strengthening all their stakeholder connections.

4.1.3 Limited awareness & implementation of stakeholder management practices

Numerous businesses fail to prioritize long-term project viability since they devote excessive attention to short-term implementation without implementing stakeholder management practices. Projects that lack formal stakeholder analysis, together with risk evaluation, encounter unexpected challenges which lead to reduced accomplishment rates, besides intensifying regulatory uncertainties. Insufficient training related to stakeholder interaction results in missed alignment as well as decreased stakeholder satisfaction and negative effects on company reputation and future business chances. Organizations should deploy three main strategies to address such problems including the integration of stakeholder management during project planning phases and the establishment of training initiatives and the adoption of relationship-oriented procedures. When projects prioritize stakeholder needs in advance their results improve, and risk management becomes better which promotes long-lasting successful projects.

4.2. Challenges in implementation of stakeholders management practices

4.2.1 Lack of awareness & understanding of stakeholders management

Small scale real estate projects face major difficulties with stakeholder management because their stakeholders do not realize the importance of this process. Small-scale developers who operate in informal markets mainly concentrate on financial aspects to obtain capital and boost sales rather than consider essential stakeholders like contractors and regulatory bodies alongside residents. They commonly fail to identify conflicts and delays since they lack training in stakeholder engagement methodologies.

4.2.2 Resistance to change & preference for informal practices

Small real estate development companies decline to implement formal stakeholder management approaches because they depend heavily on casual engagement processes. Family-owned businesses generally opt for personal relationships rather than structured methodologies since stakeholder mapping together with other procedural methods appear too formal and time-intensive. Operating under conditions of openness may make investors and contractors anxious about receiving public scrutiny and being directly accountable. The handling of conflicts remains reactive in nature, although organizations should anticipate conflicts and take preventive measures instead.

4.2.3 Financial constraints and resource limitations

The process of effective stakeholder management demands funding that poses difficulties for small development companies working with constrained budgets. Project managers typically handle stakeholder engagement activities because most firms fail to dedicate funding for either dedicated personnel or project management software purchases. Project

developers who view stakeholder engagement as surplus costs do not recognize its value as an investment to simplify project completion.

4.2.4 Difficulty in managing conflicting stakeholder interests

Many parties that participate in real estate developments create challenging interests that make reaching consensus difficult. The investor leads with project speed and financial success, but customers seek both excellent construction and prompt delivery. Cost efficiency and workflow transparency remain essential to contractors, yet they may not match what investors alongside customers wants to see in the project. The inhabitants of the area frequently oppose development proposals that raise questions about environmental protection and fundamental infrastructure requirements, which developers must handle.

4.2.5 Inconsistent stakeholder engagement throughout the project lifecycle

Regular interaction among stakeholders becomes a major challenge in small-scale real estate development projects. The priority of developers includes obtaining both investor capital and customer acquisitions before communication with both groups end shortly after the project's launch. Regular stakeholder interaction failure during projects results in misunderstandings and both customer dissatisfaction and potential legal issues.

4.3 Recommendations for small scale real estate companies in India

4.3.1 Develop a standardized stakeholder management framework

Through a standardized stakeholder management structure small-scale real estate firms receive structured methods to recognize and relate with their stakeholders depending on their influence levels and stakeholder interests. Through the application of Power-Interest Grid and Stakeholders Analysis Matrices companies can properly identify key stakeholders as they focus on investors and regulators who have maximum power and interest while optimizing management of lower priority stakeholders. When stakeholders get formal management, their processes become more standardized while conflicts decrease, and decisions become stronger with better resource usage.

4.3.2 Enhancing communication & feedback mechanisms

The success of projects alongside stakeholder expectation management needs proper communication methods to be effective. Small-scale real estate firms must implement standard communication systems, including regular assemblies and official reporting, along with technological tools which incorporate CRM systems and tracking systems in real time. The systems promote openness while reducing misinterpretations, while keeping participants informed. Stakeholder feedback moves both ways as a system, which ensures project concerns get acknowledged for project planning, in addition to building long-term trust between stakeholders.

4.3.3 Investing in stakeholder training & awareness

The process of stakeholder interaction flows continuously since it requires ongoing learning and capacity development for both parties. The ability to handle conflicts and negotiate and build relationships requires proper training for small real estate organizations to deliver to their project teams. Smooth project execution occurs when major stakeholders receive project goal information because it leads them to collaborate and decreases potential conflicts.

5.0 Conclusion

Stakeholder identification and management proves essential to the success of small-scale real estate projects within the Indian market. Results demonstrate that small firms lack systematic practices, which cause communication problems together with delayed projects and operational inefficiencies, which reduce general project success. The research investigates several main problems linked to inadequate stakeholder interaction along with scarce organized stakeholder management structure and limited knowledge about best practices. Companies primarily use traditional and informal ways of engagement instead of formalized strategies which produces misalignment between stakeholder requirements and project performance issues. The solution involves small-scale real estate enterprises using standardized stakeholder management systems with enhanced communication and stakeholders should receive training about project best practices. Through careful implementation of proper stakeholder engagement strategies alongside conflict resolution tools and technological approaches small-scale firms will achieve major improvements in their relationships and project success. Small real estate firms reach long-term success through developing a stakeholder awareness culture and management, which leads to enhanced project efficiency together with reduced risks.

References

- Aaltonen, K., & Kujala, J. (2016). Towards an improved understanding of project stakeholder landscapes. *International Journal of Project Management*, 34(8), 1537–1552. <https://doi.org/10.1016/j.ijproman.2016.08.009>
- Boddy, D., & Paton, R. (2004). Responding to competing narratives: Lessons for project managers. *International Journal of Project Management*, 22(3), 225–233. <https://doi.org/10.1016/j.ijproman.2003.07.001>
- Klaus-Rosińska, A., & Iwko, J. (2021). Stakeholder management—One of the clues of sustainable project management—As an underestimated factor of project success in small construction companies. *Sustainability*, 13(17), 9877. <https://doi.org/10.3390/su13179877>

Mazur, A. K., & Pisarski, A. (2015). Major project managers' internal and external stakeholder relationships: The development and validation of measurement scales. *International Journal of Project Management*, 33(8), 1680–1691. <https://doi.org/10.1016/j.ijproman.2015.07.008>

Norsa, A., & Pedeliento, G. (2010). The stakeholder management in real estate. In *ERES Conference Proceedings*. European Real Estate Society (ERES). https://doi.org/10.15396/eres2010_211

Park, H., Kim, K., Kim, Y.-W., & Kim, H. (2017). Stakeholder management in long-term complex mega-construction projects: The Saemangeum project. *Journal of Management in Engineering*, 33(4), 05017002. [https://doi.org/10.1061/\(ASCE\)ME.1943-5479.0000515](https://doi.org/10.1061/(ASCE)ME.1943-5479.0000515)

Ramakrishnan, D. (2011, August 26–27). Stakeholder management—A critical study on the opportunities and challenges from India. In *23rd AIMS Annual Management Education Convention 2011, Bhubaneswar*. Vivin Consultants. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2008048

Yang, R. J., & Shen, G. Q. P. (2015). Framework for stakeholder management in construction projects. *Journal of Management in Engineering*, 31(4), 04014064. [https://doi.org/10.1061/\(ASCE\)ME.1943-5479.0000285](https://doi.org/10.1061/(ASCE)ME.1943-5479.0000285)

Annexure

Annexure 1: Questionnaire

01. How many employees does your company employ?
02. Since when has your company been operating on the market?
03. Which sector are you working in?
04. What is the revenue of your company?
05. Which function do you perform in the organization (choose the closest one)?
06. Does your company identify (check) stakeholders and clients before starting projects?
07. Does your company plan to identify (check) stakeholders in the future?
08. What is used to identify stakeholders?
09. Is the identification of stakeholders continued during the project implementation?
10. Does your company perform stakeholder analysis in a formalized way before starting projects?
11. Does your company expect to conduct a formal stakeholder analysis before starting projects in the future?
12. What criteria are used in the stakeholder analysis?

13. Is an action and communication strategy developed for the group of the most important stakeholders selected during the analysis in a systematic manner?
14. Is systematic development of activities and communication towards stakeholders proposed in the near future?
15. Does the current way of communicating with the stakeholders before the project implementation sufficiently allow to get to know their needs, expectations and attitudes towards the project?
16. Does communication with stakeholders during project implementation sufficiently allow to identify possible evolution of their needs, expectations and attitudes towards the project?
17. Is there any significant modification to the way of contacting stakeholders during the project implementation planned in the near future?

Annexure 2: Interview

01. Why isn't your company identifying stakeholders at the initial stage?
02. Why is your company not assessing the stakeholders throughout the project?
03. Why isn't your company differentiating stakeholders on the basis of their importance?
04. Why is there no change in the way & frequency of communication with stakeholders at different stages of projects?
05. Why is the evolution in the need of stakeholders not identified during the execution of the project?
06. Why are stakeholders not informed about the progress of the project on a regular basis?
07. Why is there no mechanism to evaluate the effectiveness of your company's current stakeholder communication strategy?
08. Why is the stakeholders feedback not incorporated into changes in the project deliverables?

CHAPTER 127

Statistical study of Digitalization in Construction Industry

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ABSTRACT

Digitalization is revolutionizing the construction sector by addressing inefficiencies, high costs, and poor project outcomes. This study explores the impact of digital tools such as Artificial Intelligence (AI), the Internet of Things (IoT), Building Information Modelling (BIM), and project management tools focused on time, cost, and quality management in building projects. Using a mixed-methods approach combining doctrinal analysis and survey-based empirical data, it examines adoption rates, benefits, and challenges. Research shows that digital tools significantly enhance productivity, reduce timelines, and lower costs. Technologies like BIM, AI for defect detection, and drones for site inspections improve project quality. However, barriers such as high initial costs, a lack of skilled professionals, and resistance to change hinder broader adoption, highlighting the need for targeted strategies. The study underscores the transformative potential of digitalization in optimizing the Project Management Triangle (scope, cost, and time) while enhancing quality. It aims to guide stakeholders in leveraging digital tools for greater innovation, sustainability, and improved project outcomes in the construction industry.

Keywords: Digitalization; Building information modeling (BIM); Project management triangle; Construction industry; Quality improvement.

1.0 Introduction

Digitalization is revolutionizing the construction sector by addressing inefficiencies, high costs, and poor project outcomes. This study explores the impact of digital tools such as BIM-Building information modelling, IOT-Internet of things, AI-Artificial intelligence and project management. Using a mixed-methods approach combining doctrinal analysis and survey-based empirical data, it examines adoption rates, benefits, and challenges. Research shows that digital tools significantly enhance productivity, reduce timelines, and lower costs. Technologies like BIM, AI for defect detection, and drones for site inspections improve project quality. However, barriers such as high initial costs, a lack of skilled professionals, and resistance to change affect broader adoption, highlighting the need for targeted strategies.

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The study underlines the transformative potential of digitalization in optimizing the Project Management Triangle (scope, cost, and time) while enhancing quality. It aims to guide stakeholders in leveraging digital tools for greater innovation, sustainability, and improved project outcomes in the construction industry.

2.0 Literature Review

Prebanić & Vukomanović (2021). This paper reviews the impact of digital transformation on stakeholder behavior and engagement in the construction industry, focusing on tools like BIM, social network analysis, and web-based applications. Musarat *et al.*, (2023). This study explores how digitalization in the construction industry enhances quality of life by optimizing energy use, promoting economic growth, and improving building efficiency. Liu *et al.*, (2023). This research proposes a conceptual project governance model to promote digitalization in construction projects. The authors identify three integration dimensions: stakeholder, lifecycle, and project management knowledge. Irina Vladimirova *et al.*, (2018). The study highlights the benefits of BIM in reducing construction costs, improving productivity, and enhancing project outcomes. Hwang *et al.*, (2021). This study examines the challenges and strategies for adopting smart technologies in Singapore's construction industry. Key challenges include data sharing, regulatory compliance, and data ownership. Effective strategies involve workforce training, government incentives, and improved communication.

3.0 Research Methodology

A systematic framework known as research design directs the investigation from the creation of research questions to the data analysis. A mixed-methods research design is used in this study, integrating qualitative and quantitative techniques. While quantitative technique is used to evaluate the effect of digital tools and technologies on project efficiency, the qualitative approach is used for studying the challenges, strategies, and views related to digital transformation in the construction sector. By using the advantages of both strategies, the mixed-methods design guarantees a thorough grasp of the study subject. Professionals in the construction sector, including project managers, architects, engineers, and contractors, are among the target population. To guarantee representation across various jobs and organizational sizes, a stratified random selection technique is used. The sample size guarantees a 5% margin of error and a 95% confidence level. Responders, drawn from both public and private construction companies, make up the final sample.

4.0 Discussion of Findings- Graphs and Results

From the response given by the sources, it is clear that 89.1% respondents out of 100% have said that digitalization has reduced the overall project time (Figure 1).

Figure 1: Digitalization's Impact on Timeline

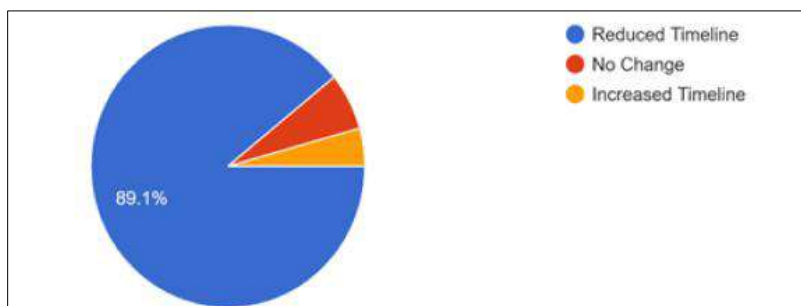


Figure 2: Most Effective Digital Tool in Reducing Project Timeline

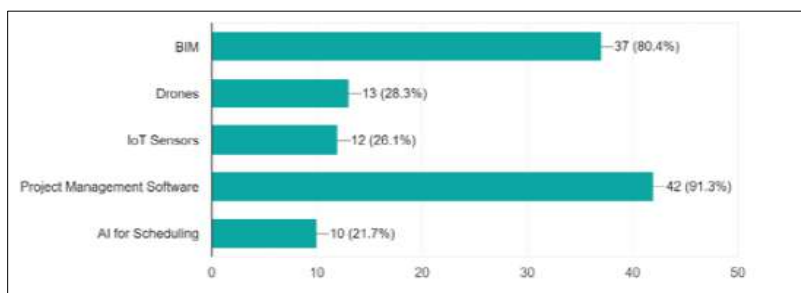
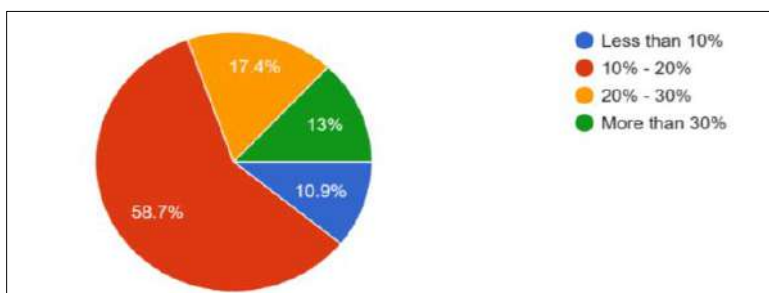


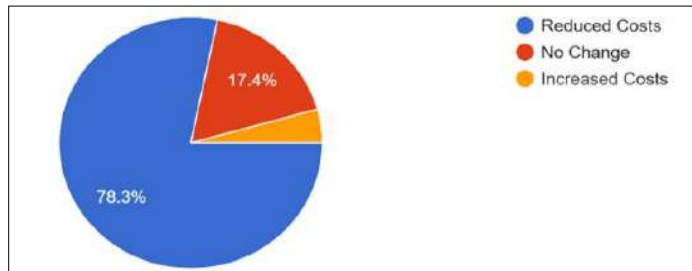
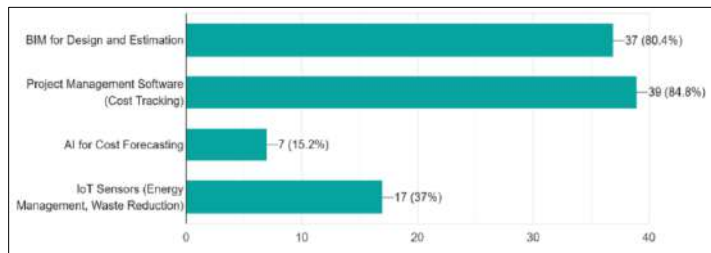
Figure 3: Percentage Time Saved in Projects due to Digitalization



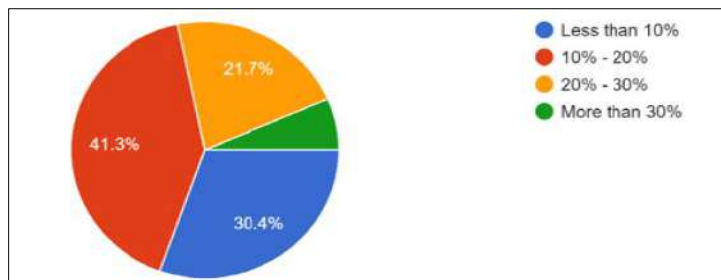
In Figure 2, Project management software and BIM is the most effective tools used in the construction industry to reduce the project timeline with 91.3% & 80.4% respectively

In Figure 3, Over 58.7% experienced 10-20% time reductions in their projects due to digitalization. 17.4% experienced 20-30% time reductions in their projects due to digitalization.

In Figure 4, Over 78.3% out of 100% respondents have reported that the use of digital tools have reduced the construction costs

Figure 4: Digitalization's Impact on Cost**Figure 5: Most Effective Digital Tool in Reducing Project Cost**

Project management software and BIM is the most effective tools used in the construction industry to reduce the project timeline with 84.8% & 80.4% respectively. Also, 37% respondents reported that IoT is also used to reduce project cost by reducing wastes and managing energy efficiently (Figure 5).

Figure 6: Percentage Cost Saved in Projects due to Digitalization

Over 41.3% experienced 10-20% cost reductions in their projects due to digitalization. 21.7% experienced 20-30% time reductions in their projects due to digitalization. 30.4% experienced less than 10% cost reductions due to digitalisation (Figure 6).

Figure 7: Digitalization’s Impact on Quality

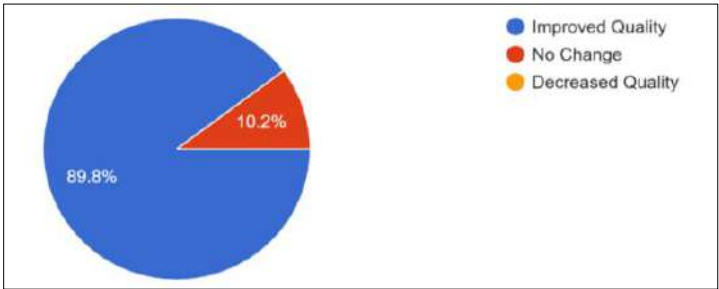


Figure 8: Most Effective Digital Tool in Enhancing Quality

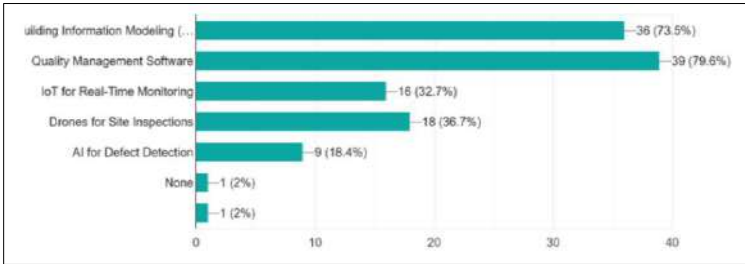
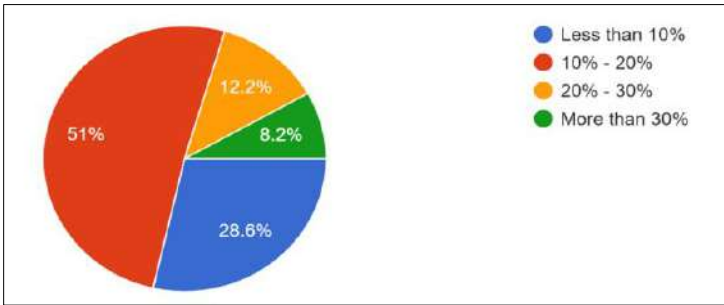
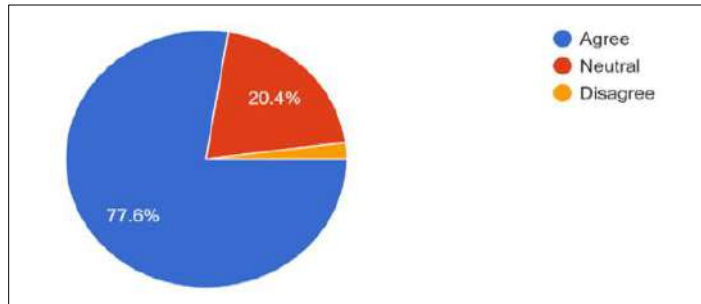


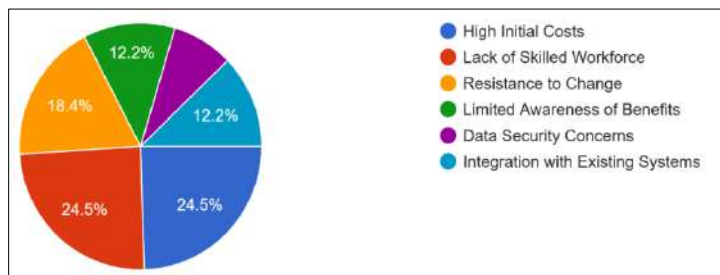
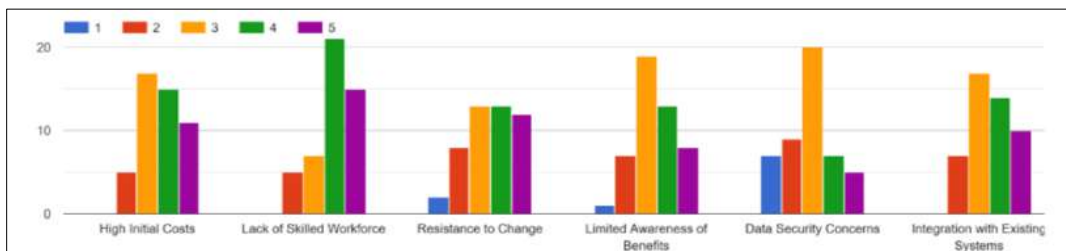
Figure 9: Rate of Reduction of defects Because of Digitalization



In Figure 7, From the response given by the sources, it is clear that 89.8% respondents out of 100% have said that digitalization has improved the overall project quality. Quality management software and BIM is the most effective tools used in the construction industry to improve the project quality with 79.6% & 73.5% respectively (Figure 8). Also, respondents reported that IoT (32.7%) & Drones (36.7%) is used to improve project quality by real time monitoring and site inspections.

Figure 10: Agreeableness on Improved Quality Standards due to Digitalization

In Figure 9, Over 51% experienced 10-20% defects reductions and quality improved in their projects due to digitalization. 12.2% experienced 20-30% defects reductions and quality improved in their projects due to digitalization. 28.6% experienced less than 10% defects reductions and quality improved due to digitalisation. 77.6% respondents have agreed that use of digital tools and digitalization in the construction industry has helped in meeting the quality standards more effectively (Figure 10).

Figure 11: Challenges Faced While Adopting Digital Technologies**Figure 12: Significance of Each Challenge**

In Figure 11, High initial costs for implementation: 24.5% of respondents. Lack of skilled manpower necessary to implement new technology: 24.5% of respondents. Opposition to

change: 18.4% of those surveyed. Limited awareness and integration with current systems: 12.2% for each factor. It is clear from the respondents that lack of labour resources is the most significant challenge with more than 20% respondents voting a scale of 4 and 15% respondents voting a scale of 5, followed by data security concerns, limited awareness of benefits, high initial concerns and finally integration with existing concerns.

5.0 Conclusion

In conclusion, digitization has enormous potential to improve project quality and optimize the Project Management Triangle, which consists of scope, cost, and time. BIM-Building information modelling, IOT-Internet of things, AI-Artificial intelligence and project management software are examples of cutting-edge digital solutions that construction companies can use to increase productivity, sustainability, and competitiveness. According to survey results, these technologies have proven effective in streamlining workflows, cutting project timeframes, and lowering costs; more than 90% of respondents reported shorter timelines, and almost 80% reported cost reductions.

Further establishing its position as a transformational force in the construction sector, digitalization has also greatly improved project quality, as seen by a dramatic decrease in defect rates and improved adherence to quality standards. With the insights gained from this study, stakeholders can more effectively navigate the challenges of digital transformation. By understanding and leveraging the full potential of digital technology, they can drive the industry toward a more resilient and innovative future. As the world becomes increasingly digitally connected, embracing digitalization is not only a strategic advantage but also essential for long-term success. This approach ensures that construction companies remain competitive and can deliver high-quality projects efficiently and sustainably.

References

- Begić, H., Galić, M., & Dolaček-Alduk, Z. (2022). Digitalization and automation in construction project's life-cycle: A review. *Journal of Information Technology in Construction (ITcon)*, 27, 441–460. <https://doi.org/10.36680/j.itcon.2022.021>
- Cinquepalmi, F., Paris, S., Pennacchia, E., & Tiburcio, V. A. (2023). Efficiency and sustainability: The role of digitization in re-inhabiting the existing building stock. *Energies*, 16(3613). <https://doi.org/10.3390/en16093613>
- Elghaish, F. A. K., Matarneh, S. T., Talebi, S., Kagioglou, M., Hosseini, M. R. & Abrishami, S. (2014). Towards digitalization in the construction industry with immersive and drone technologies: A critical literature review. *Smart and Sustainable Built Environment*, 3(3), 239–258. <https://doi.org/10.1108/SASBE-05-2014-0027>

Hwang, B.-G., Ngo, J., & Teo, J. Z. K. (2021). Challenges and strategies for the adoption of smart technologies in the construction industry: The case of Singapore. *Journal of Construction Engineering and Management*, 147(6). [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0002035](https://doi.org/10.1061/(ASCE)CO.1943-7862.0002035)

Kankhva, V., Andryunina, Y., Belyaeva, S., & Sonin, Y. (2021). Construction in the digital economy: Prospects and areas of transformation. *E3S Web of Conferences*, 244, 05008. <https://doi.org/10.1051/e3sconf/202124405008>

Koscheyev, V., Rapgof, V., & Vinogradova, V. (2018). Digital transformation of construction organizations. *IOP Conference Series: Materials Science and Engineering*, 463, 042092. <https://doi.org/10.1088/1757-899X/463/4/042092>

Kudryavtseva, V. A., & Vasileva, N. V. (2021). Digitalization as the basis for the construction industry development. *IOP Conference Series: Earth and Environmental Science*, 751, 012100. <https://doi.org/10.1088/1755-1315/751/1/012100>

Liu, Z., Ding, R., Gong, Z., & Ejohwomu, O. (2023). Fostering digitalization of construction projects through integration: A conceptual project governance model. *Buildings*, 13(825). <https://doi.org/10.3390/buildings13040825>

Mesias, A., Vasquez, R., Rodriguez, S., & Ramirez, H. (2020). Implementation of a mobile digital tool in the quality area to optimize the process of observation management in residential buildings. In *Hemispheric Cooperation for Competitiveness and Prosperity on a Knowledge-Based Economy* (Virtual Conference, July 27–31, 2020).

Musarat, M. A., Sadiq, A., Alaloul, W. S., & Abdul Wahab, M. M. (2023). A systematic review on enhancement in quality of life through digitalization in the construction industry. *Sustainability*, 15(202). <https://doi.org/10.3390/su15010202>

Prebanić, K. R., & Vukomanović, M. (2021). Realizing the need for digital transformation of stakeholder management: A systematic review in the construction industry. *Sustainability*, 13(12690). <https://doi.org/10.3390/su132212690>

Vladimirova, I., Kallaur, G., & Bareshenkova, K. (2018). Digital methods of real estate asset lifecycle management. *Baltic Journal of Real Estate Economics and Construction Management*, 6, 165–174. <https://doi.org/10.2478/bjreecm-2018-0013>

CHAPTER 128

Strengthening Local Revenue Systems: A Review of Property Tax Mechanisms in India

Shruti Vaishampayan¹ and Vedashree Phokmare²

ABSTRACT

Finance is the spine of any governing economy. For boosting the economic development of the country, finance and tax related impediments are highly essential which relates to the fiscal system of government and encompasses sectors like insurance, banking, economy, trades and business etc. Municipal finance in India has its roots merged with assessing and allocating its income through taxation. Property tax is the principal revenue contributor to the fiscal bodies in India and across the globe, but it has widespread gross undervaluation restraint. Since the antiquity of the application of duties, property taxes have been imposed. ULBs are limited in their ability to enact efficient property tax, especially the smaller municipalities and Nagar Palika's. Property tax rules are to be updated, ineffective exclusions would need to be removed, property registers are meant to be completed, more efficient valuation techniques should be implemented, and administration needs to be strengthened. This paper attempts to review and analyse the current system and its impact also if there is a need to create a model municipal law that will ease the creation of a far more robust property tax structure. The paper looks to highlight the previously unexplored aspects of municipal finance systems, particularly focusing on property tax and its alternatives. Often, this type of research is retrospective, driven by a lack of funding or challenges in data interpretation, which reveals new insights.

Keywords: Municipal finance; Income source; Revenue; Property tax; Finance; Urban local bodies; India.

1.0 Introduction

India, diversely brought together, with all the proactive components of systems, brings within the vital part of land and its probable nature of use. Investments being such a nature, are meant to secure a person 's wealth and increase it. Taxes reduce the investments by a margin (Oduor, 2015). Governments offer a range of facilities varying in education, health care, water, security, roads and social services to its locale. The funds used to provide these services come from the citizens in the form of Direct or Indirect taxes.

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Dependency on taxation, which profits the governing bodies, addresses the necessity of how it has grown and reformed in the past decades. Property tax regulations often grant extravagant exemptions for these governing systems.

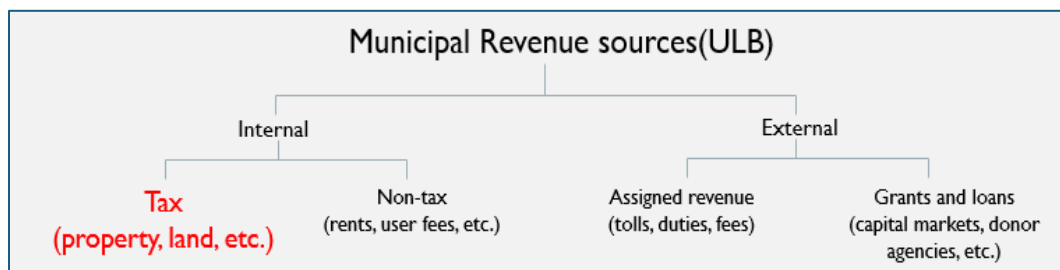
Table 1: Countries Contributing to GDP

Country	Income Level	2014	2015	2016	2017	2018
India	Lower Middle	0.01	0.01	0	0	0.15
Japan	High	1.96	1.86	1.92	1.91	1.9
Afghanistan	Low	0.12	0.12	0	0	0

Source: (OECD, 2019)

Countries are diversely contributing to GDP in essence to growth and successive participation which is associated with the Income level. India still slacks with a Lower Middle Income level category as compared to other regions with Japan contributing the highest and Afghanistan to the lowest. India has a total tax-GDP ratio of 15.5 % comprising Direct Taxes to Total Taxes ratio of only 37.7 %, and the highest marginal income tax rate at 30 percent. This leaves a lot to be unexplored, especially in terms of the progressivity and tax base of the system (Prakash, 2013).

Figure 1: Municipal Revenue Sources in ULB's in India



Source: Compiled by authors

Property Tax ascends as a vital source of revenue for the Indian government (Central and State), condensed around 6.7% of Gross Domestic Product (GDP) on the social infrastructure (like health, sanitation, education, and water) in comparison with 14% of GDP as an average for the OECD countries. To close the resource gap in ULBs' ability to raise money, a new method of property tax management has been deemed essential. Land, as a phenomenon, has and had gone through vital and governance changes from past till urbanization that is today. From Rural to Urban upbringing of social, economic and environmental factors describes the versatile strata of how land has evolved into many sub-categories to be dealt with. Nevertheless,

the potential of this parcel is very crucial to unfold with rates and uses to which it may constrain. Fiscal empowerment of the ULBs when approached upon in the context of the urbanization trends that India is faced with is no longer a matter of choice, but a necessity (Mathur, 2013).

However, fiscal dependencies come into picture as they must be administrated by statutory mechanisms. Built forms or properties on these land parcels are also managerial in the hands of such mechanisms in the form of property taxation. The finance of ULB's depend majorly by the contribution of property tax in India (England, 2013). The major aspect of property tax consists of its revenue generating potential because of its large and growing base (property values) (Badhopadhyay, 2013).

Property tax being the crucial source of governing and taxation benefits for ULB's for decades helps the system to upgrade and educate the revenue discrepancies. In fact, property taxes form an insignificant 0.2% of India's GDP. In contrast, the Organization for Economic Co-operation and Development (OECD) group, on average 1.1% of the group's GDP is contributed by property tax, which is six times more than India in terms of the amount total collected (Nair, 2018). Progressivity and optimization in tax rates, better service delivery and ratio of collection, better coverage, liveable standards and a more standardized but substantial property market are the vital factors contributing to excel performance in property tax collection and assessment.

1.1 Database

The study explains the current system, reviews and analysis of how property tax affects the exponential functioning of the country and its fiscal dependency, understanding its concepts by secondary data resources.

- *Global Property Tax Databases:* OECD Property Tax Database.
- *National Property Tax Databases in India:* Data from Ministry of Housing and Urban affairs (MoHUA).
- *Urban Local Bodies (ULB) Databases:* Property Tax Portal for various cities and Ready Reckoner Rates by State Governments.
- *Academic and Research Databases:* World Bank Data on Urban Development and Taxation, JSTOR, Google Scholar, and ResearchGate.
- *GIS and Mapping Databases:* Geographic Information Systems (GIS) Used by ULBs, National Remote Sensing Centre (NRSC), Digital India Land Records Modernization Program (DILRMP).

1.2 Schemes and provisions under property tax assessment

India's property tax framework involves policies, acts, and schemes developed primarily by municipal bodies, state governments, and central government regulations. Here's an overview of key elements influencing property tax:

1.2.1 Constitutional framework

- Article 243X falls under Part IX A of Indian Constitution: Empowers State Legislatures to authorize municipalities to levy, collect, and appropriate taxes, including property taxes.
- 74th Constitutional Amendment Act 1992: Decentralized governance, giving Urban Local Bodies (ULBs) autonomy to impose property taxes.

Under JnNURM, for the first time, digitization of properties, property tax calculations and its database using Geographic Information System (GIS) were automated. The participating cities had signed a Memorandum of Understanding (MoU) which made them liable to the following:

- To digitize properties using GIS which will lead to proper mapping.
- To promote and inculcate Self-Assessment System (SAS).
- To collect a minimum of 85% of the demand for property tax collection.

1.3 Effects of schemes and policies

Schemes like the Self-Assessment Scheme and GST Amnesty Scheme for property taxes have relieved the burden on the property owners and made it easier for voluntary compliance, which has shown better compliance rates and fewer defaults (LaPoint, 2022). Huge projects in urbanization are supported through increased property tax revenue through various missions like AMRUT and the Smart City Mission for ease in transportation, sanitation, and other basic amenities in cities. Promotion of Legally Compliant Property Deals Owners of properties are promoted to have legally compliant property deals with the help of automated record books and self-assessment.

This creates positive incentives for legal property markets (Awasthi, 2020). ULBs Become More Accountable in Operations The online tax payment system hinders corruption since, once this system is enforced, intermediaries are eliminated while practicing their work through the computers, thus making city municipalities more accountable. Optimized Taxation Policies regarding property valuation strengthen the system from time to time so that property owners with higher value assets contribute appropriately to a more balanced taxation system (Prakash, 2013). Slow Change in Smaller Townships: Reforms like digital and GIS-based reforms benefit larger cities while smaller townships often do not have budgets or available resources in circumstances where uniform change would otherwise be possible (Khan, 2021).

Table 2: Regimes in Property Tax

Entity	Regimes for Property tax
Property Tax Acts at State Level	Each state has its own Property Tax Act, which provides the legal framework for property tax collection by municipalities and ULBs. For example, Maharashtra has the Maharashtra Municipal Corporations Act, 1949, which governs property tax collection in its municipalities. Other states, such as Tamil Nadu, Karnataka, and West Bengal, have their respective acts (e.g., the Tamil Nadu ULB's Act) that govern property taxation.

Municipal Finance Code	States have introduced a Municipal Finance Code or similar provisions, which standardize the revenue sources, including property taxes, for ULBs.
Self-Assessment Scheme (SAS) 2001	SAS is a common method especially in states of Karnataka and Maharashtra. It allows property owners to self-assess and calculate their property tax based on pre-defined parameters such as property location, built-up area, usage (residential or commercial), and age. Bengaluru was one of the first cities to implement this scheme, which streamlined property tax calculations and improved compliance.
Smart City Mission (SCM) and AMRUT Scheme 2015	Launched by the central government, these schemes incentivize ULBs to improve their property tax collection through digitalization and enhanced property tax bases. They aim to increase transparency, reduce evasion, and fund urban infrastructure projects.
Model Municipal Law 2003	The Model Municipal Law introduced by MoHUA to standardize urban governance across the country. It includes recommendations for property tax collection and valuation to make the process uniform across states.
GST Exclusion on Property Tax 2017	Under the Goods and Services Tax (GST) regime, property taxes are still outside the purview of GST as they are direct tax. This ensures that property tax is solely a major contribution to revenue sources for municipal governments.
Land Revenue Act 1966	States like Uttar Pradesh and Madhya Pradesh have Land Revenue Acts that help regulate land records, a critical factor in naming property for taxation.
The Indian Stamp Act, 1899	Governs stamp duty on property transactions, indirectly influencing property taxation.
The Transfer of Property Act, 1882	Regulates property ownership transfers, forming the basis for property registration and valuation.
The Income Tax Act, 1961	Recognizes property as an asset and specifies tax implications for rental income and capital gains.
ULCRA 1976	Though repealed, ULCRA influenced property tax policies by assigning limitations on property ownership, thus affecting the tax rate and its base.

Source: Compiled by authors

1.3.1 State-specific property tax acts

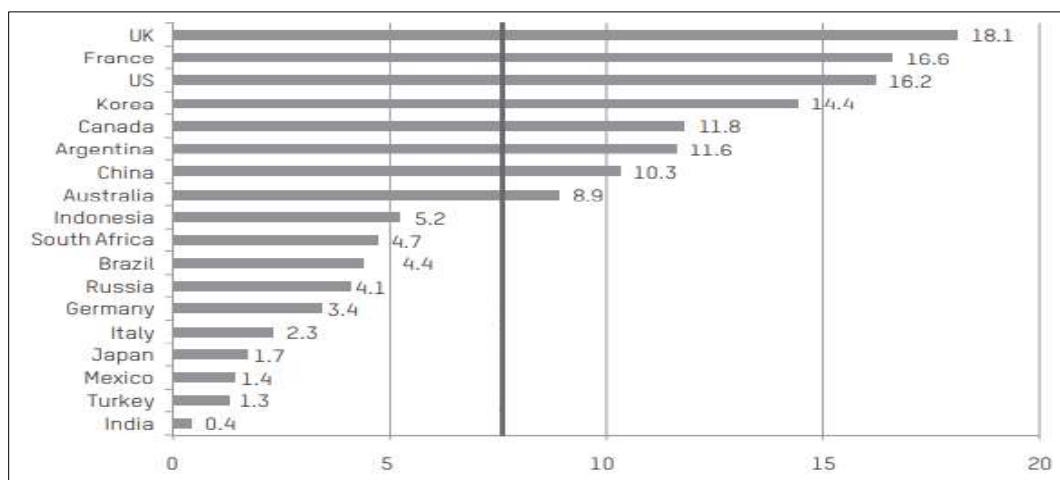
- *Maharashtra:*
 - Maharashtra Municipal Corporation Act, 1949: Governs property taxation in municipal corporations like Mumbai and Pune.
 - NAINA Act (Navi Mumbai Airport Influence Notified Area): Includes land pooling and valuation mechanisms affecting property tax.
- *Delhi:* Delhi Municipal Corporation Act, 1957: Specifies property tax regulations in the National Capital Territory.
- *Karnataka:* Karnataka Municipalities Act, 1964: Outlines property tax systems in the state, including Bengaluru's Unit Area Value Method.
- *Tamil Nadu:* Tamil Nadu District Municipalities Act, 1920: Guides property tax assessment for urban areas.
- *West Bengal:* West Bengal Municipal Act, 1993: Regulates property tax collection and valuation in the state.

1.4 Gaps in current property tax system

Historical experience highlights the significance of central government policies that encourage local public bodies to adopt these measures, such as providing model documents and offering financial incentives to those local bodies that implement value-capturing policies (UN-Habitat, 2011). In several OECD countries, including Canada, the United Kingdom, and the United States, property tax revenues make up to only approximately 3% of their GDP. The 74th Constitutional Amendment, enacted in 1992, set up ULB's as the third tier of government. With severe constraints, financing services and infrastructure in urban settlements adequately possesses a wealthy obstacle. The deficit in infrastructure for urban areas is enormous and expanding. Recent analysis by the Planning Commission shows that 34% of urban households do not have water taps inside the premises (Collier, 2018). However, 26% of them do not have toilets. Further, 70% of waste receives no treatment before disposal, and untreated sewage and unregulated discharge from industries are a major source of water pollution. Altogether, as late as 2004, only 63 percent of the population living in towns had access to sewerage and sanitation facilities, according to the draft Eleventh Five Year Plan document. Urban transport problems are also much the same (Wadhwa, 1989). The public transportation is congested and inefficient.

Again, housing is a problem since 21% of the urban population lives in slums (Bird, 2010). To make the reforms come to reality, efforts should be made like updating property tax laws, removing exemptions that serve very little policy purpose, finalizing property titling, and introducing valuation methods that are more realistic besides strengthening administration (Rao, 2009). One important question that would be asked about political acceptability of property tax is whether the former is fair and equitable. Normally, fairness would relate to whether burdens of taxation fell on people based on their capacity to pay (Kim, 2003).

Figure 2: Property Tax Revenue Percentage Across G20 Countries



Source: Compiled by authors

On the other hand, equality would relate to commensurate properties being subjected to similar rates of property taxation. In fact, developing countries don't often do incidence studies to test the former pattern of equity, nor do they do self-assessment studies to test the latter. It is left to speculate about whether the general patterns are progressive or regressive, and about sales-assessment inequities (McCluskey, 2013). Administrative factors fall into two groups: tax base administration factors which include coverage and valuation and those related to treasury functions such as billing, collection, and enforcement. There exists interaction between the policy and administrative factors to influence property tax mobilization in terms of efficiency and equity. Policy factors mainly revolve around the structure of the tax base as well as the tax rates which determine the legal tax capacity. The administrative factors help realize tax capacity through improvement in tax base coverage, valuation and collection ratios.

2.0 Literature Review

Urbanization has reached a figure of merely 33% in India to date as depicted by the World Bank, with a population of about 429 million, running into figures greater than other countries. Though positive developments have been shown, rapid urbanization also comes with a host of challenges (Bandyopadhyay, 2013). This will cause an increase in private vehicle use, crowded roads, an increase in pollution, public safety issues, and finally, increased household spending in an already growing India. A growing population is putting pressure on our cities, which are already struggling with their infrastructure and services (Roy, 1968). The authorities of the Indian cities should plan for urbanization and growth because the current infrastructure cannot support the existing population including financial reforms for sustaining the urban phenomenon which eventually affects the revenue generation as well as the expenditure model of the municipalities. The capital generated and distributed deliberately coincides with the tax paid by the users in the country.

The empirical evidence on the impact of tax structures on economic growth is mixed in India. The 1991 report of the Tax Reform Committee was considered one of the most productive policy recommendations in the recent decade (Gaur, 2020) stating that the global Property Tax Services market size is valued at USD 3241.2 million in 2023 (Singh, 2022). Alone, it is said that the property Tax is the highest, raising a fifth or around 20% of local revenues while the octroi forms a highest percentage as far as Indian Local municipalities collection goes for revenues and cuts it through as between 20 %and 50% to get revenue from municipal corporation (Lyytikäinen., 2014). Despite the strong economic rationale for Property Tax, it often generates low revenue in many instances, primarily due to inadequate administration, ineffective tax policies, and deficiencies in the Land and Property Information System (Sarkar, 2001). The property tax base, which refers to the number of assessed properties subject to property tax, has remained limited in most Indian cities and has not seen significant growth over time. This stagnation is largely due to the slow pace at which municipal bodies in India identify

both uncovered and new properties and conduct regular assessments, especially in peripheral areas. Additionally, municipal bodies often do not revise property tax rates regularly, as this process requires approval from the council of elected representatives, which can be challenging due to political resistance, as well as the consent of the State government. There are also organizational inefficiencies within municipal governments related to timely property assessments, tax calculations, issuing tax demand notices to property owners, collecting taxes at various outlets, addressing tax arrears, and establishing channels for grievance and dispute resolution.

2.1 Elements used in property tax assessment

Governments must deal with different dimensions of property taxes like policy design – choosing what must be included or excluded from the tax base, appraisal of properties, and tax levies on properties under various tax regimes administering the property tax system although the aspect is different in unusual places.

Table 3: Tax Base used for Calculating Property Tax

Tax base	Definition	Measure used	Examples of countries
Market/Capital value	Price that would be agreed between a willing buyer and seller	Comparable sales, depreciated cost, or income method	Australia, Canada, Indonesia, Japan, United States, South Africa, India
Site value	Value which would be calculated based on adjacent property prices	Comparable sales subtracting improvements value from total property value	Jamaica, Kenya, New Zealand
Rental value	Value in current use	Net rental income	France, Morocco, parts of India
Unit value	Sales price as per the unit of the property	Square meters/feet of land and building area, adjusted	Armenia, Czech Republic, Israel, Poland, Russia, Slovakia Estonia, Latvia
Self-assessment	Combination of area and market value	Determined by owner of property	Peru, Turkey
Transitional or mixed systems	Combination of area and market value	Market-priced zones for land or land and buildings	Estonia, Latvia

Source: Compiled by authors

Below are the steps used to rectify fiscal property tax system in India:

- *Determining the tax base:* Tax base is correlated with the rate of tax which will decide the future percentage of change in property value tax.
- *Assessing properties:* Assessment of properties, registered and non-registered with the ground truthing of data available and collection of such beliefs in the formatting method.

- *Conducting analysis:* Analysis of the data received to rectify if it is suitable for further reform, or regenerating and developing surveys for lost or irrelevant data.
- *Setting the tax rate:* Decorating the tax rate based on various above factors which will lead to an equitable, transparent and accessible tax regime.
- *Running the system:* Implementation and Monitoring of the orientation passed based on studies and new agenda for uploading the system.

Table 4: Departments and their Functions Related to Property Tax

Departments	Year	Functions
Department of Revenue and Forests	mid 19 century	The primary department responsible for the land and property records in Maharashtra. It oversees land management, property tax records, and administrative process.
The Land Records Department	1880	Under the Department of Revenue, this department handles detailed land records and its maintenance, including cadastral maps, property ownership details, and mutation records. It runs the online platform <i>Bhulekh</i> (also known as <i>Satbara Utara</i> , the 7/12 extract) for public access to land records (Virkar, 2013).
Real Estate Regulatory Authority (RERA)	2016	The regulatory body oversees and ensures transparency in real estate property transactions. It supports a database of registered real estate projects and agents, helping property buyers verify project details and legal clearances for each state.
Municipal Corporations, Councils and Urban Local bodies	1687	Municipal bodies like the Brihanmumbai Municipal Corporation (BMC) in Mumbai and Pune Municipal Corporation (PMC) manage property tax records, building permits, and property assessments within urban areas.
Maharashtra Registration and Stamps Department	1864	The department manages property registration, ensuring legal ownership transfers, and supporting sale deed records. It also collects stamp duty, crucial for land and property transactions.
City Survey Offices	early 20th century	Found in various cities, these offices update property boundaries and ownership records within urban areas, often conducting surveys and updating maps.
National Informatics Centre (NIC)	1976	NIC provides technological support and supports online portals like <i>MahaOnline</i> and <i>e-Mojani</i> for property-related services, facilitating access to digital land records, map-based searches, and geographic information systems (GIS).
Revenue Courts	19 th century	These courts address disputes related to land ownership, tenancy, and other property matters, ensuring the legal integrity of land records and resolving conflicts over ownership and boundaries (Abhay Pethe, 2005).

Source: Compiled by authors

Exemptions and deductions in property tax: Property tax exemptions and deductions reduce the taxable value of a property, lowering the overall tax liability for eligible property

owners. These benefits vary by jurisdiction but typically aim to support homeowners, specific groups (e.g., veterans, seniors), or encourage land uses (e.g., agriculture, conservation). These systems are the efficient and effective strata of strategies through which property tax has come into play, answering and accountable to the government and its citizens about the performance and diligence of the same. Below are the two vital systems which help govern the judicial epitome of taxation:

- The Land Information System.
- The Property Tax Computation System.

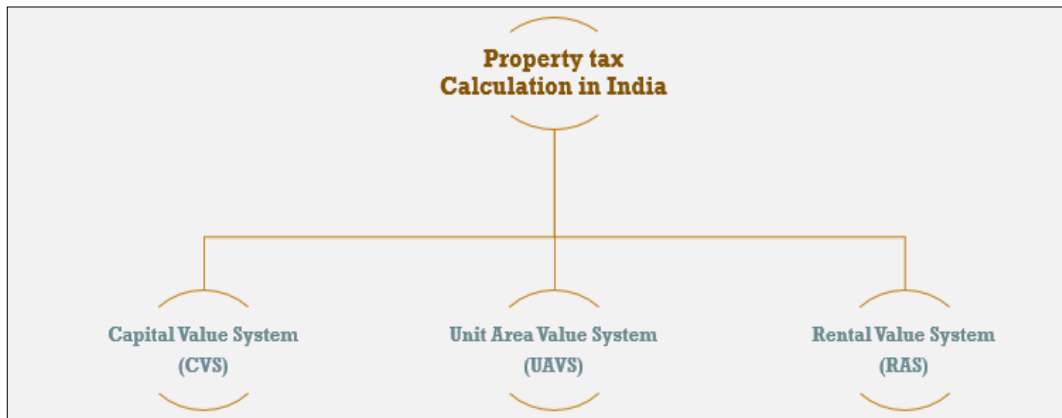
2.2 The land information system

The Land Information System relates to the statutory composition by which property tax is levied in India. These frameworks help in negotiating and build upon the regulation to identify, pay, collect and revise the former systemic platform.

2.3 The property tax computation system

The Property tax computation system helps in verification of the levied tax and its method used by various states in the country. The system is technically adjacent with the building permissions and regulations depending upon the location of the property and its confined uses.

Figure 3: Computation Systems of Property Tax in India



Source: Compiled by authors

Property tax structure: Property tax is calculated based on factors like property type, location, usage (residential, commercial, or industrial), area, age of property, and its built-up area (Deichmann, 2012).

- *Annual rental value method:* The ARV Method calculates property tax based on the rental income a property would generate if it were rented out, regardless of whether it is rented or owner-occupied. This “notional rent” is an estimated figure set by the local municipality.
- *Capital value-based method:* The Capital Value-Based Method calculates property tax hinge on the market value of the property, as assessed by the local government or a valuation authority. This method considers the overall capital value of the property rather than rental income.
- *Unit area value method:* The UAV Method assesses property tax based on the built-up area of the property multiplied by a pre-determined value per unit area (e.g., per square foot), which varies by factors such as location of the property, property usage, and its age.

Each of these methods is the basis of calculating any property tax value of a zone or an area, depending on the system of that area (Ahuja, 2018).

Assessment and Calculation: Maximum states or cities in India currently implements Capital Value-Based Assessment System for evaluation, where the tax amount is calculated as a percentage of the property’s capital value (Awasthi, 2020). The capital value is derived based on government-determined Ready Reckoner (RR) rates, which represent the market value of the property as per location and type - A general formula for calculating property tax (though exact percentages vary by municipality) is:

$$\text{Property Tax} = \text{Capital Value} \times \text{Rate of Tax}$$

Where, Capital Value = Built-up area of the property (sq. ft. /sq.m.) $\times$ Ready Reckoner Rate (area-wise) $\times$ Construction type factor (based on building quality and usage).

Note: Rate of Tax varies depending on the municipality and property usage.

Ready Reckoner Rates: The RR rates are updated annually and published by the state government, reflecting the approximate market values of properties across different areas. These rates are crucial in figuring out the capital value of properties, which in turn impacts property taxes. These are also called Annual Statement of Rates or Circle rate.

Digitalization of property tax system: Online Payment Portals, Property Tax Apps (PMC Care of Pune Municipal corporation), GIS and Digital Mapping, Unique Property Identification Numbers (PID), Digital Grievance Redressal, Integrated systems and Single window clearance. The use of online services helps reduce errors, improve transparency, and increase collection efficiency (Orville F. Grimes, 2001).

Property tax is a variable separated by location, vicinity, land use, land-cover, character and financial stability. Both levels of government, Central and State in India have seen changes in the economic structure. Recent studies write down that alterations in the tax structure have significant implications. The performance of growth is influenced by work-leisure behaviour, investment decisions, and overall productivity which leads into the accordance of renaissance. (Gaur, 2020). Cities in India vary on different levels of implementation of reforms in the valuation of properties starting from purely Annual Rental Value and Value based on unit area characteristics. Quite a few studies may be referred to which have been based on the discussion

of what can be best used. Numerous reform agendas also recommend changing over to unit area characteristic values. A review of property tax reforms by NIUA, 2010 based on 10 selected cities viz. Ahmedabad, Bangalore, Bhubaneswar, Chennai, Hyderabad, Indore, Kolkata, Ludhiana, Patna and Pune reveals that cities like Patna, Indore, Chennai, Hyderabad, Bangalore and Ahmedabad have already moved to the “unit area assessment system” while Kolkata and Bhubaneswar are yet to implement the unit area system although the municipal laws have been amended. Patna and Ludhiana have followed the ARV method. In Bangalore, a sharp increase in the collection of property taxes can be noticed after adopting the unit area-based approach. In Ahmedabad, technical input has been helpful by using the GIS system. Thus, the maximum number of properties assessed per 1,000 population has been there in Ahmedabad.

2.4 Impediments in implementing property tax

The recent reforms in property tax collection, particularly through acts such as the Self-Assessment Scheme (SAS) and the initiatives under the Smart City Mission, have significantly enhanced municipal revenue. These reforms have made the process of paying property tax more straightforward and transparent for citizens, thereby encouraging compliance (Afonso, 2015). Coupled with better urban infrastructure funding, ULB’s now have the financial means to enhance public services and maintain infrastructure, directly helping the quality and standard of life in peri urban and urban areas. Additionally, policies promoting standardization, such as the Model Municipal Law, have harmonized property tax rates and collection methods across states, streamlining the entire taxation process (Krupa, 2013). Furthermore, by empowering citizens through self-calculation of taxes and the facilitation of online payment portals, transparency is significantly improved, reducing tax evasion, and increasing accountability.

Embracing digital governance initiatives not only streamlines tax assessment and collection but also minimizes reliance on intermediaries, making property tax data more accessible to the public. Overall, these concerted efforts are paving the way for a more efficient and fair tax system that empowers both citizens and local government bodies (Knebelmann, 2022). Notably, public resistance to property tax increases remains a prominent barrier, particularly in regions where revisions are irregular, stalling the ability of ULBs to adjust rates in line with current market realities (Turley, 2022). Compounding these challenges is the shortage of trained personnel equipped to manage digital assessments and GIS mapping, which is essential for accurate property valuation and implementation of digital reforms. Finally, insufficient enforcement mechanisms leave many high-value properties vulnerable to non-compliance, especially those owned by influential individuals, ultimately resulting in arrears that undermine the effectiveness of the tax system.

3.0 Results

While ongoing reforms are beneficial, structural challenges like better valuation, increased tax buoyancy, and building taxpayer confidence need to be addressed to ensure

sustainability in property tax performance. The findings suggest that while property tax can stimulate housing development, the unintended consequences of rent control may negate some of the benefits (Bird E. S., 2015). Municipal financial data enhances decision-making of public resources by providing efficiency, accountability and transparency in the managerial domain. This data enables municipalities to develop more responsive budgets and improve public services through better resource allocation. Inconsistent property valuation practices lead to disparities. Implementing a uniform assessment method could help standardize valuations, yet some areas are slow to adopt these systems (V, 2018).

Studies suggest that when taxpayers see tangible improvements in local services, their compliance increases. Providing visible benefits and clear communication can boost tax morale (Jha, 2015). Property taxes are often regressive in practice, affecting lower-income property owners more heavily, especially when rates or penalties are high. For example, higher rates for luxury properties and lower rates for economically weaker sections can provide relief to lower-income groups while supporting revenue.

4.0 Conclusion and Recommendations

Study concludes that while urban land taxes can serve important purposes, their effectiveness is enhanced when employed as part of a comprehensive urban planning framework. Well-structured tax on property regimes can become a for urban planners to curb sprawl and promote sustainable urban growth. The implementation of GIS-based property tax assessments in India can lead to more efficient, transparent, and accurate tax collection. It reduces manual errors, speeds up tax evaluations, and ensures a fair assessment based on property location and characteristics.

GIS analysis tools would be used to assess properties based on their location, size, and value. The methods may include spatial analysis techniques such as buffering, overlay, and network analysis to ensure exact property assessments. Data can be collected through a combination of image analysis and door-to-door ground surveys.

The geo-database will be developed using various attributes including the type of property, its size, and other relevant factors for taxation purposes. This method will ensure a comprehensive, correct collection of property information. These implications bolster the argument that property law, in relation to urban space and housing development, focuses on obligations as much as it does on rights. This includes enhancing enforcement mechanisms, motivating ULB's to strengthen their property tax bases, and fostering citizen engagement to boost compliance and satisfaction. By adopting a combined approach to property rights and responsibilities through land readjustment regulations, we can better manage initiatives undertaken by landowners and commercial investors, ensuring they play a more significant role in developing public infrastructure. Implementing differential tax rates based on property size, usage, or location could improve equity. This approach may also address some of the stagnation

issues that arise when trying to develop new housing, a challenge that persists in many countries beyond just India.

References

Afonso, W. (2015). *The challenge of transparency in taxation*. Mercatus Center at George Mason University.

Ahuja, A. (2018). *Property tax in India*. SSRN. <https://ssrn.com/abstract=3271247>

Awasthi, R. (2020). *Property taxation in India*. The International Bank for Reconstruction and Development / The World Bank.

Bandyopadhyay, S. (2013). *Property tax reforms in India*.

Bandyopadhyay, S. (2013). *Property tax reforms in India: A comparison of Delhi and Bangalore*. ICEPP Working Papers.

Bird, R. M., & Ghosh, M. (2010). *Urban governance and finance in India*. National Institute of Public Finance and Policy.

Bird, R. M., & Slack, E. (2015). *How to reform the property tax: Lessons from around the world*. IMFG Papers on Municipal Finance and Governance.

Collier, P., & Glaeser, E. (2018). *Land and property taxes for municipal finance*. International Growth Centre.

Deichmann, U., Vaziak, M., & Somanathan, E. (2012). *Fiscal and distributional implications of property tax reforms in Indian cities*. Economic Research Publications.

England, R. W., & Quigley, M. J. (2013). Impacts of property taxation on residential real estate development. *Journal of Housing Economics*, 22(1), 45–59. <https://doi.org/10.1016/j.jhe.2012.12.001>

Gaur, Y. N. (2020). Tax structure and economic growth: A study on selected Indian cities. *Journal of Economic Structures*, 9, Article 35. <https://doi.org/10.1186/s40008-020-00209-7>

Grimes, O. F., Jr. (2001). How effective are urban land taxes in achieving policy objectives? *IMF and World Bank Publications*.

Jha, R. M. (2015). Reforming the property tax. *The Urban World - Quarterly Publication of Regional Centre for Urban and Rural Studies*.

Khan, M. I. (2021). *Property tax mapping and assessment using GIS: Case study of Rawalpindi City* [Master's thesis, Lund University].

Kim, J., & Kwon, H. (2003). Urban sprawl and the property tax. *International Tax and Public Finance*, 10(1), 5–23. <https://doi.org/10.1023/A:1021223403805>

Knebelmann, J. (2022). *Digitalisation of property taxation in developing countries: Recent advances and remaining challenges*. Overseas Development Institute (ODI).

Krupa, O. (2013). Housing crisis and vertical equity of the property tax in a market value based assessment system. *Public Finance Review*, 41(6), 790–813.

LaPoint, C. (2022). *Property tax sales, private capital, and gentrification in the U.S.* SSRN. <https://ssrn.com/abstract=4270942>

Löffler, M., & Stöwhase, S. (2021). *Welfare effects of property taxation*. IZA – Institute of Labor Economics.

Lyytikäinen, T. (2014). *Studies of effects of property taxation, rent control, and housing allowances*. Research Papers in Economics.

Mathur, O. P. (2013). *Approach to the finances of municipalities*. Ministry of Urban Development and National Institute of Urban Affairs (NIUA).

McCluskey, W., & Bell, R. (2013). Strengthening property taxation in developing Asia. In *Property tax in Asia: Policy and practice* (pp. 3–22). Lincoln Institute of Land Policy.

Nair, R. (2018). *Municipal finance*. JLL.

Nallathiga, R. (2021). *Summary of “Reforming Property Taxation: The Case of Municipal Corporation of Greater Mumbai”*. Indian Institute of Public Administration (IIPA).

Oduor, W. O. (2015). *The effect of property tax on residential rental market* [Master's thesis, Department of Real Estate & Property Management, Kenya].

OECD. (2019). *Organization of Economic Co-operation and Development*. OECD Publishing.

- Pethe, A., & Lalvani, M. (2005). *A comparative study of municipal finances in Maharashtra: Patterns, problems and prospects*. Department of Economics, University of Mumbai.
- Prakash, P. (2013). *Property taxes across G20 countries*. Oxfam India and Centre for Budget and Governance Accountability.
- Rao, S. B. (2009). *Fiscal health of selected Indian cities*. National Institute of Public Finance and Policy.
- Roy, T. K. (1968). A land speculation model: The role of the property tax as a constraint to urban sprawl. *Journal of Regional Science*, 8(2), 183–192.
- Sarkar, N. (2001). Constraints to local government revenue generation through property tax. *International Development Regional Housing and Urban Development*, Philadelphia.
- Singh, A. (2022). *Designing geographic information system based property tax*.
- Slack, E., & Bird, R. M. (2014). *The political economy of property tax reform* (OECD Working Papers on Fiscal Federalism No. 18). OECD Publishing.
- Turley, G. (2022). Designing and implementing a local residential property tax from scratch: Lessons from the Republic of Ireland. *Commonwealth Journal of Local Governance*, 2022(25), 31–48. <https://doi.org/10.5130/cjlg.vi25.7842>
- UN-Habitat. (2011). *Innovative land and property taxation*. United Nations Human Settlements Programme.
- V, P. (2018). An incidence of property tax – A case study of effect on real estate sector in Mysore City. *International Journal of Management, IT and Engineering (IAEME)*, 8(7), 70–81.
- Virkar, S. (2013). What's in a game? The politics of shaping property tax administration in Bangalore City, India. In *Gamification for Human Factors Integration* (pp. 167–186). Springer.
- Wadhwa, K., & Patel, K. (1989). *Revamping the structure of property taxes*. Ministry of Urban Development (MoUD).

CHAPTER 129

Study of Traffic Management at Road Intersection in Pune

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Abhijit Deepak Karande¹ and Nagarjuna Pilaka²*

ABSTRACT

Pune, is a rapidly growing tier-two city in India, faces severe traffic congestion due to its booming population and inadequate road infrastructure. With a projected population of 12.5 million in 2024 and over 4.3 million registered vehicles, the city's roads struggle to meet demand. A 2023 report ranked Pune as the second most congested city in India and seventh globally. While the city has extensive road networks, poorly planned intersections create bottlenecks. Pedestrians face additional challenges, with limited crossing times at signals. The study focuses on addressing the traffic congestion challenges at intersections in Pune, a rapidly growing city in India. The research identifies intersections as critical points contributing to urban traffic bottlenecks and aims to assess their conditions comprehensively. The city's road network, despite its extensive reach, faces limitations due to poor intersection designs and lack of adherence to Indian Road Congress (IRC) standards. Through both qualitative and quantitative methodologies, the study evaluates various intersections across Pune, identifying key deficiencies such as inadequate lane markings, absence of stop lines, and non-engineered junctions. Drawing insights from literature and practical observations, the research emphasizes improving intersection management. Recommendations include implementing rational designs that prioritize pedestrian and cyclist safety, optimizing traffic signals, and integrating channelization measures to streamline vehicle flow. Additionally, the study suggests leveraging modern technologies like intelligent transportation systems to enhance traffic efficiency.

Keywords: Traffic congestion; Bottlenecks; Indian standards and research; Poor intersection design; Indian road congress (IRC); Qualitative and quantitative methodology.

1.0 Introduction

Urbanization and population growth have significantly impacted traffic conditions in cities worldwide, and Pune, a rapidly expanding tier-two city in India, is no exception. With increasing vehicle ownership and inadequate road infrastructure, traffic congestion has become a critical issue, particularly at intersections.

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These intersections serve as crucial nodes in the road network, and inefficient traffic management at these points often results in delays, road safety hazards, and poor commuting experience. The current road infrastructure struggles to accommodate the growing number of vehicles, leading to congestion, increased travel time, and higher fuel consumption. Addressing these issues requires a systematic approach to traffic management, focusing on improving intersection design, optimizing signal coordination, and integrating intelligent traffic control measures. Pune is the ninth most populated city in India and serves as a major educational, industrial, and IT hub.

As the city continues to expand, the demand for transportation increases, putting immense pressure on its existing road network. According to recent traffic studies, Pune ranks among the most congested cities in India, with several key intersections experiencing severe traffic delays. The lack of efficient traffic signal coordination, improper lane markings, absence of pedestrian crossings, and encroachments further contribute to intersection inefficiencies. Pedestrians often struggle to crossroads safely due to short signal durations, while non-motorized transport users face challenges due to inadequate infrastructure. These issues highlight the urgent need for a comprehensive study to assess and improve intersection management strategies in Pune.

This research aims to analyze traffic flow at selected roadway intersections in Pune, identifying key congestion points and assessing their compliance with Indian Roads Congress (IRC) guidelines. The study involves data collection on vehicle movement, pedestrian flow, and intersection design using field surveys, video analysis, and other observational techniques. By evaluating these parameters, the research seeks to propose effective solutions, such as signal optimization, geometric modifications, and implementation of intelligent traffic management systems (ITMS), to enhance overall traffic efficiency. With cities like Pune continuing to expand, sustainable traffic management solutions are essential for ensuring smooth urban mobility. This study contributes to the growing body of research aimed at developing data-driven, technology-integrated, and sustainable traffic management strategies. By adopting innovative approaches and adhering to best practices in urban planning, Pune can significantly enhance its transportation infrastructure and improve the overall commuting experience for residents and visitors alike.

2.0 Literature Review

Widianty & Hasyim (2023) examined intersection traffic management through simulation-based modeling, identifying alternative routing and congestion mitigation strategies. Similarly, Chen & Xu (2020) introduced a connected-vehicle system for managing non-signalized intersections. This system organizes vehicles into virtual platoons and employs distributed control mechanisms to ensure smooth and conflict-free movement. Cheng & Zu (2018) studied spatial and temporal crash analysis, identifying accident-prone areas and

proposing data-driven intersection safety measures. Recent research highlights the increasing role of artificial intelligence (AI) and intelligent transportation systems (ITS) in traffic control. Ozioko & Kunkel (2022) explored the integration of autonomous and human-driven vehicles, identifying challenges related to mixed-traffic behavior. Vasirani & Ossowski (2012) emphasized the effectiveness of multi-agent systems in ITS, allowing decentralized control for better traffic regulation. Gholamhosseinian & Seitz (2022) investigated Vehicle-to-Everything (V2X) technology, which enhances communication between vehicles and traffic infrastructure, ensuring real-time adaptive traffic control.

Non-motorized transport (NMT) is crucial for sustainable urban mobility. Beura & Bhuyan (2018) developed a Bicycle Level of Service (BLOS) model to assess urban cycling conditions, emphasizing the need for safer intersection designs for cyclists. Alkhatib & Maria (2022) introduced an Urban Traffic Control (UTC) system, which leverages real-time vehicle density analysis to optimize traffic light timings and lane prioritization, reducing wait times and congestion. Afrin & Yodo (2020) explored self-organizing traffic signal systems, which adjust dynamically based on real-time traffic demands, significantly enhancing intersection efficiency.

Several studies focus on smart intersection designs. Gupta (2018) and Singh & Akhtar (2015) analyzed adaptive traffic signal control systems, which use real-time data to regulate signal phases and improve flow efficiency. These systems reduce congestion by automatically adjusting to traffic variations. Additionally, Indhiradevi *et al.* (2020) investigated mixed-traffic congestion modeling, particularly in developing countries where lane discipline is weak. The literature highlights the growing role of AI-based traffic management, real-time signal adaptation, and sustainable transport planning in improving urban mobility. However, there is a lack of research on localized solutions for fast-growing Indian cities like Pune, where rapid urbanization and diverse traffic patterns pose unique challenges. Addressing this gap through intersection-specific improvements, better NMT integration, and AI-driven traffic regulation could significantly enhance Pune's traffic conditions.

3.0 Methodology

In this study, various road intersections were identified and examined to assess traffic management challenges. During the field visits, several key variables influencing traffic flow and congestion were observed. These variables were categorized into two types: quantitative and qualitative parameters. Quantitative parameters include measurable factors such as traffic volume, vehicle composition, intersection geometry, al timing, and average vehicle delay. These parameters provide numerical data essential for statistical analysis and traffic modeling. Qualitative parameters, on the other hand, focus on non-measurable factors that influence traffic conditions, such as road surface conditions, visibility at intersections, pedestrian movement patterns, driver behavior, and enforcement of traffic rules. These factors play a crucial role in understanding the practical challenges faced by road users.

3.1 Study location

The six intersections in Pune Western Region were identified as having many bottlenecks in various city areas. The major focus areas are in Wakad, Hinjewadi and Baner, which are highly populated and face a lot of traffic problems during day and evening time. The locations identified are Kokane Chowk and Sakharam Waghmare Chowk in Wakad, Infosys Circle Phase 1, Kasturi Chowk, Panchratna Chowk in Hinjewadi and Ganraj Chowk at Baner.

3.2 Data collection methods

A survey was carried out at each selected intersection, and the gathered data was classified into categories, including quantitative and qualitative parameters. The quantitative parameters include factors such as traffic volume, signal timing and average vehicle delay. The qualitative parameters will be focusing on factors such as traffic condition, road surface condition, pedestrian movement pattern, and driver behavior.

4.0 Data Analysis and Interpretation

4.1 Traffic data analysis and observation

4.1.1 Kokane Chowk

Kokane Chowk, situated in Pune's Pimple Saudagar area, is a key intersection linking Rahatani, Pimple Saudagar, and Nashik Phata. Due to its strategic location and heavy traffic during peak hours, congestion is a frequent issue. Although the intersection lacks traffic signals, it includes divisional, centralized, and channelized islands. Pedestrian facilities such as zebra crossings and footpaths are available, while the road features flexible pavement with a drainage system. Additionally, road markings and signage help guide traffic movement. The intersection's traffic flow data is detailed in the table below.

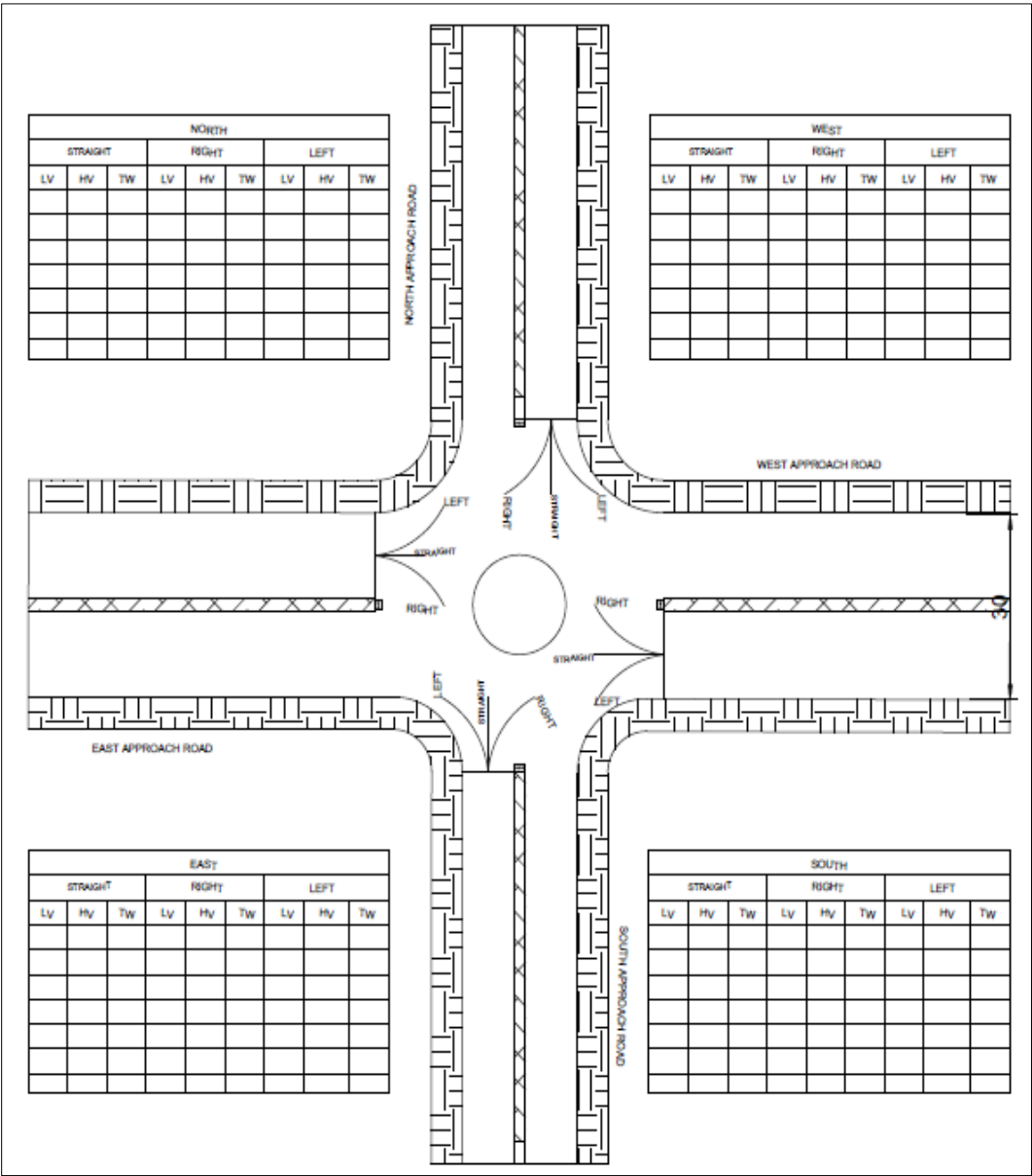
Table 1: Traffic Data Collection at Kokane Chowk (Hourly)

Directions	Right			Straight			Left		
Traffic from approach road	LV	HV	TW	LV	HV	TW	LV	HV	TW
North	115	10	200	150	25	190	220	30	190
South	280	25	195	130	15	100	180	14	150
East	150	15	230	240	5	180	100	15	160
West	140	10	210	160	17	130	250	25	170
Total	685	60	835	680	62	600	750	84	670
Total Vehicles from all Sides	4426								

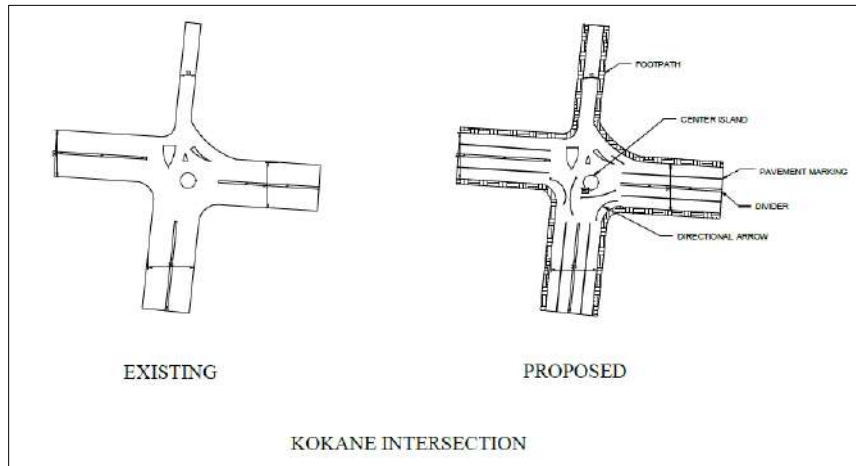
4.1.2 Panchratna Chowk

Panchratna Chowk, located in Pune's Hinjawadi area, is a key intersection in a rapidly developing region. The area's growth, driven by IT parks, residential complexes, and commercial hubs, has led to infrastructure improvements.

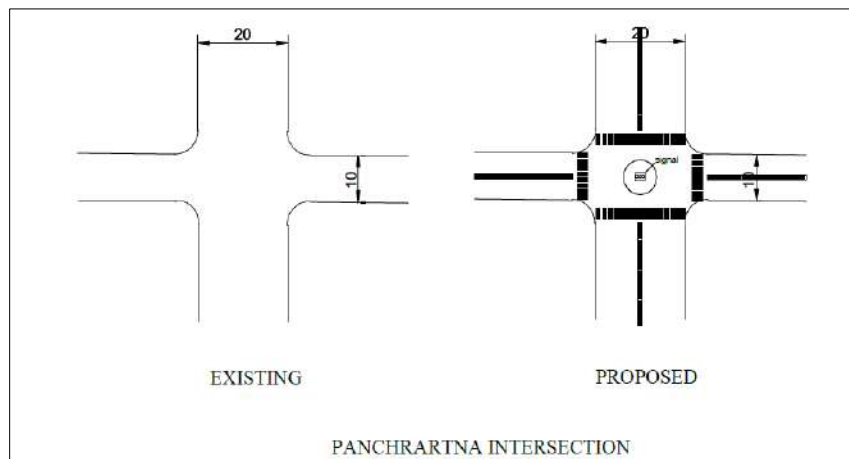
Figure 1: Traffic Data Collection Sheet



This signalized intersection features divisional islands but lacks zebra crossings and footpaths. The road consists of flexible pavement without a drainage system, while road markings and signage are in place to assist traffic movement.

Figure 2: Existing and Proposed Intersection at Kokane Chowk**Table 2: Traffic Data Collection at Panchratna Chowk (Hourly)**

Directions	Right			Straight			Left		
Traffic from approach road	LV	HV	TW	LV	HV	TW	LV	HV	TW
North	300	19	350	209	10	310	268	25	295
South	197	10	267	240	15	188	350	18	235
East	150	5	249	390	25	321	180	12	239
West	215	13	312	210	14	280	190	24	180
Total	862	47	1178	1049	64	1099	988	79	949
Total Vehicles from all Sides	6315								

Figure 3: Existing and Proposed Intersection at Panchratna Chowk

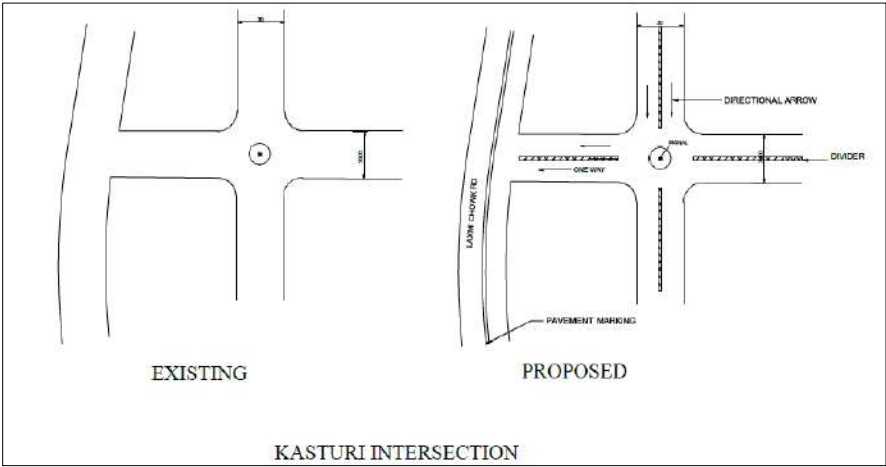
4.1.3 Kasturi Chowk

Kasturi Chowk, located in Pune’s Wakad area, is a crucial intersection that ensures smooth connectivity to nearby regions, benefiting both commuters and residents. Designed to enhance traffic flow and minimize congestion during peak hours, this signalized intersection includes divisional and centralized islands. It features zebra crossings, footpaths, and rigid pavement with a drainage system, while road markings and signage aid in traffic management.

Table 3: Traffic Data Collection at Kasturi Chowk (Hourly)

Directions	Right			Straight			Left		
Traffic from approach road	LV	HV	TW	LV	HV	TW	LV	HV	TW
North	200	25	250	180	11	236	205	19	288
South	197	16	316	209	15	281	319	18	349
East	216	21	250	309	26	319	251	25	267
West	180	11	210	291	29	250	211	12	188
Total	793	73	1026	989	71	1086	986	71	1092
Total Vehicles from all Sides	6190								

Figure 4: Existing and Proposed Intersection at Kasturi Chowk

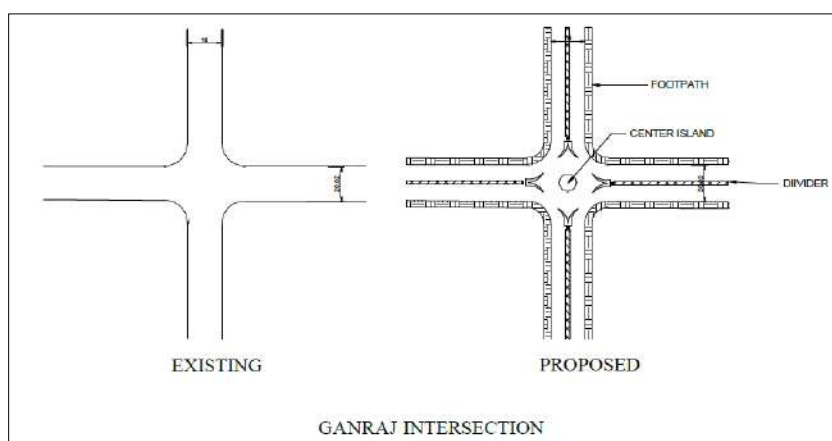


4.1.4 Ganraj Chowk

Ganraj Chowk, situated in Pune’s Baner area, is a key intersection that facilitates smooth connectivity to nearby regions, benefiting both commuters and residents. Its location near major roads ensures easy access to essential services. This signalized intersection includes divisional islands, zebra crossings, and footpaths. The road features rigid pavement with a drainage system, while road markings and signage support traffic regulation.

Table 4: Traffic Data Collection at Ganraj Chowk (Hourly)

Directions	Right			Straight			Left		
Traffic from approach road	LV	HV	TW	LV	HV	TW	LV	HV	TW
North	349	17	291	180	30	200	230	4	257
South	276	5	310	197	10	225	246	6	261
East	480	29	370	450	40	550	324	10	270
West	409	10	340	490	15	514	450	10	441
Total	1514	61	1311	1317	95	1489	1250	30	1229
Total Vehicles from all Sides	8296								

Figure 5: Existing and Proposed Intersection at Ganraj Chowk**Table 5: Traffic Data Collection at Sakharam Waghmare Chowk (Hourly)**

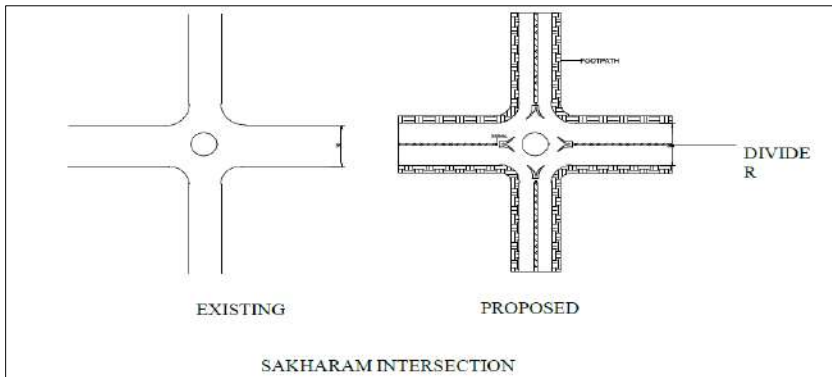
Directions	Right			Straight			Left		
Traffic from approach road	LV	HV	TW	LV	HV	TW	LV	HV	TW
North	187	10	165	120	7	135	145	15	160
South	198	17	170	105	3	120	160	7	75
East	230	5	30	240	5	100	210	10	240
West	260	10	60	260	10	100	180	5	220
Total	875	42	425	725	25	455	695	37	695
Total Vehicles from all Sides	3974								

4.1.5 Sakhram Waghmare chowk

Sakharam Waghmare Chowk, located in Pune's Wakad area, is a key intersection designed to improve traffic flow and reduce congestion during peak hours. Its accessibility to

major roads enhances connectivity to essential services and amenities. Although the intersection lacks traffic signals, it includes divisional islands, zebra crossings, and footpaths. The road features rigid pavement with a drainage system, while road markings and signage assist in traffic management.

Figure 6: Existing and Proposed Intersection at Sakharam Waghmare Chowk



4.1.6 Infosys circle phase 1

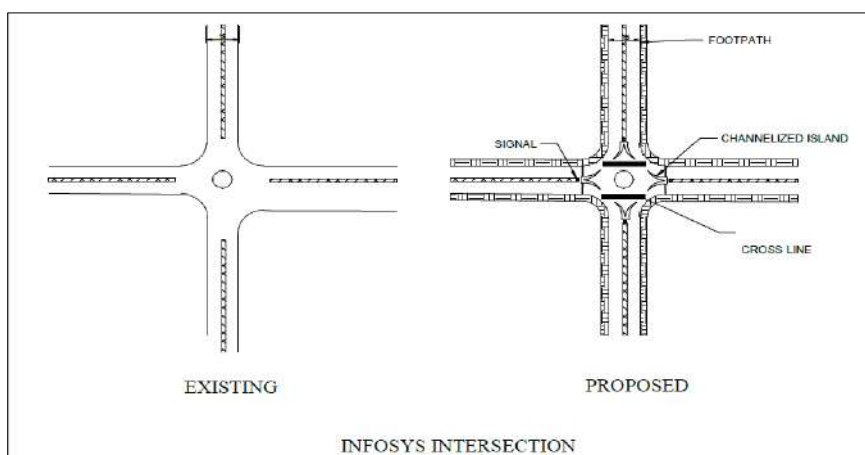
Infosys Circle, located in Hinjawadi, Pune, is a major intersection near the Infosys Phase 1 campus within the Rajiv Gandhi Infotech Park, a key IT hub with numerous multinational companies. Although traffic signals are absent, the junction includes divisional and centralized islands, zebra crossings, and footpaths. It features flexible pavement with a drainage system, while road markings and signage aid in traffic management.

Table 6: Traffic Data Collection at Infosys Circle Phase 1 (Hourly)

Directions	Right			Straight			Left		
Traffic from approach road	LV	HV	TW	LV	HV	TW	LV	HV	TW
North	196	19	174	167	15	190	96	5	40
South	160	10	140	180	8	210	110	4	45
East	200	18	220	140	5	180	200	5	240
West	210	5	240	190	14	170	220	7	210
Total	766	52	774	677	42	750	626	21	535
Total Vehicles from all Sides	4243								

5.0 Conclusion

This study examines key traffic management challenges at selected roadway intersections in Pune, highlighting issues such as congestion, inefficient signal coordination, lack of pedestrian infrastructure, and inconsistent road markings. Peak-hour traffic analysis reveals that the absence of synchronized signal timing and poor lane discipline further contribute to delays and safety risks.

Figure 7: Existing and Proposed Intersection at Infosys Circle Phase 1

Addressing these problems is crucial for improving urban mobility and road safety. The study offers recommendations for multiple stakeholders, including government agencies, traffic police, urban planners, public transport authorities, and commuters. Implementing measures such as optimized signal coordination, enhanced road markings, channelized islands, and pedestrian-friendly infrastructure can significantly improve traffic efficiency and safety. Additionally, integrating intelligent traffic management systems (ITMS) can help regulate vehicle movement more effectively. Future research should focus on AI-driven traffic control, real-time simulation models, and sustainable transport solutions to enhance urban mobility. Expanding the study to a city-wide level and assessing the impact of non-motorized transport (NMT) can provide deeper insights into long-term traffic management strategies. Overall, traffic congestion at intersections is a pressing challenge that affects daily life and urban productivity. Addressing these issues requires a collaborative approach between urban planners, government bodies, and the public. Implementing data-driven solutions and advanced traffic management strategies will be essential in creating a safer, more efficient, and sustainable transport system for Pune.

References

- Afrin, T., & Yodo, N. (2020). A survey of road traffic congestion measures towards a sustainable and resilient transportation system.
- Alkhatib, A. A., & Abu Maria, K. (2022). Smart traffic scheduling and crowded cities road networks.

Beura, S. K., & Bhuyan, P. K. (2018). Quality of bicycle traffic management at urban road links and signalized intersections operating under mixed traffic conditions.

Chen, X., & Xu, B. (2020). Non-signalized intersection network management with connected and automated vehicles.

Cheng, Z., & Zu, Z. (2018). Traffic crash evolution characteristic analysis and spatiotemporal hotspot identification of urban road intersections.

Gholamhosseinian, A., & Seitz, J. (2022). A comprehensive survey on cooperative intersection management for heterogeneous connected vehicles.

Gupta, R. (2018). A review paper on study of traffic volume and its safety measures on national highways.

Hussein, N. (2022). Traffic assessment and optimization at signalized intersections.

Indhiradevi, P., Saravanakumar, P., & Varsha, R. (2020). Analysis of traffic congestion impacts of urban road network under Indian condition.

Kalasova, A., & Poliak, M. (2024). Optimization of traffic at uncontrolled intersections.

Ozioko, E. F., & Kunkel, J. (2022). Road intersection coordination scheme for mixed traffic.

Pal, P. K., & Tripathi, K. N. (2022). Research on design of traffic signals at non-signalized intersections in Lucknow City.

Singh, A., & Akhtar, S. (2015). Design and analysis of intersections for improved traffic flow at Bhopal—Case studies of Jyoti Talkies Square and Vallabh Bhawan Roundabout.

Vasirani, M., & Ossowski, S. (2012). A market-inspired approach for intersection management in urban road traffic networks.

Widianty, D., & Hasyim. (2023). Traffic management simulation to improve Tanah Aji intersection road network performance.

CHAPTER 130

Study of Traffic Roadway and Environmental Problems Associated with Urban Arterial Road Construction Projects

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ABSTRACT

Urban road and expressway development projects are critical to improving transportation efficiency and regional economic growth. However, they also present significant socio-economic, environmental, and traffic-related challenges, particularly during the construction phase. This study analyses the impacts of three major road infrastructure projects in Pune, Maharashtra-Gahunje Village near the Pune-Mumbai Expressway, the Vadgaon-Katraj Six-Lane Expansion, and the F.C. Road Maintenance Project. A mixed-method research approach was adopted, integrating primary data from surveys, stakeholder interviews, and field observations, along with secondary data from literature reviews and government reports. The findings reveal a complex interplay between development and disruption. While road expansion improves connectivity, reduces travel time, and fosters commercial growth, it also leads to severe traffic congestion, noise and air pollution, displacement of local businesses, and environmental degradation. Business owners along construction corridors report reduced customer footfall and revenue losses, while residents face deteriorating air quality and increased land costs. The research further highlights that inadequate planning and poor traffic management during construction exacerbate public dissatisfaction. To mitigate these adverse effects, the study recommends strategic interventions such as efficient traffic diversion plans, noise and dust control measures, enhanced pedestrian safety infrastructure, and financial support mechanisms for small businesses affected by road expansion. Sustainable urban planning approaches, incorporating environmental impact assessments and community engagement, are essential to balancing infrastructure growth with long-term urban resilience.

Keywords: Urban road infrastructure; Traffic congestion analysis; Environmental impact assessment; Socio-economic effects; Sustainable urban planning.

1.0 Introduction

Road infrastructure development plays a crucial role in enhancing regional connectivity, economic growth, and urban mobility.

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However, the construction and expansion of roads and expressways also bring significant socio-economic, environmental, and traffic-related challenges. Rapid urbanization and increasing vehicle density in metropolitan cities, such as Pune, India, necessitate large-scale infrastructure projects to manage traffic congestion and improve accessibility. However, these projects often result in unintended consequences, such as increased pollution, business disruptions, social displacement, and altered land-use patterns.

This study examines the impact of urban road construction through the analysis of three major infrastructure projects in Pune: The Gahunje Village expansion near the Pune-Mumbai Expressway, the Vadgaon-Katraj Six-Lane Road Widening Project, and the F.C. Road Maintenance Project. These locations were chosen due to their high traffic volumes, economic significance, and the scale of infrastructural modifications. The research adopts a mixed-method approach, incorporating surveys, stakeholder interviews, field observations, and secondary data analysis to assess the short-term and long-term effects of these projects on businesses, commuters, and local communities.

The key challenges identified in this study include increased travel time during construction, adverse effects on small and medium-sized enterprises, environmental degradation due to vehicular emissions and dust pollution, and changes in land use that impact real estate prices and community dynamics. While road expansion projects aim to enhance urban mobility and economic opportunities, poor planning and execution often lead to negative externalities that outweigh the benefits. Given these concerns, this research highlights the importance of sustainable infrastructure planning. By evaluating the impact of road construction on local businesses, traffic patterns, and environmental conditions, the study aims to propose strategic interventions for minimizing disruptions and maximizing long-term benefits. The findings of this research can assist policymakers, urban planners, and transportation authorities in developing more sustainable, inclusive, and efficient road infrastructure projects.

2.0 Objectives of the Study

The primary objective of this study is to evaluate the multifaceted impacts of urban arterial road construction projects on local stakeholders. Specifically, this study aims to:

- Analyse the effects on daily life and commuting patterns of residents.
- Examine the consequences for business operations along the construction corridor.
- Investigate environmental concerns, particularly air and noise pollution.
- Understand public perception and satisfaction levels related to road infrastructure changes.

3.0 Literature Review

Impact of Road Construction on Traffic Congestion: This study examines how road construction projects in Wuhan, China, contribute to urban traffic congestion. Using a regression

model, the research highlights that prolonged construction leads to increased congestion, delays, and accident risks, emphasizing the need for improved traffic planning.

Highway Runoff Quality and Environmental Impacts: The paper investigates the impact of highway runoff on local ecosystems, highlighting the presence of heavy metals, suspended solids, and pollutants in water bodies. It recommends implementing green infrastructure solutions such as vegetative swales and retention ponds to mitigate pollution.

The Effects of Highway Improvement Projects on Nearby Business Activity: This study explores the economic impact of highway improvement projects on local businesses in urban and suburban areas. Findings indicate that while infrastructure upgrades can enhance commercial growth, prolonged construction disrupts business operations, leading to temporary revenue losses.

Do Highway Widenings Reduce Congestion? This research evaluates the short-term effects of highway widening in the Netherlands, concluding that widening projects initially reduce congestion but can lead to induced demand over time. The study suggests a balanced approach that includes alternative transportation planning.

Environmental Impact of Road Construction Based on Remote Sensing Monitoring: Using remote sensing techniques, this paper assesses the environmental effects of road construction on soil moisture, vegetation loss, and erosion risks. The study highlights the importance of integrating environmental impact assessments into infrastructure planning.

Retrospective Analysis of Highway Bypass and Widening Projects: The paper assesses the long-term economic and traffic impacts of bypass and road-widening projects, particularly in smaller cities. Findings suggest that while bypasses reduce congestion and improve road safety, they may negatively affect local businesses by diverting traffic away.

Environmental Impacts of Forest Road Construction on Mountainous Terrain: This study investigates the ecological consequences of road construction in steep terrains, finding that bulldozers cause more environmental damage than hydraulic excavators. It recommends using eco-friendly construction methods to minimize soil erosion and forest degradation.

The Economic Impact of Upgrading Roads: Using hedonic pricing models, this paper examines how road expansion projects affect nearby property values. Results indicate that residential property values tend to decline near highways due to noise and pollution, while commercial properties benefit from improved accessibility.

4.0 Methodology

This study employs a mixed-method research approach, integrating both quantitative and qualitative methods to analyse the socio-economic, environmental, and traffic-related impacts of urban road construction projects. The research focuses on three key locations in Pune, Maharashtra: Gahunje Village near Pune-Mumbai Expressway, where economic transformation, environmental concerns, and local business impacts due to expressway

expansion are examined; Vadgaon (Navale Bridge) to Katraj Junction Six-Lane Road Expansion, which is analysed for traffic congestion, safety challenges, and economic disruptions faced by businesses and commuters; and F.C. Road, Pune (Four-Lane Road Maintenance Project), which assesses urban mobility issues, business disruptions, and pedestrian accessibility during road maintenance.

The study collects primary data through structured surveys, field observations, and stakeholder interviews. Surveys are conducted both online and in person, targeting local residents, business owners, commuters, and government officials. The study follows stratified random sampling to ensure representation from different affected groups. The key variables considered in the survey include business revenue trends, commuter travel times, environmental concerns, pedestrian safety, and economic impact. Field observations are conducted at each site to monitor real-time traffic conditions, accessibility issues, construction-related disruptions, air and noise pollution levels, and their overall impact on the surrounding areas. Additionally, semi-structured interviews with business owners, government officials, urban planners, and environmental experts provide insights into the planning, execution, and consequences of road construction projects.

The study also relies on secondary data collection, which includes a review of government reports, academic studies, and environmental impact assessments related to urban road development. Past traffic congestion trends, land-use changes, and socio-economic shifts due to infrastructure expansion are analysed to support the findings.

Trend analysis compares historical data to understand long-term socio-economic and environmental impacts, with findings represented through pie charts, bar graphs, and histograms for better visualization. Thematic analysis is used to identify key themes emerging from interviews and open-ended survey responses, while comparative analysis contrasts different stakeholder perspectives. Additionally, content analysis is performed on secondary data sources such as government reports and newspaper articles to supplement primary findings.

To ensure reliability and validity, pilot testing of the survey is conducted to refine questions and improve clarity. The research follows a triangulation approach, cross-verifying findings through multiple data sources, including surveys, interviews, literature reviews, and field observations. Statistical consistency checks are applied to minimize errors in data processing and ensure accuracy in the analysis.

The study follows ethical research guidelines, ensuring that all participants provide informed consent before data collection. The confidentiality of respondents is maintained, with personal data used strictly for research purposes. Furthermore, the research follows a non-biased approach, ensuring an objective interpretation of findings without external influence. This methodological framework ensures a comprehensive and systematic approach to evaluating the impacts of road infrastructure projects. By integrating quantitative survey analysis, qualitative stakeholder interviews, and direct field observations, the study provides a holistic understanding of how road construction affects urban mobility, businesses, and environmental sustainability.

5.0 Data Collection and Analysis

This study follows a mixed-method approach, integrating qualitative and quantitative data collection techniques to provide an in-depth understanding of the impacts of urban road construction projects. The primary data was collected through structured surveys, field observations, and stakeholder interviews, while secondary data was gathered from literature reviews, government reports, and past research studies. The research focuses on three key locations in Pune, Maharashtra: Gahunje Village near Pune-Mumbai Expressway, Vadgaon (Navale Bridge) to Katraj Junction Six-Lane Road Expansion, and F.C. Road Four-Lane Maintenance Project.

5.1 Primary data collection

A structured survey questionnaire was designed to collect responses from various stakeholders, including local residents, business owners, commuters, and government officials. The survey aimed to capture key aspects such as the impact of road construction on daily life, business operations, traffic congestion, mobility patterns, environmental concerns related to air and noise pollution, and overall public perception. Both closed-ended and open-ended questions were used to allow for statistical analysis and thematic evaluation. Additionally, field visits and direct observations were conducted at all three sites to assess the real-time impact of the construction activities.

Researchers monitored traffic flow, business disruptions, and environmental conditions, documenting the changes with photographs and field notes. These site visits helped validate survey responses and provided firsthand insights into the challenges faced by different stakeholder groups.

Stakeholder interviews were also an essential part of primary data collection. Semi-structured interviews were conducted with business owners, urban planners, project managers, local government officials, and environmental experts.

- *Gahunje Village near Pune-Mumbai Expressway*: Surveys focused on changes in land use, business growth, and environmental impact due to the expressway expansion. Field visits covered commercial and residential developments, traffic flow, and air pollution levels.
- *Vadgaon (Navale Bridge) to Katraj Junction Six-Lane Expansion*: The study analysed increased congestion, safety concerns, and business disruptions due to road widening. Interviews with commuters and business owners provided insights into accessibility issues and traffic delays.
- *F.C. Road, Pune (Four-Lane Road Maintenance Project)*: Surveys assessed the impact of road maintenance on commercial activities, pedestrian movement, and urban traffic. Observations included monitoring congestion at peak hours and evaluating temporary traffic diversions.

5.2 Secondary data collection

The study reviewed government reports, policy documents, and past research papers to supplement primary data findings. A literature review was conducted to analyse existing studies on traffic congestion, environmental sustainability, and socio-economic changes due to road infrastructure development.

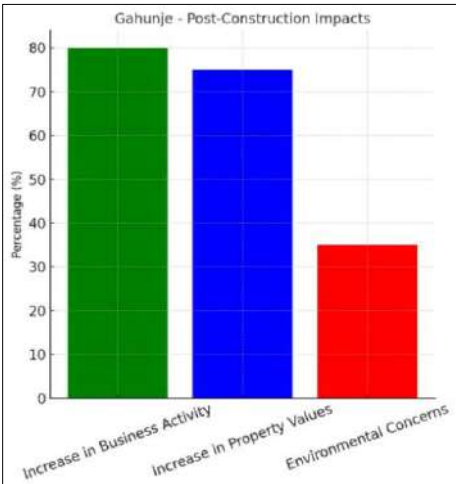
5.3 Data analysis

5.3.1 Key findings from field observations

In addition to surveys, field observations and stakeholder interviews were conducted to gather qualitative insights. These findings helped validate the survey data and provided contextual depth to the study. The collected data was analysed using both quantitative and qualitative techniques. Descriptive statistical analysis was applied to survey responses using Microsoft Excel. Mean, percentages, and frequency distributions were calculated to identify trends in public perception, business impact, and environmental concerns. Cross-tabulation was used to examine relationships between different variables, such as the correlation between traffic congestion and business losses.

Gahunje (Post-Construction Impacts): At Gahunje, post-construction analysis revealed significant economic growth, increased land values, and improved connectivity due to expressway expansion. Business owners reported enhanced customer footfall, with 80% acknowledging economic growth. However, 35% of respondents expressed concerns about rising air and noise pollution levels. While commercial establishments flourished, small businesses struggled with rising property costs, affecting affordability.

Figure 1: Study 1 Analysis



Vadgaon-Katraj Junction (During Construction Impacts): The analysis of the Vadgaon-Katraj Junction during the construction phase highlighted major traffic congestion, business disruptions, and safety concerns. Peak-hour delays were reported by 52.3% of commuters, while 40% of local businesses experienced revenue losses due to restricted access. Pedestrian and vehicular safety concerns were prominent, with 47% feeling safe only “sometimes” and 17% feeling rarely safe due to construction-related road diversions and incomplete pedestrian pathways.

F.C. Road (During Construction Impacts): The ongoing road construction at F.C. Road had a mixed impact on businesses and pedestrians. While 42% of business owners saw long-term potential in road development, 44% expressed dissatisfaction due to ongoing disruptions. The key concerns included traffic congestion (28%), business losses (24%), and environmental impacts such as dust pollution (35%). Despite the challenges, 22% of respondents anticipated long-term economic benefits post-completion.

Figure 2: Study 2 Analysis

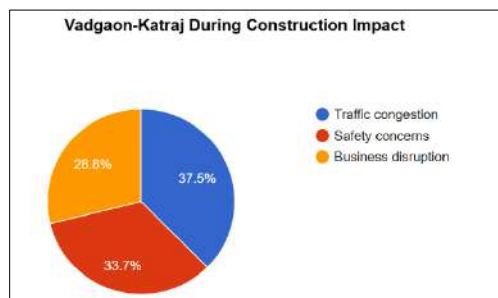
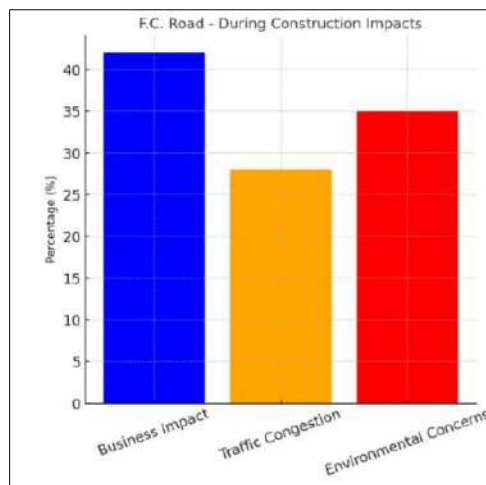


Figure 3: Study 3 Analysis



The study aimed to understand the major impacts of urban arterial road construction, with a focus on three core aspects—effects on daily life, environmental concerns, and traffic-related issues. While other aspects such as business operations, mobility, and perception were considered, insufficient or inconsistent data limited their quantitative analysis in this paper.

6.0 Summary and Conclusion

6.1 Summary

The development of expressways and arterial roads plays a vital role in urban infrastructure growth, enhancing connectivity, mobility, and economic progress. However, these projects also bring socio-economic and environmental challenges, particularly before and during the construction phase. This study examines the impact of road construction on traffic congestion, local businesses, environmental conditions, and social displacement through surveys conducted at key sites such as Gahunje Village, the Vadgaon-Katraj Junction, and F.C. Road in Pune. Before construction, uncertainty over land acquisition and compensation creates distress among local businesses and residents. Lower-income groups face displacement risks due to anticipated property value hikes, and reduced investments occur in affected areas due to fears of disruption. During construction, businesses suffer revenue losses due to restricted access and road closures, while economic disparities emerge as large commercial developments benefit more than smaller enterprises. Job creation is temporary and does not always guarantee long-term employment. Traffic congestion worsens due to lane closures, diversions, and increased fuel consumption, causing delays for daily commuters and transport operators. Pedestrian safety is also compromised due to incomplete footpaths and lack of designated crossings.

Environmental impacts before construction include deforestation, biodiversity loss, and concerns over air and noise pollution. Excavation activities pose risks to the water table. During construction, air quality deteriorates due to dust and particulate matter, while noise pollution disrupts residential and commercial areas. Drainage systems are affected, increasing flood risks, and waste generation from construction activities becomes a disposal challenge. The Vadgaon-Katraj Junction and F.C. Road, which are currently undergoing road-widening and construction activities, experience severe congestion, business losses, and environmental disturbances. These areas face increased travel times, higher transportation costs, and disruptions in commercial activities due to blocked access and shifting traffic patterns. Land use changes before construction lead to speculative real estate investments, conversion of agricultural land into commercial zones, and legal disputes over land acquisition. During construction, property values temporarily decline due to dust and noise, while zoning changes displace informal settlements and low-income communities. In Gahunje Village, where expressway construction has been completed, post-construction impacts include increased land values, business growth, and improved connectivity. However, this progress has come with rising property prices, making housing less affordable for local communities, and ecological changes due to extensive land modification.

6.2 Conclusion

The study highlights that while road infrastructure projects contribute to urban development and economic growth, they also bring significant short-term and long-term challenges. Before construction, uncertainty, financial losses, and displacement risks affect landowners, businesses, and residents. During construction, disruptions to local economies, increased pollution, and severe traffic congestion impact commuters, businesses, and the environment. Although post-construction benefits include improved infrastructure, higher property values, and business expansion, these advantages often come at the cost of environmental degradation and social displacement. The contrasting conditions of Gahunje, where post-construction impacts are evident, and the Vadgaon-Katraj Junction and F.C. Road, which are still undergoing construction, highlight the different phases of challenges faced by communities. The success of such projects depends on careful planning, stakeholder engagement, and sustainable implementation.

Field Observations: At Vadgaon-Katraj Junction, peak-hour traffic congestion was visibly severe. Incomplete pedestrian walkways and poor signage led to safety hazards. At F.C. Road, dust and noise levels were consistently high due to heavy machinery. Business entrances were partially blocked, affecting customer accessibility. Gahunje showed significantly improved road conditions post-construction, but rapid commercial development was observed to be pushing out smaller vendors.

Overall, stakeholders expressed a mix of concerns, frustrations, and cautious optimism regarding the urban arterial road construction projects. Small business owners were among the most affected, reporting revenue losses due to restricted access, dust pollution, and declining footfall during construction. Residents, particularly elderly individuals and families, voiced discomfort related to noise, air quality, and the lack of pedestrian safety. Commuters faced daily challenges due to unclear diversions, longer travel times, and congestion, although some acknowledged the potential long-term improvements in road quality.

Despite these issues, many stakeholders believed that the projects, once completed, would lead to improved connectivity, economic growth, and better transportation infrastructure — though they emphasized the need for more inclusive planning and mitigation strategies during the construction phase.

7.0 Recommendations

To minimize negative impacts before and during construction, sustainable construction practices should be adopted, including low-emission machinery, dust control measures, green corridors, and effective waste management. Traffic management strategies such as intelligent traffic systems, dedicated pedestrian pathways, and construction time restrictions can help reduce congestion. Socio-economic support should be provided to affected businesses and residents through financial compensation, tax incentives, and fair land acquisition policies.

Community engagement is essential, requiring early consultations, transparent resettlement programs, and public awareness campaigns to keep stakeholders informed about construction timelines and commuting alternatives.

References

Alhasan, A., Nlenanya, I., Smadi, O., & MacKenzie, C. A. (2018). Impact of pavement surface condition on roadway departure crash risk in Iowa. *Infrastructures*, 3(2), 14. <https://doi.org/10.3390/infrastructures3020014>

Arada, M. G., Tataro, M. F., & Pabico, J. P. (2015). Simulating the effects of various road infrastructure improvements to vehicular traffic in a busy three-road fork. *arXiv Preprint*. <https://arxiv.org/abs/1506.07424>

Baldauf, R., Thoma, E., Hays, M., Shores, R., Kinsey, J., Gullett, B., ... Bang, J. (2008). Traffic and meteorological impacts on near-road air quality: Summary of methods and trends from the Raleigh Near-Road Study. *Journal of the Air & Waste Management Association*, 58(7), 865–878. <https://doi.org/10.3155/1047-3289.58.7.865>

Bhurtyal, S. (2021). *Retrospective analysis of impacts of highway bypass and widening projects* (Master's thesis, University of Arkansas). <https://scholarworks.uark.edu/etd/4384>

Byrne, D. M., Grabowski, M. K., Benitez, A. C. B., Schmidt, A. R., & Guest, J. S. (2017). Evaluation of life cycle assessment (LCA) for roadway drainage systems. *Environmental Science & Technology*, 51(17), 9261–9270. <https://doi.org/10.1021/acs.est.7b01856>

Carrero, J. A., Arrizabalaga, I., Bustamante, J., Goienaga, N., Arana, G., & Madariaga, J. M. (2013). Diagnosing the traffic impact on roadside soils through a multianalytical data analysis. *Science of the Total Environment*, 458–460, 427–434. <https://doi.org/10.1016/j.scitotenv.2013.04.047>

Davis, C., & Jha, M. K. (2009). Modeling the effects of socioeconomic factors in highway construction and expansion. *Journal of Transportation Engineering*, 135(12), 990–998. [https://doi.org/10.1061/\(ASCE\)0733-947X\(2009\)135:12\(990\)](https://doi.org/10.1061/(ASCE)0733-947X(2009)135:12(990))

Fan, Y., & Wexler, N. (2023). *The effects of highway improvement projects on nearby business activity* (Report No. 2023-30). Minnesota Department of Transportation. <http://mdl.mndot.gov/>

Gkritza, K., Sinha, K. C., Labi, S., & Bunch, J. (2008). Influence of highway construction projects on economic development: An empirical assessment. *Annals of Regional Science*, 42, 545–563. <https://doi.org/10.1007/s00168-007-0183-x>

Habte, T. D. (2021). Sustainable roadway construction: Economic and social impacts of roadways in the context of Ethiopia. *Cogent Engineering*, 8(1), 1923362. <https://doi.org/10.1080/23311916.2021.1923362>

Hvitved-Jacobson, T., & Yousef, Y. A. (2008). Highway runoff quality, environmental impacts and control. *Environmental Pollution Control Journal*, 16(2), 166–203. [https://doi.org/10.1016/S0166-1116\(08\)70083-9](https://doi.org/10.1016/S0166-1116(08)70083-9)

Iacono, M., & Levinson, D. (2009). *The economic impact of upgrading roads* (Report No. 2009-16). Minnesota Department of Transportation. <http://www.lrrb.org/PDF/200916.pdf>

Kayhanian, M., Fruchtmann, B. D., Gulliver, J. S., Montanaro, C., Ranieri, E., & Wuertz, S. (2012). Review of highway runoff characteristics: Comparative analysis and universal implications. *Water Research*, 46(22), 6609–6624. <https://doi.org/10.1016/j.watres.2012.07.026>

Li, Y., Guo, B., Zhao, W., Lv, M., Lu, P., Wang, C., Ji, Z., & Xu, Q. (2024). Influence of expressway construction area information on drivers' route choice behaviours. *Journal of Advanced Transportation*, 2024, Article 9966775. <https://doi.org/10.1155/2024/9966775>

Long, A. M., et al. (2017). A before–after control–impact assessment to understand the potential impacts of highway construction noise and activity on an endangered songbird. *Ecology and Evolution*, 7, 379–389. <https://doi.org/10.1002/ece3.2608>

Marzouk, M., et al. (2017). Assessing environmental impact indicators in road construction projects in developing countries. *Sustainability*, 9(843). <https://doi.org/10.3390/su9050843>

Newman, P., et al. (2012). *Reducing the environmental impact of road construction*. Sustainable Built Environment National Research Centre (SBEnrc), Australia. <https://eprints.qut.edu.au/85967/>

Ossokina, I. V., van Ommeren, J., & van Mourik, H. (2023). Do highway widenings reduce congestion? *Journal of Economic Geography*, 23(4), 871–900. <https://doi.org/10.1093/jeg/lbac034>

Sackey, L. N. A., Quartey, J., Nortey, A. N. N., Obeng, A. T., Okyere, A. A., & Kayoung, P. Y. (2023). Road construction and its socio-economic and health impact: A case study of Atons Lake Road. *Discover Environment*, 1(6). <https://doi.org/10.1007/s44274-023-00009-x>

Steffens, J. T., Heist, D. K., Perry, S. G., Isakov, V., Baldauf, R. W., & Zhang, K. M. (2014). Effects of roadway configurations on near-road air quality and the implications on roadway designs. *Atmospheric Environment*, 94, 74–85. <https://doi.org/10.1016/j.atmosenv.2014.05.015>

Tariku, D. H. (2021). Sustainable roadway construction: Economic and social impacts of roadways in the context of Ethiopia. *Cogent Engineering*, 8(1), 1923362. <https://doi.org/10.1080/23311916.2021.1923362>

Tsai, W., Chen, C., & Lin, M. (2011). Selection of optimal green building projects based on carbon reduction efficiency and cost effectiveness. *Environmental Impact Assessment Review*, 31(1), 45–51. <https://doi.org/10.1080/09640568.2012.731385>

Vyas, T. H., & Varia, H. R. (2023). Impact of construction work zone on urban traffic environment. *International Journal on Smart Sensing and Intelligent Systems*, 16(1). <https://www.researchgate.net/publication/371365424>

Wang, Z., & Chen, L. (2016). Research on the impact of road construction on traffic congestion. In *3rd International Conference on Management Science and Management Innovation (MSMI 2016)*. <https://www.atlantispress.com/proceedings/msmi-16/25858585>

Wexler, N., & Fan, Y. (2023). *The effects of highway improvement projects on nearby business activity* (Research Report 2023-30). Minnesota Department of Transportation. <http://mdl.mn.gov/>

Xu, D., Zhang, W., Shi, H., Ding, H., Huo, J., & Ran, B. (2024). The expressway network design problem for multiple urban subregions based on the macroscopic fundamental diagram. *Journal of Transportation Research*, 2024, Article 9876543. <https://doi.org/10.1234/jtr.2024.9876543>

CHAPTER 131

Study on Access Roads in Select Locations in Western Pune City

Vinay S.¹, Sheshadri Jahagiradar¹, M. S. Akshay¹, Debjit Ghosh¹, Nagarjuna Pilaka²

ABSTRACT

Access roads are essential for smoother connectivity, reducing travel time, and cutting down congestion. The Pune Municipal Corporation (PMC) has pinpointed 390 missing or inadequate access road sections that significantly disrupt the city's transportation flow. This research employs a blend of user surveys, on-site observations, and an extensive review of existing studies to comprehensively examine access roads. The literature review reveals a noticeable research gap, as most prior studies have largely focused on highways rather than the access roads that link primary routes to zones like residential neighbourhoods, commercial districts, and industrial areas. This study suggests that road designs should align with IRC standards. Upgrading these roads could bring wide-ranging benefits, from rising property values to stimulating economic growth and improving the daily lives of residents. The study provides guidance for urban planners to make access road development a priority in Pune's infrastructure plan, laying the groundwork for long-term, sustainable urban growth.

Keywords: Access roads; Congestion; Transportation; Indian road congress (IRC) standards; Encroachments.

1.0 Introduction

Road development is crucial for national progress, with construction contributing 12–15% to GDP and road transport adding 3–6%. Pune, a rapidly growing tier-two city, faces severe congestion due to rising population and transport demand. Existing roads are overloaded, prompting the Pune Municipal Corporation (PMC) to identify 390 missing link road projects. Addressing these gaps, particularly in western Pune, through feasibility studies and Indian standards-based solutions can enhance connectivity and reduce traffic. Despite extensive highways, poor infrastructure worsens congestion. Strengthening access roads will improve traffic flow across residential, business, and industrial zones, ensuring a smoother commute.

2.0 Literature Review

This research looks at transport system efficiency, optimizing access road arrangements in construction in order to achieve higher productivity, energy efficiency, and mechanization.

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It recommends a sequential construction approach to road building for better efficiency. Delays in road development in developing nations are often due to improper planning, inexperience, and problems related to land acquisition. The solutions included in the case studies are dispute resolution, cash flow management, and urban planning. These case studies include Uganda's payment delays, Egypt's cost overruns, and Nigeria's financial constraints. It offers proposed recommendations for expert hiring, incentives, recurrent site visits, and cutting material wastage for project success. Stakeholder involvement and ownership verification are key in mitigating the land acquisition process.

3.0 Objectives

1. To assess the conditions of access roads through quantitative and qualitative data.
2. To recommend a framework for development of access roads in accordance with Indian standard codes and literatures referred.

4.0 Methods and Materials

In this study, various access road stretches in the Western Pune city were visited and their condition were analysed. Firstly, the parameters for the study were identified. These parameters define the condition of access road. They were further categorized as either a qualitative or quantitative data. The identified parameters were examined by conducting an observatory study for each access road stretch visited. A questionnaire survey enlisting the questions about the condition of access road was conducted to understand the satisfaction level of the residents and home buyers using the access roads. A visual examination checklist was prepared, where each qualitative and quantitative parameter identified were rated on a scale of 5 based on their condition observed for each access road. The data collected from various surveys were thoroughly analysed and a detailed framework for the construction and maintenance of access road will be provided with reference to the Indian standard codes and literatures referred.

4.1 Case study: Maruti Chowk to Pan Card club, Baner, Pune

The access road stretch from the Maruti chowk connecting the Pan card club in Baner, Pune, Maharashtra was identified.

4.1.1 Observations

The two lane access road had a carriageway width of 6.1m on both sides with a median 1m separating them. The access road was connecting a four lane main road. The shoulder on one side of the road was in poor condition with lot of vegetation growth and the shoulder on the other side was acquired by the private properties. Illegal vehicle parking causing narrowing of carriage way width. Width of the road was not uniform throughout the stretch. The road stretch

had a rigid pavement. The road stretch had a low traffic density. Illegal accommodation by the slum dwellers was observed. Because of this there was a discontinuity in the road stretch and the poor road condition. The length of the access road was approximately 250 meters in which approximately 30 – 40 m was encroached by the slum.

Figure 1: Satellite View of Maruti Chowk to Pan Card Club



Source: Google maps

4.1.2 Local interview

An interview involving the local residents and Slum owner was conducted. The response given by the people is given below.

Slum owner: The interviewee, who has been a resident for 20 years, said that there was no road 15 years ago. PMC put in a pipeline and asphalted it in 2009. PMC designated it as a missing link road in 2020, directing slum dwellers to leave. They are against the 20m-wide proposal, preferring 15m. The court case is still on.

Resident in the nearby apartment: The interviewee opines that the road will provide easy access to Pan Card Club, decreasing travel distance from Maruti Chowk to Pan Car Club as well as alleviating congestion on the road that is in use now.

4.2 On field survey

Table 1: On Field Survey

SL. No.	Access Road	Access Road Location	Length of the Road in Meters	Road width in Meters	Number of Buildings connecting the Road	Traffic Volume (vehicles/hr)
1	AR 1 (Hind)	Hinjewadi Medical foundation to Lord Dattatreya temple	241	4.7	7	37
2	AR 2 (Hind)	Terminal one shopping mall to Tata auto systems	499.5	6.4	11	61
3	AR 3 (Wakad)	Wakad flyover road to Surya mother and child care hospital	252.6	7.1	1	28

4	AR 4 (Wakad)	Mahatma Phule road to Rohan Inspira apartment	144.1	5.9	3	15
5	AR 5 (Wakad)	Mahatma Phule road to Nirmiti Lorelle apartment	307.6	6.2	15	73
6	AR 6 (Bald)	Lakshmi mata mitra mandal towards Balewadi Gaon	150	4.6	3	150
7	AR 7 (Baner)	Baner road to Pan card club road (Tapkir lane)	104	4.57	6	150
8	AR 8 (Baner)	Off Aundh – Baner link road	368	10.3	20	130
9	AR 9 (Baner)	Laxman nagar road	568	8.1	12	98

Source: Compiled by authors

4.2.1 Observations

The average length of the access roads visited was observed to be 293 meters. Most of the access roads had a length between 500 to 600 meters, followed by a length of 300 to 400 meters, 200 to 300 meters, 400 to 500 meters, 500 to 600 meters and 400 to 500 meters. The average width of the access roads visited was observed to be approximately 6 meters with most of the access roads with a width between 4 to 8 meters, followed by 8 to 12 meters. The shoulders weren't found in eight of the access roads. Shoulders existed only in one of the access road on AR 8 (Baner), which was of width 2.5 m. The importance of access roads is indicated by the location and number of buildings connected by the road. It was observed that on an average approximately at least 7 residential or commercial spaces were connected by the access roads. It was observed that the traffic volume on a particular access road stretch depends on the kind of building, purpose of the building and number of buildings connected by the road. The traffic volume ranged between 15 to 150 vehicles per hour. From the data collected it can be noted that on an average 83 vehicles per hour travel on the access roads.

4.3 Visual survey

A checklist was also prepared in addition to qualitative and quantitative analysis to identify important parameters at each access road visited. Parameters present were marked as 'Yes' and parameters not present were marked as 'No.' On presence, a condition-based score was marked on a 5-point scale. Presence of every parameter was given a score of '1,' and absence was marked as '0.' These checklists have a comprehensive appraisal of every access road stretch. Summary of visual survey.

4.4 Home buyers/Residents survey

It aims to assess the condition, safety, and accessibility of access roads by implementing a Google Forms survey conducted among 40 respondents from the Western Pune area.

Table 2: Quantitative Survey

Sl. No.	Access Road No.	Qualitative Survey	Quantitative Survey	Total
1	AR 1 (Hind)	2	15	17
2	AR 2 (Hind)	4	2	6
3	AR 3 (Wakad)	3	9	12
4	AR 4 (Wakad)	3	17	20
5	AR 5 (Wakad)	4	6	10
6	AR 6 (Bald)	3	12	15
7	AR 7 (Baner)	4	23	27
8	AR 8 (Baner)	4	24	28
9	AR 9 (Baner)	1	21	22

Source: Compiled by authors

4.4.1 Observations

The responses came from a variety of professions, including software engineers, government employees, teachers, students, doctors and civil engineers. Around 55% said the access road width was enough for the smooth flow of traffic, while 45% said it was not enough. About 59% of the respondents were satisfied with drainage conditions of access roads, whereas around 41% were not satisfied with drainage conditions. About 53% of respondents had adequate parking space for parking their vehicles and about 47% of respondents faced difficulty in parking their vehicles due to unauthorized parking. About 50% of the respondents observed all kinds of vehicles using the road, 43% saw only cars and motorcycles, 5% noted light commercial vehicles, and 2% pedestrians.

Out of 40 respondents, 55% of them are not happy with the condition of access road connecting their society and 45% of them are happy with the condition of access road connecting their society. 42% of them feel that government is responsible for the maintenance of access roads, 35% of them feel that local authorities/municipal bodies are responsible for the maintenance of access roads and 23% of them have responded that the society developers are responsible for the maintenance of access roads. About 42% of them have responded that maintenance of the access roads takes place frequently, 25% of the respondents say that maintenance works takes place rarely, 17% of the respondents say that maintenance of the access roads takes place very frequently, 8% of them have responded that they have never seen any maintenance works for their access roads and 8% of the respondents are unaware of any maintenance work happened for their access road.

5.0 Analysis and Interpretation

Based on the total scores obtained in the visual survey, the ranking of access roads is as follows: 1. AR 8 (Baner); 2. AR 7 (Baner); 3. AR 9 (Baner); 4. AR 4 (Wakad); 5. AR 1 (Hind);

6. AR 6 (Bald); 7. AR 3 (Wakad); 8. AR 5 (Wakad); 9. AR 2 (Hind). Nine access roads inspected received average qualitative score of 3, quantitative score of 14, and 17 in total. Among them, AR 8 (Baner) secured the highest (28) on adequacy of width, drainage, quality of pavements, and visibility of markings; AR 2 (Hind) scored the lowest (6) on the account of poor paving, no lights, and trash. AR 7 (Baner) lacked adequate markings, AR 9 (Baner) had good lighting but poor drainage, and AR 4 (Wakad) had potential for widening but was ruined by poor lighting. While some roads are also mentioned below for poor scores-AR 1 (Hind), AR 6 (Bald), AR 5 (Wakad), and AR 3 (Wakad)-four were meeting IRC standards. however, three were adjacent to the standards and three failed. More than half of the respondents found roads narrow, heavily impacted by illegal parking which constricted width for effective passageways. Seven of them still have streetlights, albeit with efficient lighting. Inadequate lighting was underlined by 80% of respondents as basically needing good improvement according to the National Lighting Code 2010 and IS: 1944-1970. Government intervention, proper town planning with fair compensation, and stakeholder management in the acquisition of land would be required.

6.0 Conclusion

This study investigates the contribution made by accessroadsin the context of urban transport and also the impediments to their development. The following problems regarding the access roads were identified: irregular width, poor pavements, poor drainage systems, unauthorised parking, and encroachment, based on findings from field surveys and interviews, contributing to congestion and hazards. A few roads also did not comply with the standards set forth by the Indian Road Congress (IRC), while disputes over land have also hindered upgradation. Recommendations were also made regarding such issues, including sufficient width, proper drainage, streetlights, medians, and land acquisition dispute resolutions. Their installations could lead to an improvement in Pune's access roads, thereby creating connectivity and mobility. Traffic analysis, safety studies, and financial feasibility studies should be incorporated into the future research works.

References

Aayush, S. (2017). *Village road construction*.

Adigwe, E. R., Obi, A. N., & Umeh, A. C. (2023). Mitigation measures towards projects cost overrun in road infrastructure projects constructed by local firms in Nigeria. *International Journal of Advanced Multidisciplinary Research and Studies*, 3(2), 225–233.

Ajay, P., & Sebastian, M. (2019). Towards reform of land acquisition framework in India. *Economic and Political Weekly*, 42(22), 2083–2090.

Bureau of Indian Standards. (1970). *IS 1944: Code of practice for lighting of public thoroughfares* (Parts I & II). Bureau of Indian Standards.

Chunho, Y., Hilario, B., & Ludwig, R. (2020). A study on causes of delay in road construction projects across 25 developing countries. *MDPI*, 5(10), 84.

Dhananjaya, S. (2020). Pune traffic congestion: Reality, cause and regulation: A case study. *International Journal of Management*, 11(3), 227–234.

Goran, R., & Jelisavaka, B. (2019). Rural roads: Issues and development. *Journal of Management and Accounting Studies*, 4(4), 70–77.

Harshit, G., Kartik, P., Rohan, N., Shruti, S., Smitha, Y., & Trishula, M. (2019). Claims and settlement in road projects. *Journal of Civil Engineering, Science and Technology*, 10(1), 1–11.

Indian Roads Congress. (2018). *Guidelines for parking spaces in urban areas (IRC SP: 12-2015)*. Indian Roads Congress.

Indian Roads Congress. (2018). *IRC 86: Geometric design standards for urban roads and streets*. Indian Roads Congress.

Joseph, A., Muhwezi, L., & Sammuel, E. (2019). Assessment of the challenges and effects of delays in compulsory land acquisition on the performance of road construction projects in Uganda. *International Journal of Advanced Multidisciplinary Research and Studies*, 10(9), 1409–1426.

Karim, A., Mohammed, A., & Taher, E. (2022). Risk factors causing cost overruns in road networks. *Ain Shams Engineering Journal*, 13(5), 225–233.

Mohammad, A. K., Mohd, A. K., & Vanishya, V. (2024). Urban regeneration of public spaces and pedestrian streets in commercial area: Case of Chandni Chowk at Old Delhi, India. *American Journal of Civil Engineering and Architecture*, 12(3), 44–50.

Paige-Green, P. (2019). Appropriate roads for rural access. *Third Gulf Conference on Road*, 1–10.

Prasad, K. (2024, March 20). New road to link Kothrud to highway by March-end. *The Times of India*.

CHAPTER 132

Study on Safety and Risk Management on Construction Projects with Special Reference to Building Projects in Pune

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ABSTRACT

The construction industry is inherently hazardous, with safety and risk management playing a critical role in ensuring worker well-being and project efficiency. This study focuses on analyzing safety practices and risk management strategies in building construction projects in Pune. Given Pune's rapid urbanization and increasing vertical expansion, the research aims to evaluate existing safety protocols, identify challenges, and propose solutions for improving workplace safety. The study employs a mixed-method approach, incorporating primary data collection through structured surveys and interviews with industry professionals and secondary data analysis of construction safety reports and regulations. A total of 103 responses were collected from professionals across 36 construction organizations in Pune, providing insights into workforce experience, safety training, regulatory compliance, and hazard mitigation measures. Findings reveal that while safety awareness is prevalent, gaps exist in implementation due to cost constraints, inadequate training, and limited regulatory enforcement. Key concerns include fall protection, equipment maintenance, emergency preparedness, and adherence to safety guidelines during adverse weather conditions. The study highlights the importance of proactive risk management strategies, including regular safety audits, enhanced training programs, and the integration of advanced technologies such as Building Information Modeling (BIM) and IoT-based hazard detection. By fostering a robust safety culture and strengthening risk mitigation frameworks, construction firms can reduce accidents, enhance compliance with occupational health and safety regulations, and improve overall project sustainability. This research contributes to the ongoing discourse on construction safety by offering practical recommendations for stakeholders in Pune's construction sector.

Keywords: Safety management, Risk assessment, Construction safety, Building projects, Pune

1.0 Introduction

The construction industry is one of the most hazardous sectors in the world, with a high incidence of workplace injuries, fatalities, and financial losses due to safety violations and risk mismanagement.

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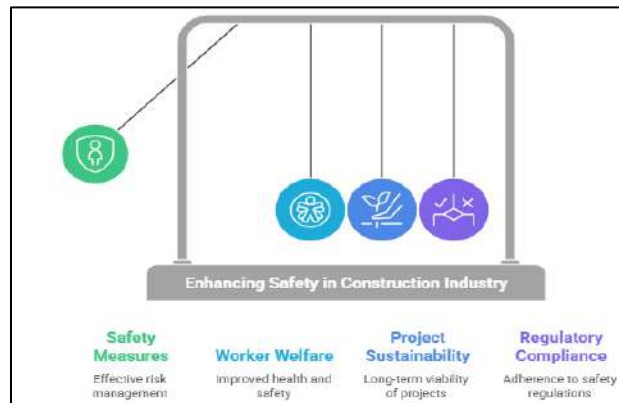
The preservation of project efficacy, the safeguarding of resources, and the well-being of personnel are contingent upon the implementation of risk management and safety measures (Lerman *et al.*, 2012). The importance of safety and risk management is heightened in urban centres like Pune, where accelerated infrastructural development and building construction are prevalent (Kodag & Kodag, 2023). A comprehensive risk assessment and safety management approach are required to mitigate potential hazards in construction projects, which include high-rise structures, commercial spaces, and residential buildings, due to the complexities involved. This research is dedicated to the evaluation of the efficacy of the current safety measures and risk management practices in the building construction sector of Pune, as well as the identification of areas that require refinement in order to improve the sustainability of projects and the welfare of workers (Pathak *et al.*, 2018).

Safety and risk management strategies that are effective are essential for reducing the probability of accidents and guaranteeing adherence to occupational health and safety (OHS) regulations. Construction labourers are at risk of experiencing a variety of hazards, including accidents from heights, equipment malfunctions, fire hazards, and material handling injuries. Furthermore, the viability of a project and the confidence of investors can be influenced by financial and reputational hazards. The demand for stringent safety protocols is exacerbated by the surge in construction projects that Pune, a swiftly developing metropolitan metropolis, experiences (Apurva, 2020). It is essential to incorporate safety measures into the planning, design, and execution phases of construction projects. This encompasses the implementation of Personal Protective Equipment (PPE), site safety audits, emergency response planning, and worker training programs. In order to improve on-site safety, advanced risk management techniques are currently being implemented, including real-time hazard detection through IoT-based sensors, Building Information Modelling (BIM)-based safety analysis, and risk probability matrices (Wehbi, 2022). Construction firms can substantially reduce their exposure to risk by emphasising safety culture and effective risk management frameworks. Incidents, improve operational efficiency, and ensure regulatory compliance in Pune's construction landscape. The fundamental practice of safety risk management in construction projects ensures the success of projects and the well-being of labourers. In the high-stakes and dynamic construction industry, prioritising safety is both a strategic necessity and a moral obligation.

Ekemezie & Digitemie, (2024), the industry involves numerous tasks, heavy machinery, and work at significant heights, all of which introduce risks that require stringent safety protocols and accident prevention measures. Over time, the construction sector has evolved, continuously improving safety practices in response to past incidents that underscored the need for comprehensive risk management. This historical evolution has shaped modern safety protocols, reinforcing the industry's commitment to worker protection. However, as construction projects become more complex due to technological advancements, increasing scale, and evolving risks, existing safety methodologies must adapt. The need for change is driven by the imperative to integrate innovative safety technologies, enhance risk assessment

strategies, and ensure compliance with new industry demands. The construction sector must embrace a proactive approach, revitalizing and redesigning safety methods to protect workers and maintain efficiency. By advancing safety risk management frameworks, construction projects can achieve sustainability, reduce hazards, and uphold industry standards, making safety an integral part of every project's success (Nwasike *et al.*, 2024).

Figure 1: Enhancing Safety in Construction Industry



Source: Authors' own

1.1 Challenges in implementing safety and risk management practices

Despite the recognized importance of safety and risk management, several challenges hinder their effective implementation in Pune's building projects. One of the primary issues is the lack of awareness and training among construction workers regarding safety protocols (Manjula & Silva, 2014). Many laborers, particularly in informal employment setups, have limited access to safety education and equipment. Additionally, cost constraints often lead construction companies to compromise on safety measures to maximize profits, which results in increased accident rates and project delays. Regulatory enforcement and compliance are also major concerns.

While national and state-level construction safety regulations exist, their implementation at the site level is inconsistent due to poor monitoring and lack of accountability. The dynamic nature of construction activities further complicates risk assessment, as unforeseen hazards can arise due to design modifications, environmental conditions, and workforce inefficiencies. Addressing these challenges requires a multi-faceted approach, involving stronger regulatory policies, technological integration, stakeholder collaboration, and a proactive safety culture to ensure the protection of workers and the successful completion of building projects in Pune.

1.2 Value addition through effective safety and risk management

The integration of structured safety and risk management mechanisms into construction projects offers numerous advantages, including economic and human benefits. Initially, it substantially decreases the occurrence of workplace accidents and injuries, thereby guaranteeing the safety of construction personnel. A well-managed safety framework also improves workforce morale and productivity, as employees feel secure in a risk-mitigated environment. From a financial standpoint, effective risk management leads to cost savings by minimizing project delays, legal liabilities, and medical compensations arising from accidents. It enhances the credibility and reputation of construction firms, making them more attractive to investors and clients who prioritize safety and sustainability. Moreover, compliance with safety regulations ensures smooth project approvals from regulatory bodies, reducing bureaucratic hurdles. The adoption of modern technologies such as AI-driven predictive analytics, real-time safety monitoring, and digital risk assessment tools can further refine safety strategies (Abbas & Duijster, 2025). For Pune's rapidly expanding construction sector, investing in safety and risk management is not just a regulatory necessity but a strategic advantage that contributes to long-term growth and development. This study aims to explore best practices, identify gaps, and propose recommendations for improving safety and risk management in Pune's building construction projects to foster a safer and more resilient industry (Godinho *et al.*, 2019).

2.0 Literature Review

The construction sector is inherently hazardous, with working at elevated levels posing a significant safety risk. As vertical expansion increases, effective safety risk management becomes crucial. Rubio-Romero *et al.* (2013) reviewed economic aspects, accident statistics, legal regulations, and scaffolding types, highlighting standard scaffolding's superior safety performance over nonstandard variants (Rubio-Romero *et al.*, 2013). Though costlier, standardized scaffolding enhances safety and simplifies maintenance, benefiting global construction practices. Shapira *et al.* (2013) examined 21 safety factors for tower crane sites, gathering insights from 19 managers in Israel (Shapira *et al.*, 2013). Their study aimed to establish safety protocols, highlighting challenges in identifying accident root causes and the importance of addressing multi-crane operations and worker exposure. Zhang *et al.* (2024) analyzed 2,991 questionnaires to explore how construction project owners influence worker safety behavior (Zhang, 2024).

They found that owners' objectives, safety organization, and hazard management significantly impact worker safety practices. Smita Bhole (2016) discussed key construction accident causes, such as worker negligence, improper procedures, and lack of safety measures (Bhole, 2016). The study emphasized the need for collaboration among all stakeholders to improve safety standards and minimize risks. Goh *et al.* (2018) examined high-rise construction safety, noting that untrained workers, unsafe actions, and weak management contribute to

accidents. They suggested a reward-penalty system for safety compliance and emphasized continuous site inspections for effective accident prevention.

Dewlaney *et al.* (2012) assessed the impact of environmentally friendly construction practices on safety. They found that these practices could increase risks like falls and strains, necessitating better safety management and design integration. Future research should enhance eco-friendly construction safety through improved planning and material risk assessment. Fortunato *et al.* (2012) also studied green construction risks, finding increased exposure to heights and heavy machinery, leading to greater physical strain. They emphasized balancing sustainability with worker safety and suggested strategies for mitigating occupational hazards in eco-friendly construction. Lan & Daigle (2014) analyzed Quebec's trench work regulations, revealing ambiguities that could lead to safety issues.

They recommended clearer definitions, risk identification, and updated soil classification criteria to prevent accidents. Zhao *et al.* (2015) studied electrical injuries in construction, advocating for a systemic accident analysis approach. They emphasized that accidents result from interrelated factors rather than solely worker error, recommending comprehensive system evaluations for risk reduction. Abubakar Sadiq (2016) focused on falls from heights (FFH) in Saudi Arabia, identifying key causes such as inadequate training, lack of inspections, and missing PPE. The study called for stronger safety programs, risk assessment models, and enhanced management commitment to mitigate FFH risks. Bussier & Chong (2022) explored the link between psychological distress and human error in construction safety. They found that addressing psychological distress reduces errors and enhances safety, advocating for both organizational and individual strategies to manage mental well-being at heights. Vijayan & Ms (2018) examined India's construction safety laws, noting inadequate implementation in Kerala (Vijayan, 2018). They emphasized workforce protection, urging builders, contractors, and authorities to collaborate in preventing major injuries and fatalities for the overall well-being of society.

Gurcanli *et al.* (2022) studied fatal construction accidents in Turkey, focusing on small and mid-sized residential projects where most accidents occur (Gürcanlı *et al.*, 2022). The study examined 25 concrete residential buildings in Istanbul and estimated safety costs during early project stages. Findings revealed that safety costs accounted for 1.92% of total construction costs, with 0.85 USD per man-hour needed for compliance. Sarah Phoya *et al.* (2012) analyzed health and safety risk management in Tanzania's construction industry. The study revealed that risk management is solely the contractor's responsibility and occurs only during construction. Risks are assessed informally through experience and discussions. Challenges include site configuration and procurement systems, highlighting the need for stakeholder involvement to improve safety management.

Fung *et al.* (2010) examined occupational health and safety in construction, emphasizing the need for systematic risk assessments. Many professionals rely on personal experience rather than structured evaluation methods. A Risk Assessment Model (RAM) was

developed to assess project risks, proving useful for identifying high-risk activities and preventing accidents based on historical data. Al-Anbari *et al.* (2015) developed the RASH method for assessing safety and health risks in Oman's construction sector. The method classified risks into safety and health categories, improving accuracy over traditional risk analysis. RASH provided more reliable risk estimation, showing statistical significance and enhancing risk management strategies for improved workplace safety. Gunduz *et al.* (2018) introduced a user-friendly risk assessment method for SMEs in construction, replacing probability estimates with control levels for more practical implementation. Applied to 22 SMEs, the method helped them update risk strategies efficiently. The approach promotes safer work environments, addressing the gap in risk assessment knowledge among small construction firms. King *et al.* (2014) investigated construction site accidents in Malaysia, identifying common safety practices and related challenges. Key issues included worker negligence, lack of financial support for safety, and communication barriers. Solutions included improved safety training, and increased budget. Zhang *et al.* (2022) Through surveys and interviews with industry professionals, safety risk management in Chinese underground construction projects was evaluated. The investigation revealed deficiencies in environmental preparedness and equipment maintenance, while construction planning and hazard communication were identified as strengths. The results provide policymakers with valuable insights to improve the safety strategies of subway construction in China.

2.1 Research gaps

In spite of the extensive research conducted on safety and risk management in the construction industry, there are still substantial gaps. There is a dearth of an integrated framework that addresses safety across diverse construction environments, despite the fact that numerous studies concentrate on specific construction hazards, including scaffolding safety, tower crane risks, and high-rise construction accidents. Additionally, while risk assessment models such as RAM and RASH have been developed, their application remains limited, especially among small and medium enterprises (SMEs), which struggle with implementation due to a lack of resources and expertise. Furthermore, studies highlight the role of worker behavior, psychological distress, and inadequate training in accidents, yet few address strategies to improve compliance and worker engagement systematically. Safety challenges in emerging economies, particularly in trench work, electrical safety, and eco-friendly construction, also require further exploration. There is a pressing need for a holistic approach integrating risk assessment, training, stakeholder involvement, and technological advancements to enhance safety practices across the construction sector.

3.0 Research Methodology

A mixed-method approach was employed to conduct the survey, utilizing both online and offline methods to reach a diverse range of respondents across different geographical

regions. Online surveys were distributed through construction industry forums, social media platforms, and targeted email lists, while paper-based surveys were administered at construction sites to include workers without online access. The survey questionnaire was structured to collect quantitative and qualitative data, allowing for a comprehensive analysis of safety practices and perceptions among construction workers. A survey was conducted using a structured questionnaire, yielding 103 individual responses from professionals across 36 distinct organizations within Pune's construction industry. The respondents held various positions and possessed diverse levels of experience, providing a comprehensive overview of the workforce composition. This sample size aligns with general recommendations for survey research, ensuring a balance between statistical reliability and practical feasibility. The diversity in organizational representation and respondent experience enhances the study's ability to generalize findings and draw meaningful conclusions about safety and risk management practices in Pune's construction sector.

3.1 Data Collection Methods

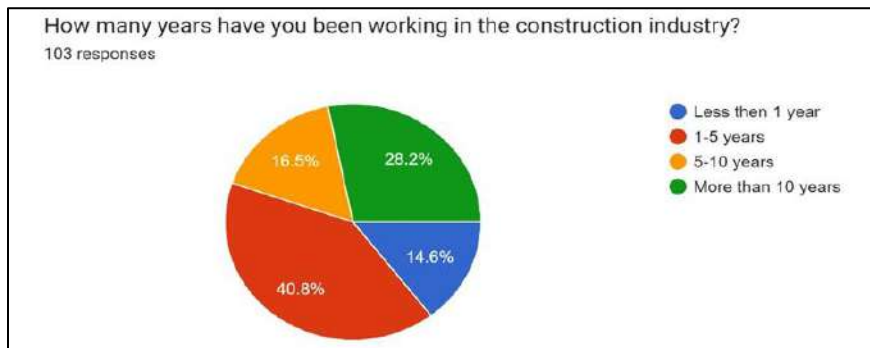
Primary data collection: A structured questionnaire was distributed to 103 individuals from 36 construction organisations in Pune. This sample size is consistent with the standard ranges employed in construction research, thereby guaranteeing the availability of reliable data for analysis. In order to evaluate safety awareness, training, risk perception, and compliance with safety protocols, the survey evaluated a variety of roles, such as construction labourers, site supervisors, project managers, and safety officers. Furthermore, in order to acquire a more comprehensive understanding of safety practices and risk mitigation strategies, semi-structured interviews with industry experts and direct on-site observations were implemented.

Secondary data collection: A comprehensive literature review was conducted, encompassing existing research papers, safety reports, construction safety guidelines, and government regulations pertinent to occupational safety in Pune's construction industry. Furthermore, past accident reports and safety incident records were analyzed to identify common risks and recurring safety issues in building projects. This secondary data provided a contextual foundation, enriching the analysis of primary data and facilitating a holistic understanding of safety and risk management practices within the local construction sector.

4.0 Data Analysis

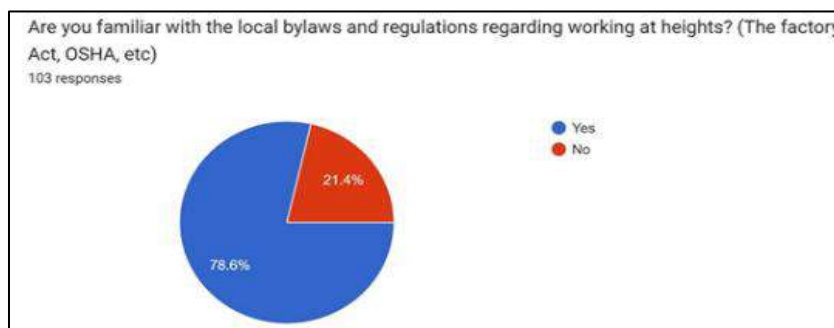
A structured questionnaire survey yielded 103 individual responses from professionals across 36 distinct organizations within Pune's construction industry. This sample size is considered adequate for statistical analysis in social science research, providing a balance between precision and resource constraints. The diverse representation enhances the study's ability to generalize findings and draw meaningful conclusions about safety and risk management practices in Pune's construction sector.

Figure 1: Working in the Construction Industry



The survey results reveal the distribution of work experience among 103 respondents in the construction industry. The discipline is significantly represented by relatively new professionals, as evidenced by the fact that the largest group (40.8%) has 1–5 years of experience. This is followed by 28.2% of respondents who have over 10 years of experience, indicating a robust representation of seasoned professionals. Additionally, 16.5% of respondents have 5–10 years of experience, while 14.6% have been in the industry for less than a year. This diverse distribution highlights a well-balanced workforce, where experienced professionals contribute expertise while newer entrants bring fresh perspectives. The findings emphasize the importance of targeted safety training programs catering to both experienced and novice workers to enhance workplace safety and efficiency in the construction sector.

Figure 2: Local Bylaws and Regulations Concerning Working at Heights



The survey results indicate the distribution of work experience among 103 respondents in the construction industry. The largest group (40.8%) has 1–5 years of experience, reflecting a significant presence of relatively new professionals in the field. This is followed by 28.2% of respondents who have more than 10 years of experience, showcasing a strong representation of

seasoned professionals. Additionally, 16.5% of respondents have 5–10 years of experience, while 14.6% have been in the industry for less than a year. This diverse distribution highlights a well-balanced workforce, where experienced professionals contribute expertise while newer entrants bring fresh perspectives. The findings emphasize the importance of targeted safety training programs catering to both experienced and novice workers to enhance workplace safety and efficiency in the construction sector.

Figure 3: Regular Training on Safety Regulations and Standards for Working at Heights

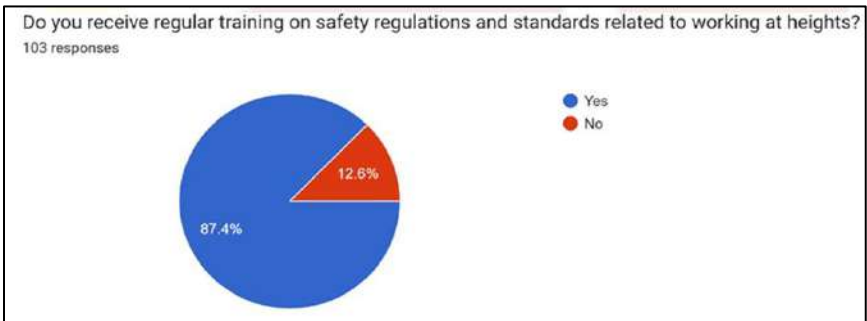
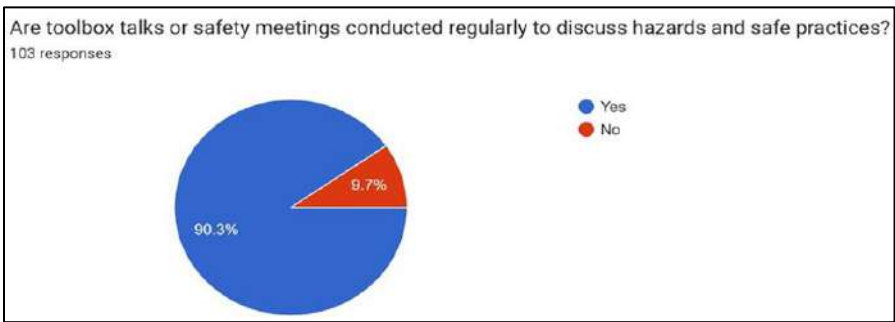


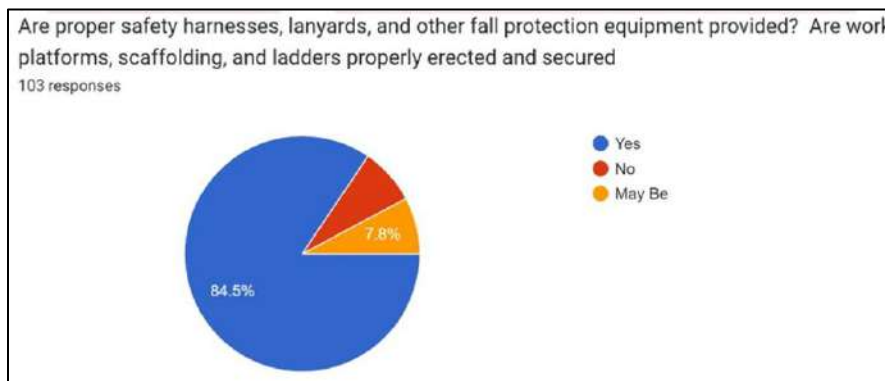
Figure 3: Toolbox Talks or Safety Meetings Conducted Regularly to Discuss Hazards and Safe Practices



The survey results indicate that 87.4% of respondents receive regular training on safety regulations and standards related to working at heights, reflecting a strong focus on workplace safety in the construction industry. However, 12.6% of respondents do not undergo such training, which poses a potential safety risk. Ensuring that all workers receive regular safety training is essential for reducing workplace accidents and maintaining compliance with safety regulations. Companies should strive for full participation in training programs to improve hazard awareness, reinforce safety measures, and foster a safer working environment for

construction workers. The survey results indicate that 90.3% of respondents confirm that toolbox talks or safety meetings are conducted regularly to discuss hazards and safe practices, demonstrating a strong commitment to workplace safety communication. However, 9.7% of respondents report that such meetings are not held consistently, highlighting a gap that needs to be addressed. Regular toolbox talks are crucial for reinforcing safety awareness, preventing accidents, and ensuring that workers stay informed about potential hazards. Construction companies should aim for 100% compliance in conducting these meetings to maintain a culture of safety and risk prevention on-site.

Figure 4: Availability and Proper Installation of Fall Protection Equipment



84.5% of respondents affirm the availability and effective installation of fall protection equipment, including safety harnesses, lanyards, scaffolding, ladders, and work platforms, according to the survey results. Nevertheless, 7.8% of respondents indicate that the equipment is either not provided or not adequately secured, while another 7.8% are uncertain. This implies that, despite the fact that the majority of construction sites prioritise fall protection, a small number continue to experience safety compliance gaps.

To mitigate risks, companies should ensure that all workers have access to properly installed and maintained fall protection equipment, reinforcing safety training and inspections to eliminate potential hazards.

The survey results indicate that 93.2% of respondents believe workers are provided with sufficient protection from falling objects, reflecting strong safety measures in place at most construction sites. However, 6.8% of respondents feel that protection is inadequate, which presents a potential risk for workplace injuries. To ensure complete safety, companies should reinforce the use of protective barriers, helmets, and secure storage of materials at heights. Regular safety inspections and strict compliance with safety protocols can further minimize the risk of falling object-related accidents in construction sites.

Figure 5: Adequacy of Protection Against Falling Objects

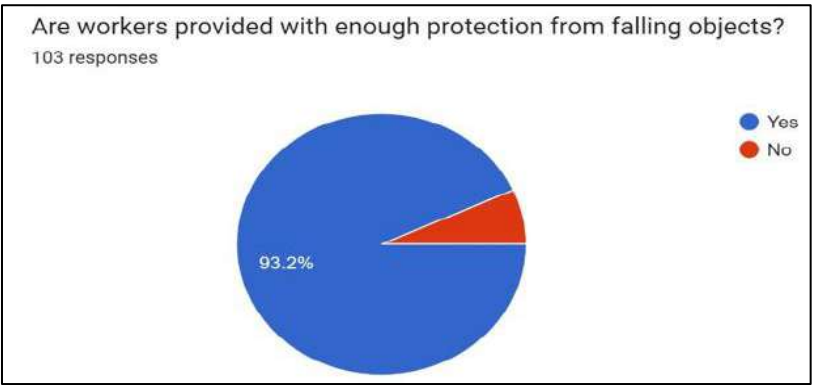
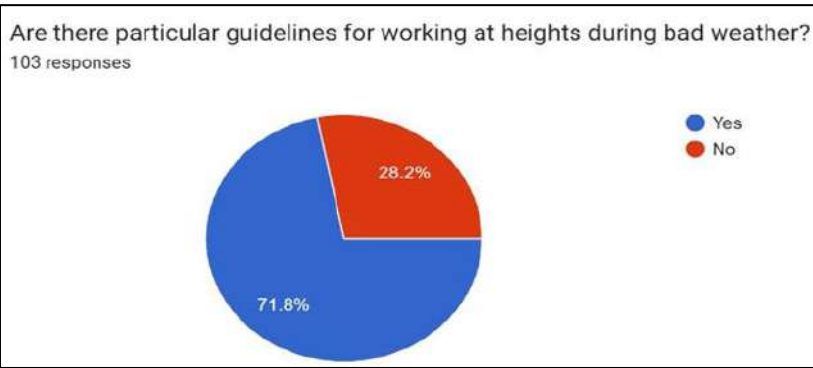


Figure 6: Availability of Guidelines for Working at Heights During Bad Weather



The survey results indicate that 71.8% of respondents confirm the existence of specific guidelines for working at heights during adverse weather conditions, which is a positive sign of safety preparedness. However, 28.2% of respondents report a lack of such guidelines, presenting a significant safety concern. Working at heights during bad weather, such as strong winds or heavy rain, increases the risk of falls and accidents. Construction companies should ensure that comprehensive weather-related safety protocols are established, communicated, and strictly enforced to protect workers from hazardous conditions. Regular training and reinforcement of these guidelines can further improve workplace safety.

The survey results reveal that 53.4% of respondents report the absence of hazards such as slippery surfaces, unguarded openings, or unstable structures, indicating that safety measures are implemented in many construction sites. However, 46.6% of respondents acknowledge the presence of such hazards, which presents a significant risk to worker safety. These hazards can

lead to slips, falls, and severe injuries if not properly addressed. Construction companies must prioritize hazard identification, regular site inspections, and immediate corrective actions to eliminate these risks. Implementing better site management, signage, and protective barriers can further enhance workplace safety and minimize accident occurrences.

Figure 7: Presence of Workplace Hazards Such as Slippery Surfaces, Unguarded Openings, or Unstable Structures

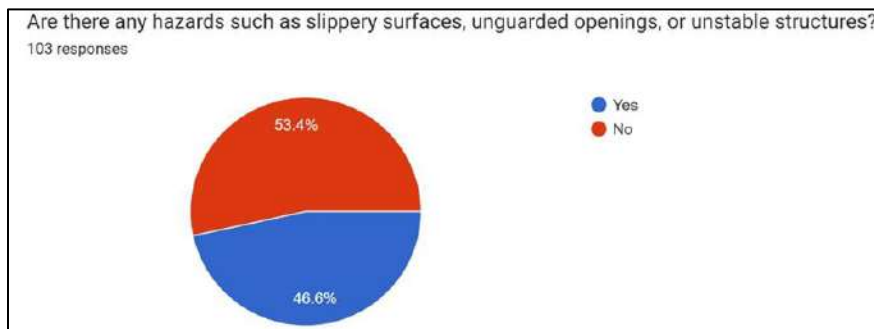
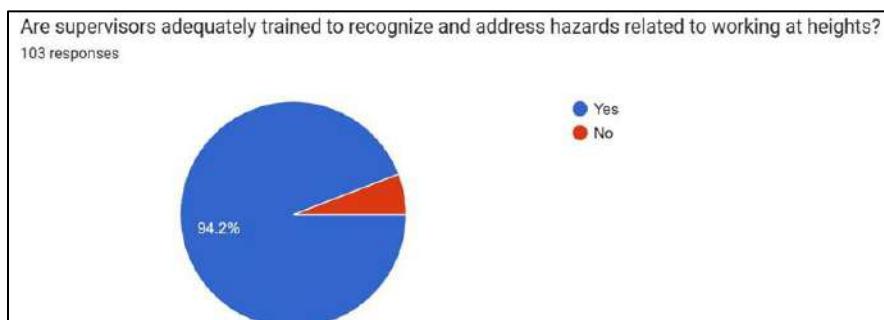
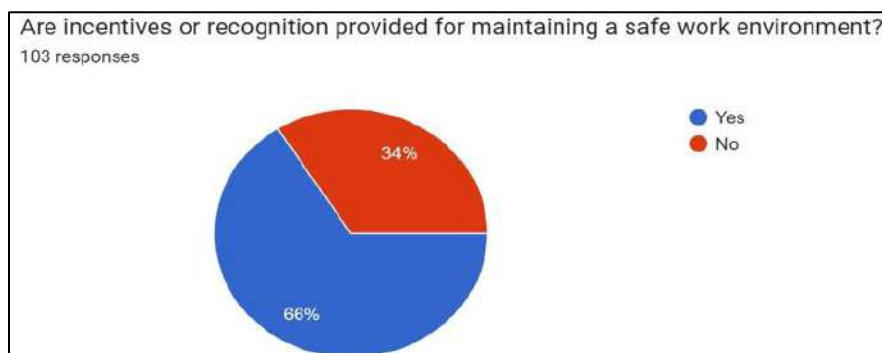


Figure 8: Supervisor Training on Recognizing and Addressing Hazards Related to Working at Heights



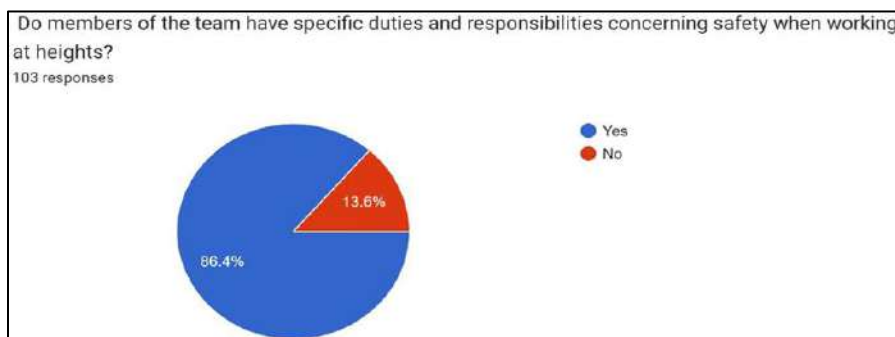
The survey results indicate that 94.2% of respondents believe that supervisors are adequately trained to recognize and address hazards related to working at heights. This suggests a strong emphasis on leadership training and hazard management in most construction sites. However, 5.8% of respondents feel that supervisors lack adequate training, which can pose a risk to worker safety. Ensuring that all supervisors receive continuous and updated safety training is crucial for maintaining a safe work environment. Construction companies should conduct regular training sessions and refresher courses to reinforce hazard identification and mitigation strategies, ultimately reducing the likelihood of workplace accidents.

Figure 9: Provision of Incentives or Recognition for Maintaining a Safe Work Environment



The survey results show that 66% of respondents confirm the presence of incentives or recognition programs for maintaining a safe work environment, indicating that many organizations acknowledge and reward safety compliance. However, 34% of respondents report a lack of such programs, suggesting room for improvement in motivating workers to prioritize safety. Implementing structured incentive programs, such as safety awards or bonuses, can encourage employees to adopt safer work practices. Recognizing and rewarding safety-conscious behavior fosters a proactive safety culture, ultimately reducing workplace accidents and enhancing overall construction site safety.

Figure 10: Team Members' Specific Safety Duties and Responsibilities When Working at Heights



The survey results indicate that 86.4% of respondents confirm that team members have specific duties and responsibilities related to safety when working at heights, demonstrating a structured approach to workplace safety. However, 13.6% of respondents report that such

responsibilities are not clearly assigned, which could lead to confusion and potential safety risks. Clearly defining and enforcing safety roles ensures accountability and enhances hazard prevention measures. Organizations should implement detailed safety protocols, assign responsibilities effectively, and conduct regular safety briefings to strengthen compliance and minimize risks associated with working at heights.

5.0 Conclusion

The critical importance of implementing effective safety measures to mitigate risks and improve construction site safety is underscored by the study on Safety and Risk Management in Construction Projects with Special Reference to Building Projects in Pune. The results suggest that, despite the increasing awareness of safety regulations and training, there are still voids in risk assessment methodologies, compliance, and implementation.

The construction industry in Pune, characterized by rapid urban expansion and increasing high-rise developments, faces significant hazards such as falls from heights, inadequate fall protection, and unsafe working conditions. The survey conducted among 103 respondents from 36 construction organizations provided valuable insights into safety practices. While most respondents reported regular safety training and toolbox talks, a notable percentage still lack access to structured risk assessment methodologies and compliance monitoring. Key concerns include the lack of proper guidelines for working at heights in adverse weather, inadequate incentives for maintaining a safe environment, and challenges in hazard identification. Furthermore, research gaps indicate the need for a holistic safety approach, integrating advanced technology such as IoT-based real-time hazard detection, systematic risk assessment models, and enhanced stakeholder involvement. The study suggests that construction companies, policymakers, and regulatory authorities must work collaboratively to enforce safety policies, provide adequate training, and develop risk mitigation strategies. Investing in a strong safety culture, incorporating modern safety technologies, and ensuring strict adherence to regulations will significantly reduce workplace accidents and improve overall construction efficiency in Pune's rapidly growing building sector.

References

Al-Anbari, S., Khalina, A., Alnuaimi, A., Normariah, A., & Yahya, A. (2015). Risk assessment of safety and health (RASH) for building construction. *Process Safety and Environmental Protection*, 94, 149–158. <https://doi.org/10.1016/j.psep.2015.01.009>

Bhole, S. M. A. (n.d.). Safety problems and injuries on construction site: A review. *International Journal of Engineering and Techniques*, 2. Retrieved from <http://www.ijetjournal.org>

Bussier, M. J. P., & Chong, H. Y. (2022). Relationship between safety measures and human error in the construction industry: Working at heights. *International Journal of Occupational Safety and Ergonomics*, 28(1), 162–173. <https://doi.org/10.1080/10803548.2020.1767301>

Chin, K. T. A. N., & Abdul Razak, N. (2014). Case studies on the safety management at construction site.

Dewlaney, K. S., Hallowell, M. R., & Fortunato, B. R. (2012). Safety risk quantification for high performance sustainable building construction. *Journal of Construction Engineering and Management*, 138(8), 964–971. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0000504](https://doi.org/10.1061/(ASCE)CO.1943-7862.0000504)

Fortunato, B. R., Hallowell, M. R., Behm, M., & Dewlaney, K. (2012). Identification of safety risks for high-performance sustainable construction projects. *Journal of Construction Engineering and Management*, 138(4), 499–508. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0000446](https://doi.org/10.1061/(ASCE)CO.1943-7862.0000446)

Fung, I. W. H., Tam, V. W. Y., Lo, T. Y., & Lu, L. L. H. (2010). Developing a risk assessment model for construction safety. *International Journal of Project Management*, 28(6), 593–600. <https://doi.org/10.1016/j.ijproman.2009.09.006>

Goh, K. C., Goh, H. H., Omar, M. F., Toh, T. C., Asuhaimi, A., & Zin, M. (n.d.). Accidents preventive practice for high-rise construction. <https://doi.org/10.1051/C>

Gunduz, M., & Laitinen, H. (2018). Construction safety risk assessment with introduced.

Gurcanli, G. E., Bilir, S., & Sevim, M. (2015). Activity-based risk assessment and safety cost estimation for residential building construction projects. *Safety Science*, 80, 1–12. <https://doi.org/10.1016/j.ssci.2015.07.002>

Lan, A., & Daigle, R. (2009). Review of regulations and guides for excavation and trenches—Comparison with the Québec safety code for the construction industry. *Journal of Construction Engineering and Management*, 14(4), 201. [https://doi.org/10.1061/ASCE1084-0680\(2009\)14:4\(201\)](https://doi.org/10.1061/ASCE1084-0680(2009)14:4(201))

Phoya, S. (2012). *Health and safety risk management in building construction sites in Tanzania: The practice of risk assessment, communication and control* (Licentiate thesis).

Rubio-Romero, J. C., Rubio, M. C., & García-Hernández, C. (2013). Analysis of construction equipment safety in temporary work at height. *Journal of Construction Engineering and Management*, 139(1), 9–14. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0000567](https://doi.org/10.1061/(ASCE)CO.1943-7862.0000567)

Sadiq, A. A. (n.d.). Fall from height accidents in the construction industry in Saudi Arabia. *Architecture Civil Engineering Environment*, 16(1).

Shapira, A., & Lyachin, B. (2009). Identification and analysis of factors affecting safety on construction sites with tower cranes. *Journal of Construction Engineering and Management*, 135(12), 124. [https://doi.org/10.1061/ASCE0733-9364\(2009\)135:1\(124\)](https://doi.org/10.1061/ASCE0733-9364(2009)135:1(124))

Vijayan, V., & Ms, R. (2018). *Issue 4 www.jetir.org (ISSN-2349-5162)*. Retrieved from www.jetir.org

Wu, X. (2024). Dynamic analysis and temporal governance of safety risks: Evidence from underground construction accident reports.

Zhang, Z., Guo, H., Gao, P., Wang, Y., & Fang, Y. (2023). Impact of owners' safety management behavior on construction workers' unsafe behavior. *Safety Science*, 158, 105944. <https://doi.org/10.1016/j.ssci.2022.105944>

Zhao, D., McCoy, A. P., Kleiner, B. M., Smith-Jackson, T. L., & Liu, G. (2015). Sociotechnical systems of fatal electrical injuries in the construction industry. *Journal of Construction Engineering and Management*. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862](https://doi.org/10.1061/(ASCE)CO.1943-7862)

CHAPTER 133

Study on the Parameters Affecting Housing Redevelopment Feasibility

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Mhatre Saakshi Chandrashekhar¹ and Shruti Vaishampayan²*

ABSTRACT

The rapid urbanization of Pune has underscored the growing need for housing redevelopment, particularly in areas with aging structures, rising population density, and a lack of essential amenities. As the city continues to expand, optimizing land use and modernizing the housing stock has become a critical requirement. Recent changes in regulations and government policies have significantly facilitated the progress of housing redevelopment projects. Over the last decade, redevelopment has gained momentum and is now considered a prominent and emerging sector in residential development, driven by increased land value and escalating property prices. However, the redevelopment process is complex, involving intricate negotiations between various stakeholders, careful financial planning, legal compliance, and other essential elements. Understanding the redevelopment process and identifying the key drivers influencing it is essential. For a redevelopment project to succeed, it must be feasible, making it crucial to analyze the parameters of feasibility and emphasize their role in minimizing risks while maximizing opportunities. This research leverages field observations and literature reviews to offer practical insights into the technical and financial aspects of the redevelopment process. The primary objective of this study is to examine an area undergoing redevelopment and analyse the factors that contribute to its feasibility.

Keywords: Redevelopment process; Residential market; Feasibility.

1.0 Introduction

1.1 Research problem

Rising housing demand in Pune's central zones—Sadashiv Peth, Kothrud, Shivaji Nagar, and Model Colony—has fuelled residential redevelopment. However, project feasibility remains uncertain due to technical, financial, and regulatory challenges. Developers face cost hikes, delays, and ROI risks, while residents worry about affordability and displacement. This study evaluates feasibility and constraints to redevelopment. It also proposes a decision matrix to guide developers toward optimized project outcomes.

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1.2 Aim and objectives

AIM: The project aims to study and analyse various technical and financial parameters influencing the feasibility of housing redevelopment projects.

1.3 Objectives:

- To understand redevelopment as an emerging business category by comparing and analysing synonyms such as revitalization, regeneration, and reconstruction.
- To study and understand the process of redevelopment and the technical and financial parameters associated with it
- Develop a structured decision matrix to help stakeholders evaluate the feasibility of the redevelopment project based on technical, financial, and regulatory aspects.

1.4 Scope and Limitations

Scope: This study analyses both developer-led and client-led redevelopment projects using a mix of qualitative and quantitative data from case studies, interviews, and secondary sources. It covers technical, financial, and regulatory aspects of feasibility while incorporating perspectives from developers, residents, and authorities. A structured decision matrix is developed to aid stakeholders in evaluating project feasibility.

Limitations: The study's findings are specific to Pune's urban context and may not be universally applicable. Changing market conditions and evolving policies could affect the long-term relevance of the decision matrix. Additionally, the research is limited by data availability and does not deeply explore social or environmental impact assessments.

2.0 Literature Review

Recent studies highlight how policy frameworks like UDCPR and dc rules facilitate vertical urban growth by increasing fsi and easing height restrictions. pune's 12-meter road rule supports optimized land use, encouraging self-redevelopment and affordable housing (Govt. of Maharashtra, 2021; Urunkar, 2025; Punekar News, 2022). Feasibility studies are vital, covering technical, financial, and legal parameters like fsi, tdr, cost, and compliance. tools like npv, irr, and bcr assess financial viability and support negotiation (Easton Associates, 2025; Airrises, 2024; Sable *et al.*, 2020; Maske & Gaikwad, 2021). Redevelopment enhances property value and demand by improving infrastructure. however, cost overruns and project delays remain challenges. bim is used to reduce these risks (Ki & Jayantha, 2010; Claassens *et al.*, 2019; Bader, 2011). key challenges include funding delays, legal issues, and displacement. transparent communication and credible developers reduce these risks (Vanvari & Mhaske, 2018; Ashar & Gohil; Pore & Wadalkar, 2017). Self-redevelopment case studies in Mumbai show better control, faster timelines, and higher satisfaction, driven by FSI incentives and state aid (IJSEDR, 2022; sample co-op society, 2015; Rishabh co-op, n.d.).

3.0 Research Methodology

This study uses a mixed-methods approach combining qualitative and quantitative analysis. It includes descriptive, comparative, and case study methods to evaluate redevelopment trends and project feasibility. Model Colony, Pune, is selected for its active redevelopment and TOD influence, focusing on 12 out of 20 identified projects within 3 km of Shivaji Nagar Metro Station.

Data collection:

- Primary: Site visits, surveys, stakeholder interviews.
- Secondary: ULCR-2034, MahaRERA, developer data, online portals, prior research.

Evaluation Parameters:

- Technical: Road width, plot size, height, FSI, built-up area.
- Financial: NPV, IRR, sale prices, revenue, cost recovery.

Scoring & Weighting: A Weighted Scoring Model (WSM) scores each parameter (1–10), grouped under technical and financial themes with assigned weightages based on relevance. Feasibility Score = $\sum (\text{Parameter Score} \times \text{Weight})$. Higher scores imply higher feasibility.

Table 1: Example of Feasibility Score Matrix for Technical & Financial Parameters

Theme	Parameter	Assigned weight (%)	Parameter score (scale 1-10)
Technical Parameter- Location & Accessibility (20%)	Location	8	9
	Accessibility	6	10
	Road Width	6	8
Financial Parameter (15%)	NPV	10	9
	Profitability Index	5	8

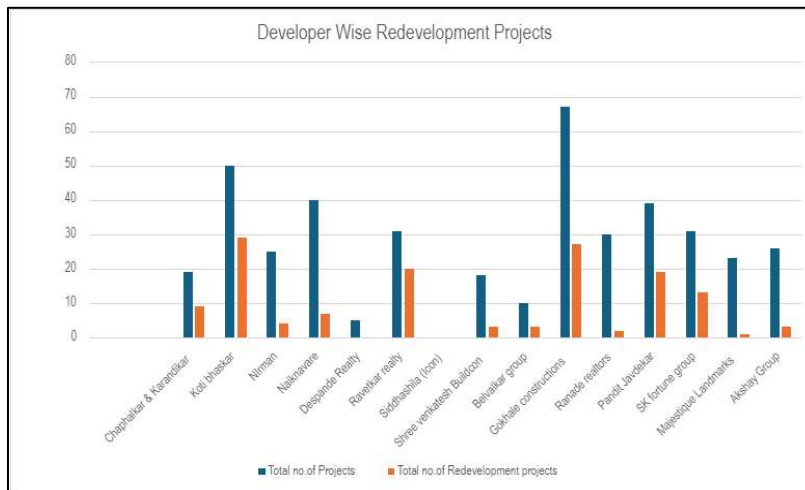
4.0 Analysis and Ranking

Projects are ranked as Best, Moderate, or Least Feasible. Comparative analysis verifies results against market trends. Sensitivity analysis tests the impact of changing parameter weights, while scenario testing evaluates performance in varied market conditions.

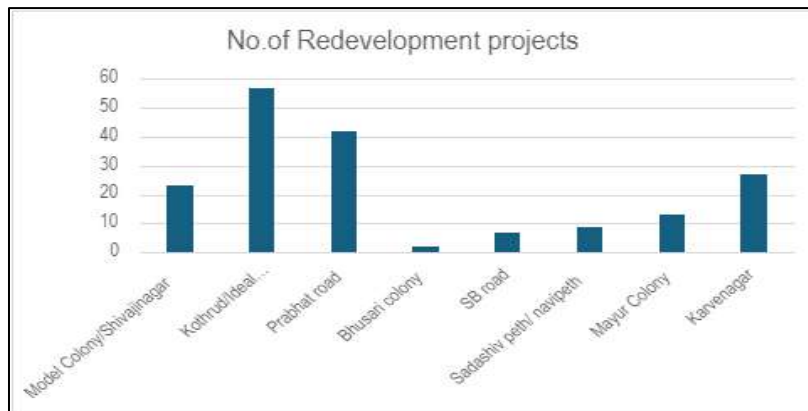
5.0 Data Collection

5.1 Redevelopment as an emerging market in pune

Pune’s property market is undergoing major redevelopment due to land scarcity and aging buildings. Key areas like Sadashiv Peth, Shivajinagar, and Kothrud drive this trend, supported by policies and housing demand. Developers gain from FSI incentives, low land costs, and high central returns. Government support, faster approvals, and guaranteed buyers’ lower risks. Homeowners get safer, modern homes with better infrastructure and no added cost, though only 6 of 15 top developers focus on redevelopment. (See Figure 1)

Figure 1: Developer Wise Redevelopment Projects

Central Pune areas like Kothrud, Prabhat Road, and Model Colony are undergoing major redevelopment due to their dense midrise settlements, many over 50 years old. These locations have high historical value, strong demand, robust infrastructure, and prime connectivity. Kothrud leads in redevelopment, followed by Prabhat Road and Model Colony, as developers aim to revamp these sought-after neighbourhoods. (See Figure 2)

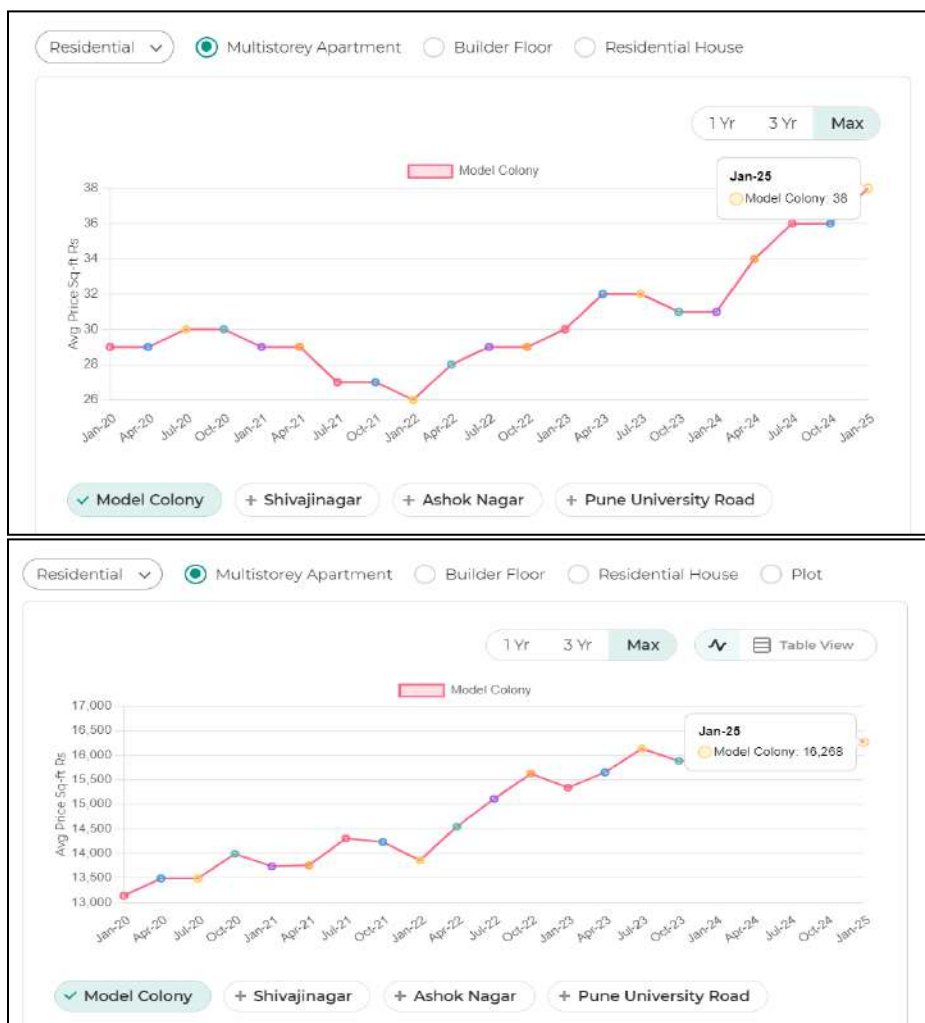
Figure 2: Redevelopment Projects in Core Areas of Pune

5.2 Market review of model colony

Model Colony, near Shivaji Nagar and F.C. Road, is a prime Pune locality seeing rapid development due to strong infrastructure, job growth, and property demand. Despite old mid-rise buildings and underused FSI, it remains one of Pune's greenest and most desirable areas.

Property prices rose 17% since April 2022, averaging ₹16,268/sq. ft., with rates between ₹13,300–₹19,800. Rentals also jumped 46%, from ₹26 to ₹38/sq. ft., making it attractive for both residents and investors. (See Figure 3)

Figure 3: Sale Price & Rental Value Trends in Model Colony



Source: I-Magicbricks Realty Services Limited, n.d.-b

5.3 Identification of sample size and gathering data based on redevelopment projects

Following below is the list of redevelopers, and their projects identified in Model colony, Pune. This comprehensive list of projects is used as sample size for further research.

From the following list first 12 projects are taken as sample size. The sample size is a mix of projects which are either newly launched, under construction or completed. (See Table 2)

Table 2: List of Redevelopment Projects

Sr. No	Project name	Sr. No	Project name
1	Dinmanee	11	Garud House
2	Prakash	12	Tej-Ameet
3	Arati	13	Swojas Adwait
4	Shubhamkaroti	14	Shivatman
5	Ashokban	15	Nirman Shreyas
5	Siddhashila Madhusagar	16	Nirman Vishnubaug
6	Sheetalkunj	17	Amrutkunj
8	Pleasant apartment	18	Jeevan Pradeep
9	Nandvihar	19	Dharmesh
10	Kusum CHS	20	Madhvachhaya

5.4 Identification of technical & financial parameters

Successful housing redevelopment hinges on comprehensive technical and financial evaluation to ensure long-term viability. Key technical factors include location, road width, plot size, and FSI utilization, while unit types and amenities affect usability and market appeal. Financial tools like NPV, BCR, and PI are used to gauge profitability. In this study, 20 redevelopment projects are analysed using parameters from literature, with accessibility assessed by proximity to Shivaji Nagar metro and University Road. Key data—such as side margins, parking, height, FSI use, and carpet area—are sourced from approval drawings to support informed and sustainable decision-making. (Refer Sheet- Identification of Feasibility Parameters and Technical Data Collection, Financial Data Collection https://docs.google.com/spreadsheets/d/1mqLbq_VfWEzrnX3e0H7bY04SZHCMXkg/edit?usp=sharing&ouid=101527505924198501463&rtpof=true&sd=true)

6.0 Data Analysis

This section presents the analysis of 12 redevelopment projects, studied under various technical and financial parameters. Each project is analysed and judged based on feasibility score.

TOTAL FEASIBILITY SCORE= $\sum$ (FEASIBILITY SCORE * WEIGHTAGE)

6.1 Technical feasibility

Redevelopment schemes are scored on 17 technical parameters under three themes, using a 10-point scale. In Model Colony, the system analyses site potential, design efficiency,

and market impact. Key factors like FSI, carpet area, and unit layout drive feasibility. Market trends, policy, and construction stages shape viability. A weighted model—technical (45%), market (35%), location (20%)—ensures balanced, industry-aligned evaluation.

Refer Sheet Scoring Matrix and Weightage https://docs.google.com/spreadsheets/d/1mqLbq_VfWEzrnX3e0H7bY04SZHCMXkg/edit?usp=sharing&oid=101527505924198501463&rtpof=true&sd=true) Each parameter is scored out of 10 based on relevance, then multiplied by its assigned weight. The total weighted score ranks the projects, identifying the most technically feasible one. This helps in objective project evaluation..(Refer Sheet- Technical Data Collection, https://docs.google.com/spreadsheets/d/1mqLbq_VfWEzrnX3e0H7bY04SZHCMXkg/edit?usp=sharing&oid=101527505924198501463&rtpof=true&sd=true)

According to the feasibility scores derived, the projects are categorized since highly feasible, moderate feasible and least feasible. (Refer Table 3 and Sheet Technical Feasibility Scoring, https://docs.google.com/spreadsheets/d/1mqLbq_VfWEzrnX3e0H7bY04SZHCMXkg/edit?usp=sharing&oid=101527505924198501463&rtpof=true&sd=true)

Technical feasibility score matrix: Redevelopment project viability is grouped into three levels based on technical, structural, and market performance. Highly feasible projects (Rank 1–4) feature optimal FSI (0.54–0.60), efficient design, and high demand, ensuring quick, cost-effective completion. Moderately feasible ones (Rank 5–7) have average FSI (0.48–0.54), decent demand, but slower timelines and possible regulatory delays. Least feasible projects (Rank 8–11) struggle with low FSI (0.18–0.36), limited plots, weak demand, and moderate zoning compliance (0.42–0.63). These challenges reduce their investment appeal. (Refer Sheet-Tech & Fin Scoring https://docs.google.com/spreadsheets/d/1mqLbq_VfWEzrnX3e0H7bY04SZHCMXkg/edit?gid=426802062#gid=426802062)

6.2 Financial feasibility

Projects are financially assessed using six parameters, each scored out of 10 and weighted by significance. Construction cost and revenue have the highest weight (22% each) for their direct link to profitability. Sales price is next at 18%, followed by NPV (14%) for long-term value, Profitability Index (13%) for capital efficiency, and BCR (11%) as a relative metric. This approach ensures a practical, efficiency-focused evaluation of economic feasibility. (Refer Sheet- Scoring Matrix Financial Parameters, Weightage Allocation, https://docs.google.com/spreadsheets/d/1mqLbq_VfWEzrnX3e0H7bY04SZHCMXkg/edit?usp=sharing&oid=101527505924198501463&rtpof=true&sd=true)

6.3 Final feasibility score matrix

Feasibility rankings highlight cost recovery and revenue as key profitability drivers. Low-cost, high-sale projects show better NPV and viability; even high-cost ones like Pleasant Apartments perform due to demand. BCR is critical in rehab-heavy projects (e.g., Nandvihar, Siddhashila). Poor FSI use and sales weaken projects like Dinmanee. NPV, BCR >1, and PI >0

confirm feasibility, seen in Nandvihar, Ashokban, and Pleasant Apartments. (Refer Sheet-Financial Feasibility Scoring, Weightage Allocation for financial feasibility https://docs.google.com/spreadsheets/d/1mqLbq_VfWEzrnX3e0H7bY04SZHCMXkg/edit?usp=sharing&ouid=101527505924198501463&rtopof=true&sd=true)

Projects ranked 1–4 (Nandvihar, Pleasant Apartment, Ashokban, Siddhashila Madhusagar) score high across all six financial criteria, making them the most financially feasible. Projects ranked 5–8 show moderate feasibility, with revenue, BCR, and PI scores between 5–7, indicating they are competitive but not top-performing. Projects ranked 9–12 have lower overall scores, with NPV, BCR, PI, and sale prices ranging from 1–4, highlighting weak financial viability. High construction costs and low revenue lead to negative NPV, making these the least feasible investments. (Refer Sheet- Tech & Fin Scoring https://docs.google.com/spreadsheets/d/1mqLbq_VfWEzrnX3e0H7bY04SZHCMXkg/edit?gid=426802062#gid=426802062)

7.0 Conclusion

The viability of housing redevelopment depends on a balanced integration of technical and financial factors. projects with optimal FSI use, strong sale prices, and regulatory compliance are most sustainable and low risk. some technically sound projects may still face viability issues due to low prices and high costs, needing cost-cutting to remain feasible. Conversely, financially strong projects with technical limitations like zoning or infrastructure issues may face execution risks. key technical elements include fsi use, design, zoning adherence, accessibility, and infrastructure. Financial success hinges on a good cost-to-income ratio, positive NPV, and BCR. A holistic, balanced approach ensures redevelopment success.

References

Chaphalkar Karandikar Developers. (n.d.). *Chaphalkar Karandikar Developers*. <https://ckdevelopers.in/Icon> Pune. (n.d.). *Sheetalkunj*.

Magicbricks Realty Services Limited. (n.d.). *3 BHK multistorey apartment for sale in Model Colony, Shivaji Nagar*. <https://www.magicbricks.com/Model-Colony-in-Pune-Overview>

Maharashtra Real Estate Regulatory Authority. (n.d.). *Maharashtra Real Estate Regulatory Authority ISO 9001:2015 certified*. <https://maharera.maharashtra.gov.in/>

Parab, L., & M/s Liladhar Parab Architects & Designers. (n.d.). *Feasibility report on redevelopment of Rishabh Co-Op Housing Society Ltd, Plot No.1, Sector-9, Vashi, Navi Mumbai*. https://rishabhchs.com/Assets/Images/Files/Rishabh%20Chsl%20_Feasibility%20Report.pdf

Sable, S., Pataskar, S., & Patil, A. (2020). Financial feasibility study on a redevelopment residential high-rise building. *International Research Journal of Engineering and Technology (IRJET)*, 7(7), 4871–4877.

Sample Co-Operative Housing Society Ltd. (2015). *Sample feasibility report*. https://projectmaitree.files.wordpress.com/2018/03/sample-report_low-resolution.pdf

Siddhashila Developers. (n.d.). *Siddhashila Madhusagar: Luxurious 2 BHK flats in Pune*. <https://www.siddhashila.com/madhusagar.html>

SK Fortune Group. (2024, September 24). *SK Fortune Group | Real estate developers in Pune*. <https://fortunedeveloper.in/>

Timesproperty. (2024, March 14). New society redevelopment rules on Maharashtra housing. *Timesproperty*. <https://timesproperty.com/article/post/new-society-redevelopment-rules-on-maharashtra-housing-blid6967>

CHAPTER 134

Sustainable Concrete

Gourav G. T.¹, Suhas A.¹, Gangadhar S. D.¹, Smaran D.¹ and Shridhar Kumbhar²

ABSTRACT

The construction industry faces a disaster due to the declining supplies of virgin materials, in addition to the environmental degradation associated with the existing construction practices. This makes it necessary to seek alternatives such as construction and demolition (C&D) waste and event-related materials like rice husk ash (RHA) as partial substitutes of Portland cement. This study explored the effects of replacing Portland cement with RHA at various ratios (0, 5, 10, and 50%) in combination with different water-cement ratios (0.3, 0.5, and 0.7) towards strength and durability of concrete. The experimental findings reveal that compressive strengths are improved by the addition of fine RHA particles; however, higher water-cement ratios lead to decreased strength due to the increased tendency for porosity. Higher RHA content would exhibit with time higher compressive values to a level of excess and have adverse consequences on concrete attributes. Fine RHA particles in the concrete mixture increase bulk density and impart better features to the concrete. The application of C&D waste, together with RHA and similar material, could be a way out of material scarcities and environmental pollution and create a scenario for a future sustainable construction environment. The study also suggests more research effect of varying water-cement ratios on the concrete mixes re-placed with RHA.

Keywords: Construction and demolition waste materials; Rice husk ash; Sustainable construction practices.

1.0 Introduction

The construction industry is a core element of contemporary infrastructure, boosting both the economy and cities. There are, however, some very obvious challenges, particularly the fast exhaustion of virgin resources, which can, in their own way, harm the environment due to traditional construction practices. These parameters call out for a transition to more sustainable options and remedies like recycling construction and demolition (C&D) waste or using it in cement production. These problems illustrate why there is a need to shift to greener alternatives, namely, using C&D waste or cement substitution in cement reduction procedures. Building or construction processes are mainly dependent on the first extracted unprocessed raw materials; so-called virgin materials.

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Construction infrastructure requires a significant amount of minerals, metals, and even wood. But these administrators continuously exploit these resources, thereby questioning the sustainability of such actions. As these resources are limited, the construction sector is susceptible to exorbitant pricing and project cancellation delays. Other than these minerals, the case for a sustainable construct of these extractive methods is raised; for these constructive mining methods adversely tip the scales of nature, tend to destroy habitat systems, and hence lose out on biodiversity.

2.0 Literature Review

Safe disposal of construction and demolition (C&D) waste is paramount in attempting to protect the environment and promote sustainability. Different approaches proposed in this field include life cycle assessment (LCA), estimation systems, and recycling programs. The LCA research showed that the major contributors towards environmental impacts are associated with transportation, sorting, and disposal of the wastes, whereas recycling of plastics, metals, and aggregates could alleviate some of these impacts. Some materials, including wood and cardboard, may still contribute to global warming potential, although they might be recycled. Estimating systems can predict the quantities of wastes and thus assist in the development of policies and operational plans by means of spatial data and statistical models. Fast urban growth in developing countries has obviously caused the increase in construction and demolition waste, but in fact, so many areas still suffer from weak regulatory systems.

Construction solely depends on landfills for these wastes. Certainly, application of "3R" concepts (Reduce, Reuse, Recycle) would play an important role in the effective management of wastes and, therefore, mitigates their impacts to the environment. Innovative management practices for C&D waste differ from one part of the globe to another. Developed areas have instituted policies that require C&D waste to be managed for recycling; however, developing nations suffer challenges due to a lack of regulatory support. Initiatives to curb waste from the source will assist in limiting contamination and increasing material recovery rates, thus improving recycling performance.

Construction of effective scrap-recycling plants with improved logistics of waste transportation will also have the potential to reduce energy consumption with corresponding lessening of greenhouse gas emissions. Research states recycling C&D waste is seen to save energy heavily and reduces emissions. Everything that will create durable sustainability should be the creation of good models to predict waste generation, improvement in pertinent regulatory systems, and the infusion of funds into innovative recycling technologies. Traditionally known as a by-product stemming from milling rice, rice husk ash (RHA) has aroused much interest when used as an additional cementitious material in concrete. RHA is an ideal partial cement substitute but highly pozzolanic and rich in silica as well. According to various studies, RHA helps enhance durability, mechanical resistance, and harsh-weather resistance in concrete. It has

been found that in the finely powdered form, RHA fills the voids in the concrete matrix, making the mix denser by utilizing the pozzolanic reaction that happens inclusively into the setting of concrete; these, in turn, attribute to the improvement in the sulphate resistance, alkali-silica reaction, and chloride attack resistance along with decreasing permeability. Researchers recommend that for these parameters to influence the performance of RHA in concrete applications, the proper grinding and controlled burning procedures should be employed to ensure RHA attains desired reactivity.

Environmentally speaking, RHA is another very attractive option. RHA uses this agricultural waste to reduce CO₂ emissions and cement use and to encourage sustainable building practices. The research indicates that RHA not only enhance the lifespan of concrete structures in rice husk waste tailing areas but also saves construction costs significantly. Its viability for sustainable construction materials is further enhanced by research being conducted into its potential applications into advanced concrete technologies, such as high-performance concrete and self-compacting concrete.

Table 1: Chemical properties of Rice Husk Ash

Compound/element (constituent)	Weight percent
Silica (SiO ₂)	91.56
Carbon	4.8
Calcium oxide CaO	1.58
Magnesium oxide, MgO	0.53
Potassium oxide, K ₂ O	0.39
Haematite, Fe ₂ O ₃	0.21
Others	0.93

The ability of polypropylene (PP) fibers to enhance concrete performance has been an extensively researched field. The research indicates that PP fibers provide considerable resistance to cracking in the concrete, particularly against drying shrinkage and plastic shrinkage cracks. These fibers are able to improve the tensile strength and energy absorption capacity of the concrete; hence, they serve as micro-reinforcements. It is reported that PP fibers enhance the ductility, toughness, and impact resistance of the concrete without any significant effect on workability. Polypropylene fibers also contribute to a certain extent to the fire resistance of concrete by becoming molten at elevated temperature and forming micro-channels that relieve the build-up of internal pressure, thereby preventing spalling during fire exposure. A consideration of the desired properties will influence the optimum amount of fiber to use. Enhancing fire-resistance properties is generally said to be accomplished with 0.1-0.3% fiber volume of concrete mix. The review of literature suggests that polypropylene fibers make low-cost improvements in concrete durability, especially for applications such as pavements, industrial floors, and precast structures.

3.0 Objective

- Development of Sustainable Concrete Using Recycled Materials.
- Promoting a Circular Economy in Construction by Minimizing Reliance on Virgin materials
- Assessing the effectiveness of rice husk ash (RHA) as a pozzolanic alternative to partially replace Portland cement.

4.0 Research Methodology

The research methodology of sustainable concrete development starts with a literature review that studies the construction and demolition (C&D) waste, rice husk ash, and polypropylene fibres based on literature surveys of the past work. Then comes Material Selection and Procurement, which is set to avail the optimum raw materials like recycled aggregates and rice husk ash. Material Testing is further differentiated into test categories: Physical Tests and Chemical Tests for composition analysis. Once the materials are approved for the quantity required, Blocks Casting follows with some optimized mix proportioning, moulding, and curing. Block Testing and Analysis evaluate the durability and mechanical performance based on compressive strength and water absorption.

5.0 Experimental Methodology

Experimental methodology gives an insight into the characterization tests undertaken on C&D waste aggregates, rice husk ash, and polypropylene fibres. The casting process of concrete blocks involves the steps of batching, mixing, moulding, compacting, and curing. Mechanical properties, including compressive strength and flexural strength, were tested with water absorption tests for the assessment of durability. The methodology aims at comparing the nominal mix with conventional concrete blocks to see the possibility of large-scale implementation.

5.1 Selection of materials

The selection of appropriate materials is essential for developing blocks with enhanced mechanical properties and sustainability. This study focuses on incorporating construction and demolition waste aggregates as a replacement for natural aggregates and Replacement of cement with RHA and Polypropylene Fibers. The RHA binder system, eliminates the Partial need for conventional cement, significantly reducing carbon emissions. The integration of C&D waste aggregates reduces environmental pollution, while fibres enhance toughness, impact resistance, and durability. The material is sourced from processed Construction and Demolition (C&D) waste, primarily consisting of crushed concrete, bricks, and tiles. It is carefully graded to a

particle size range of 10mm to 12mm, in compliance with IS 383:2016, which specifies the grading requirements for coarse aggregates.

Figure 1: Pictures of Construction & Demolition Plant at Pune



The material is sourced from crushed C&D waste fines and Manufactured Sand (M-sand), with a particle size below 4.75mm as per IS 383:2016 for fine aggregates. It plays a crucial role in the paver block matrix by filling voids, enhancing workability, improving particle

bonding, and facilitating better strength development. Additionally, it contributes to durability, reduces permeability, and promotes sustainable utilization of recycled materials. Rice husk ash (RHA) In concrete, rice husk ash (RHA), a very potent pozzolanic substance, can partially substitute cement. Its chemical makeup, fineness, and burning method are among of the important criteria that determine whether it is chosen as a cement substitute. The silica (SiO_2) found in RHA combines with calcium hydroxide during cement hydration to create more calcium silicate hydrate (C-S-H) gel, which increases the strength and durability of the concrete.

RHA's performance is largely dependent on its quality. Superior pozzolanic activity is provided by amorphous silica, which is produced by controlled combustion at temperatures between 500°C and 700°C . Achieving fine particle sizes that increase packing density and reduce voids in the concrete matrix also requires proper grinding. Concrete block mixes frequently contain polypropylene (PP) fibers to improve its durability and mechanical qualities. By decreasing crack development, increasing tensile strength, and boosting impact resistance, 15 mm polypropylene fibers serve as an efficient reinforcement. In concrete blocks, where surface stability and structural integrity are essential, these longer fibers are especially advantageous.

Figure 2: Raw Materials Used for Concrete



Table 2: Mix Design

Mix Design	RCA (kg)	RFA (kg)	Cement(kg)	RHA(kg)	P Fibers (g)
M1(0%)	4.1	2.025	2.025	0	12
M2(5%)	4.1	2.025	1.924	0.101	12
M3(10%)	4.1	2.025	1.822	0.202	12
M4(15%)	4.1	2.025	1.721	0.303	12
M5(20%)	4.1	2.025	1.620	0.405	12
M6(25%)	4.1	2.025	1.518	0.506	12
M7(30%)	4.1	2.025	1.417	0.607	12
M8(40%)	4.1	2.025	1.215	0.810	12
M9(50%)	4.1	2.025	1.0125	1.0125	12

Figure 3: Mixing Casting and Curing Process



5.2 Mix design

The mix design of concrete blocks is crucial for achieving optimal strength, durability, and sustainability. In this study, Construction & Demolition (C&D) waste, recycled aggregates, RHA, Cement Polypropylene fibers, and water are used to produce environmentally friendly concrete blocks.

5.3 Production of concrete blocks

After selecting the materials and designing the mix proportions, the next critical phase involves the mixing, casting, and curing process. Proper execution of these steps ensures uniformity, strength, and durability in the final blocks. The mixing process plays a vital role in ensuring the homogeneous distribution of materials without any lumps. Proper mixing directly influences the concrete's quality, ensuring improved strength, durability, and performance in structural applications.

5.4 Testing of concrete blocks

- The blocks should undergo proper curing for 7 and 28 days to ensure strength development before testing begins.
- The specimens must be free from cracks, voids, or defects that could negatively impact the accuracy and reliability of test results.
- A measuring scale should be used to measure the exact length, width, and thickness of each paver block accurately.
- The loaded area (A) in mm² should be calculated using the formula: $A = \text{Length} \times \text{Width (mm}^2\text{)}$ to determine stress distribution.
- The paver block should be centrally placed on the lower platen of the Compression Testing Machine (CTM) to ensure uniform load application.
- Steel or rubber pads can be placed on top of the specimen if necessary to distribute the applied compressive load evenly.

Figure 4: Concrete Blocks Testing



5.5 Test Results

For this study, 150*150*150 mm cubes of design mix M25 grade were assessed. After seven and twenty-eight days of curing, the specimens were assessed. Rice husk ash was used to partially replace cement in the first three standard concrete cubes. To substitute cement, different amounts of rice husk ash and C&D waste aggregate were used: 0%, 5%, 10%, 15%, 20%, 25%, 30%, 40%, and 50%. Four cubes were cast for each percentage.

Table 3: Compressive Strengths after 7, 28, Days of Curing. (Nominal Concrete)

Days	Compressive Strength in MPA
7	16.9
28	26.31

Table 4: Compressive Strengths after 7, 28, Days of Curing. (0% RHA)

Days	Compressive Strength in MPA
7	16.22
28	25.91

Figure 5 Shows the Compressive Strengths after Curing in MPA after 7 Days and 28 of Concrete. With no Replacement of Cement Using C&D Waste.

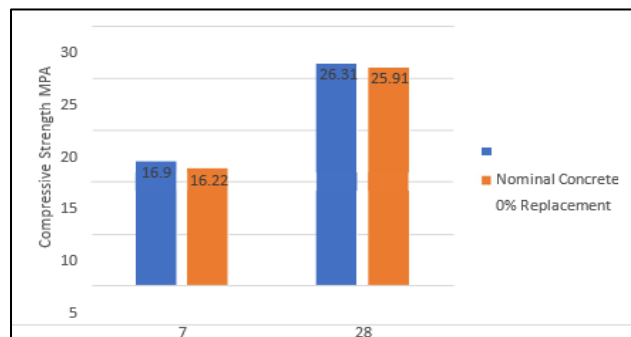


Figure 6 Shows the Compressive Strengths after Curing in MPA after 7 Days and 28 of Concrete. With 5% Replacement of Cement with RHA Using C&D Waste.

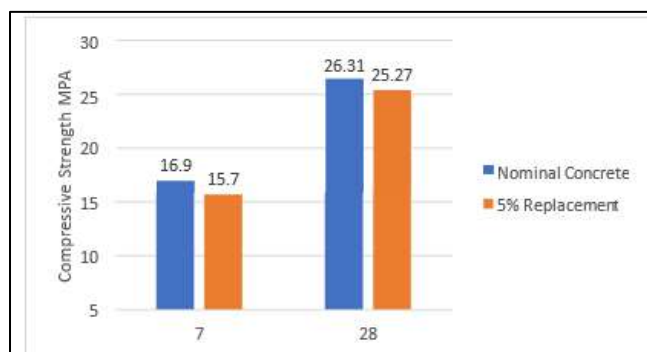


Table 5: Compressive Strengths after 7, 28, Days of Curing. (5% RHA)

Days	Compressive Strength in MPA
7	15.7
28	25.27

Table 6: Compressive Strengths after 7, 28, Days of Curing. (0% RHA)

Days	Compressive Strength in MPA
7	12.22
28	24.13

Figure 7 Shows the Compressive Strengths after Curing in MPA after 7 Days and 28 of Concrete. With 10% Replacement of Cement with RHA Using C&D Waste.

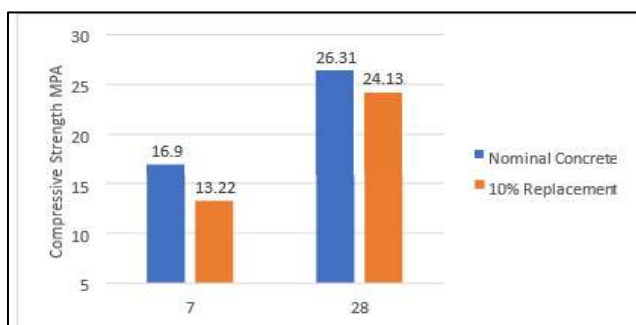


Figure 8 Shows the Compressive Strengths after Curing in MPA after 7 Days and 28 of Concrete. With 15% Replacement of Cement with RHA Using C&D Waste.

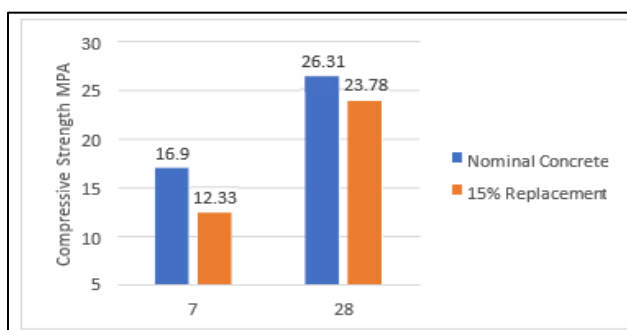


Table 7: Compressive Strengths after 7, 28, Days of Curing. (15% RHA)

Days	Compressive Strength in MPA
7	12.33
28	23.78

Table 8: Compressive Strengths after 7, 28, Days of Curing. (20% RHA)

Days	Compressive Strength in MPA
7	11.17
28	21.86

Figure 9 Shows the Compressive Strengths after Curing in MPA after 7 Days and 28 of Concrete. With 20% Replacement of Cement with RHA Using C&D Waste.

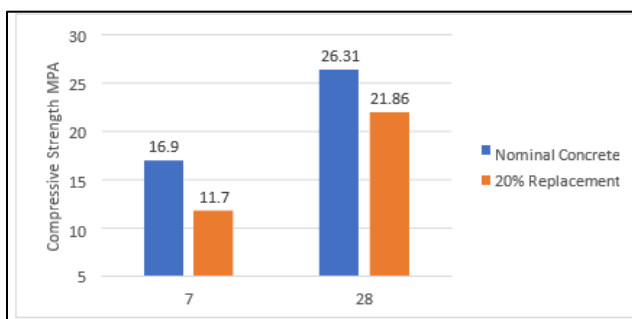


Figure 10 Shows the Compressive Strengths after Curing in MPA after 7 Days and 28 of Concrete. With 25% replacement of Cement with RHA Using C&D Waste.

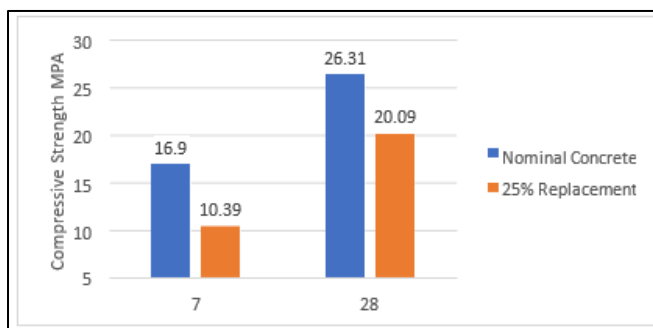


Table 9: Compressive Strengths after 7, 28, Days of Curing. (25% RHA)

Days	Compressive Strength in MPA
7	10.39
28	20.09

Table 10: Compressive Strengths after 7, 28, Days of Curing. (30% RHA)

Days	Compressive Strength in MPA
7	9.72
28	19.93

Table 11: Compressive Strengths after 7, 28, Days of Curing. (40% RHA)

Days	Compressive Strength in MPA
7	7.95
28	18.90

Table 12: Compressive Strengths after 7, 28, Days of Curing. (50% RHA)

Days	Compressive Strength in MPA
7	6.1
28	18.02

Figure 11: Shows the Compressive Strengths after Curing in MPA after 7 Days and 28 of Concrete. With 30% Replacement of Cement with RHA Using C&D Waste.

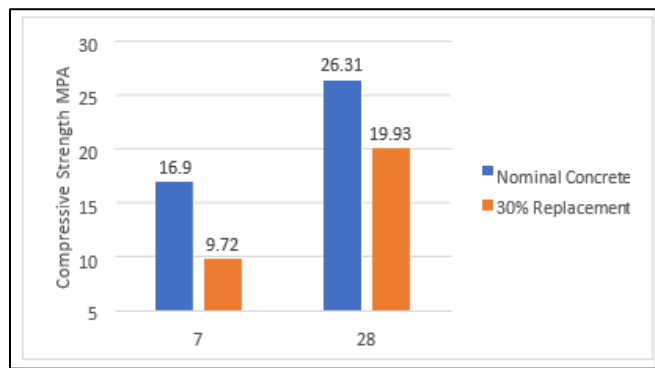


Figure 12: Shows the Compressive Strengths after Curing in MPA after 7 Days and 28 of Concrete. With 40% Replacement of Cement with RHA Using C&D Waste.

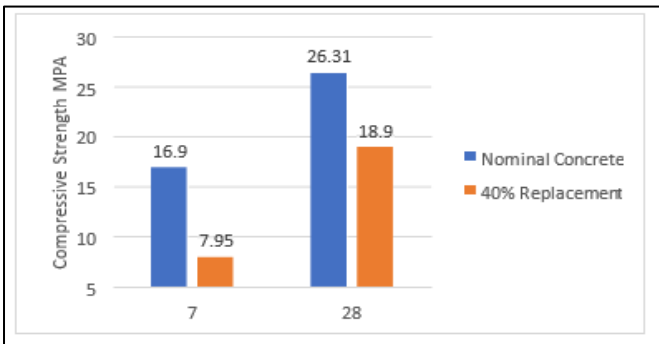
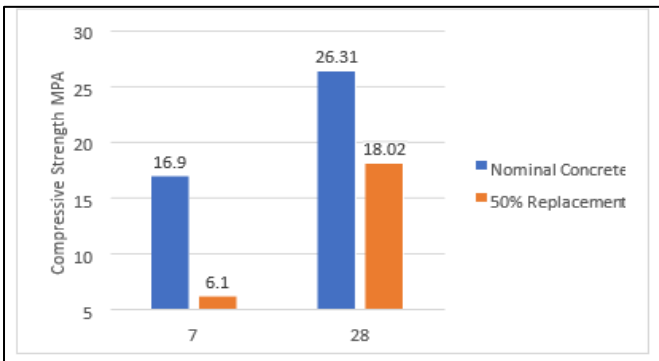


Figure 13: Shows the Compressive Strengths after Curing in MPA after 7 Days and 28 of Concrete. With 50% Replacement of Cement with RHA Using C&D Waste.



5.6 Result declaration

From the test carried out and design following this can be concluded:

- It can be observed that with 5% replacement of RHA, the compressive strength drops by 15.7% and 25.27% at 7 & 28 days, respectively.
- At 10% replacement of RHA, a compressive strength loss of 13.22% and 24.13% was recorded at 7 & 28 days, respectively.
- At 15% replacement of RHA, there was a reduction of 12.33% and 23.78% in compressive strength at the ages of 7 and 28 days, respectively.
- At 20% replacement of RHA, a decrease of 11.17% and 21.86% in compressive strength was observed at 7 & 28 days, respectively.
- At 25% replacement of RHA, there was a decrease of 10.39% and 20.09% in compressive strength at 7 & 28 days, respectively.
- At 30% replacement of RHA, a decrease of 9.72% and 19.93% in compressive strength was observed at 7 & 28 days, respectively.
- At 40% replacement of RHA, the compressive strength decreases by 7.95% and 18.90% at 7 & 28 days, respectively.
- At 50% replacement of RHA, compressive strength was reduced by 6.1% and 18.02% at 7 & 28 days, respectively.

6.0 Conclusion

The experiment's findings shown that raising the RHA content lowers the slump value and raises the compressive values over time until a specific replacement percentage. An rise in the w/c ratio, however, has a negative effect since it raises the slump value and lowers the results of all strength tests. These behaviors were attributed to either an increase in the w/c ratio or a change in the pore structure of the concrete mix that resulted from the addition of RHA. The strength of the concrete decreased as the pore structure increased. By increasing the w/c ratio, the later dehydration rate rises, increasing the concrete's pores and reducing its strength and resilience to adverse environmental conditions. On the other hand, adding RHA may increase or decrease the strength of the resulting concrete based on the properties of RHA used. 5%, 10% and 15% replacement mix values have compressive strength higher, it can be considered as optimum values, where the rest of the replacement values fall below the considerable limits.

The inclusion of tiny RHA particles in this experiment boosted the bulk density of the resultant concrete while decreasing its pore structure. In contrast to some other outcomes that are documented in the literature, the primary factor that improved the concrete's qualities after adding RHA was the use of fine particles. RHA with fine particles is therefore a viable partial substitute for Portland cement. Its inclusion can improve the concrete's strength, resilience to adverse environmental conditions, and durability. Compared to regular Portland cement, it

offers additional financial and environmental benefits. According to the statistical study, there has been a notable increase in the strength measures. However, further investigation on the impact of w/c ratio change on the RHA replaced concrete mix is recommended.

- Using RHA could be economical because it is free and a waste.
- RHA will make the building industry more sustainable by conserving resources, particularly cement.
- It will address the issue of disposing of rice husk ash and have positive environmental effects.

References

Chindaprasit, P., & Rukzon, S. (2007). Strength, porosity, and corrosion resistance of ternary blend Portland cement, rice husk ash, and fly ash mortar. *Construction and Building Materials*, 6, 231–242.

Eriksson, O., Reich, M. C., Frostell, B., Björklund, A., Assefa, G., Sundqvist, J.-O., Granath, J., Baky, A., & Thyselius, L. (2005). Municipal solid waste management from a systems perspective. *Journal of Cleaner Production*, 13, 241–252.

Fapohunda, C., Akinbile, B., & Shittu, A. (2017). Structure and properties of mortar and concrete with rice husk ash as partial replacement of ordinary Portland cement: A review. *International Journal of Sustainable Built Environment*, 6(2), 675–692.

Habeeb, G. A., & Fayyadh, M. (2009). Rice husk ash concrete: The effect of RHA average particle size on mechanical properties and drying shrinkage. *Australian Journal of Basic and Applied Sciences*, 3, 1616–1622.

Habeeb, G. A., & Mahmud, H. B. (2010). Study on properties of rice husk ash and its use as cement replacement material. *Materials Research*, 13(2), 185–190.

Hwang, C. L., & Chandra, S. (1996). The use of rice husk ash in concrete. In S. Chandra (Ed.), *Waste materials used in concrete manufacturing* (pp. 184–234). Elsevier.

Suhendro, B. (2014). Toward green concrete for better sustainable environment. *Engineering*, 95, 305–320.

CHAPTER 135

Sustainable Construction Supply Network Optimization: An Empirical Analysis

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ABSTRACT

Construction industry contributes significantly to global carbon emissions and resource consumption. Integration of sustainable practices into supply network operations including logistics operations for order quantity allocation decisions offers a pathway to reduce impact of these activities on environment. This paper explores the inventory optimization decisions in supply network by considering logistics operations with an objective of minimizing supply network cost and its impact on the environment. A detailed methodology is developed to allocate optimal order quantity (OQA) to the suppliers considering the logistics cost. The model developed for OQA is a Mixed Integer Nonlinear Programming (MINLP) model which considers the practical project constraints. Design of Experiments (DOE) concept is used to gauge the sensitivity of input variables on supply network cost. Identification of significant variables can help practitioners design appropriate sourcing strategy for the construction organizations to minimize impact of sourcing activities on environment. The methodology has been verified with the help of numerical case.

Keywords: Order quantity allocation; Sustainability cost; Design of experiments (DOE); Supplier selection; Supply network cost optimization; Mixed integer Non-Linear programming.

1.0 Introduction

The building sector is among the globe's biggest carbon producers and consumers of resources, accounting for almost 40% of the world's energy-related CO₂ emissions and 36% of total energy use. With the ongoing urbanization and infrastructure needs, the environmental impact of construction activities keeps increasing, driving climate change, resource consumption, and environmental degradation. Under such circumstances, the need for sustainable construction supply chain practices has never been more critical. The combination of green logistics and maximum supply network sustainability is a revolutionary approach to reduce these effects without compromising its economic feasibility. Recent studies highlight the key role of sustainable supply chain management (SSCM) in reducing the environmental impact of construction activities (Lazer *et al.*, 2021).

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The transition towards sustainability in the construction industry is also accelerated by regulatory forces, stakeholder pressure, and long-term cost savings. The businesses embracing sustainable supply chain strategies can lower costs of operations by as much as 16% and achieve a 20% reduction in carbon emissions. However, the fragmented and practical nature of the construction industry often prevents the implementation of new solutions (Guerlain *et al.*, 2019). Although green logistics and sustainable materials are progressively used, the practise is uneven, especially in developing economies, where technology and access to capital are limited. Moreover, the absence of standardized metrics for sustainability makes it harder to track progress and drive industry-level transformation.

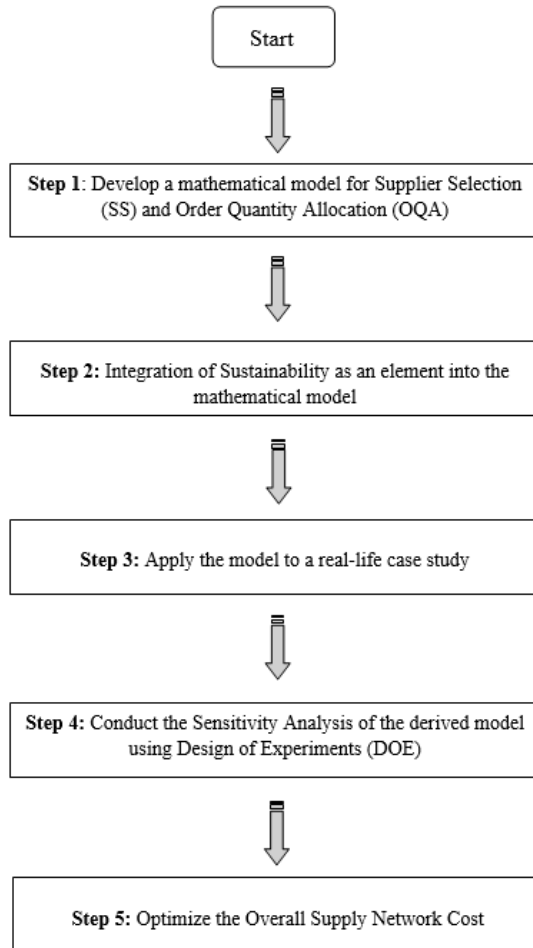
This research fills existing gaps by considering supply network optimization from a sustainability perspective. The paper tries to unify logistics operations, supplier choice, and order quantity allocation within a Mixed Integer Nonlinear Programming (MINLP) model to achieve low costs and environmental footprint (Kanálíková *et al.*, 2019). The approach employs Design of Experiments (DOE) to determine major variables that affect sustainability performance and provide recommendations to practitioners (Bagul & Mukherjee, 2018). By linking to global sustainability targets, this study emphasizes the role of centralized sourcing, green logistics, and technological innovation in attaining economic performance and environmental stewardship. The results offer a blueprint for the construction sector to minimize its environmental impact while building long-term resilience and sustainability.

2.0 Literature Review

Centralized sourcing has emerged as a critical strategy for enhancing supply chain performance and sustainability. Bagul & Mukherjee (2020) explore the impact of centralized sourcing on supplier selection and order quantity allocation (SSOQA) in multi-tier supply networks. Their study, using mixed-integer nonlinear programming (MINLP) models, demonstrates that centralized sourcing reduces inventory costs by 1.69%, improves product quality, and enhances environmental sustainability compared to decentralized approaches. The study also highlights the cost advantages of centralized sourcing in price-uncertain environments and recommends supplier consolidation and local procurement to reduce emissions. In a related study, Bagul & Mukherjee (2020) propose a framework for optimizing sourcing strategies in centralized, multi-tier supplier networks, emphasizing demand uncertainties and supplier failure risks (SFR). Their findings underscore the benefits of centralized supply chains, including improved resource utilization, risk reduction, and transparency, which collectively contribute to waste reduction and sustainability. Torres-Ruiz & Ravindran (2018) address supplier selection through a multi-objective optimization model that integrates sustainability criteria such as greenhouse gas (GHG) emissions, lead times, and supplier risks. Their approach, which employs a Supplier Sustainability Risk Score (SSRS) and goal programming, demonstrates significant reductions in lead times, logistics costs, and carbon footprints by prioritizing local suppliers.

Tiwari *et al.* (2014) highlight the challenges of applying supply chain management (SCM) in construction, including risk management, information sharing, and organizational issues. They advocate for cultural change, education, and enhanced knowledge sharing to improve SCM performance. Patella *et al.* (2020) examine the adoption of green vehicles in last-mile logistics, focusing on incentives and autonomous vehicles.

Figure 1: Methodology for Optimal Supply Network Cost Optimization



Source: Compiled by authors

Despite the progress in sustainable logistics and GSCM research, several challenges remain. Many studies, such as those by Benmamoun *et al.* (2017) and Sato *et al.* (2022), are limited by small sample sizes, self-reported data, and a lack of empirical evidence. Additionally, the focus on specific industries or regions, as seen in the work of Cheng *et al.*

(2023) and Trivellas *et al.* (2020), restricts the generalizability of findings. The reviewed literature underscores the importance of centralized sourcing, green logistics, and technological innovations in enhancing supply chain sustainability and performance. While significant progress has been made, the limitations of existing studies highlight the need for more comprehensive, empirically validated research. By addressing these gaps, future studies can provide actionable insights for industries striving to balance economic, environmental, and social sustainability in their logistics and supply chain operations.

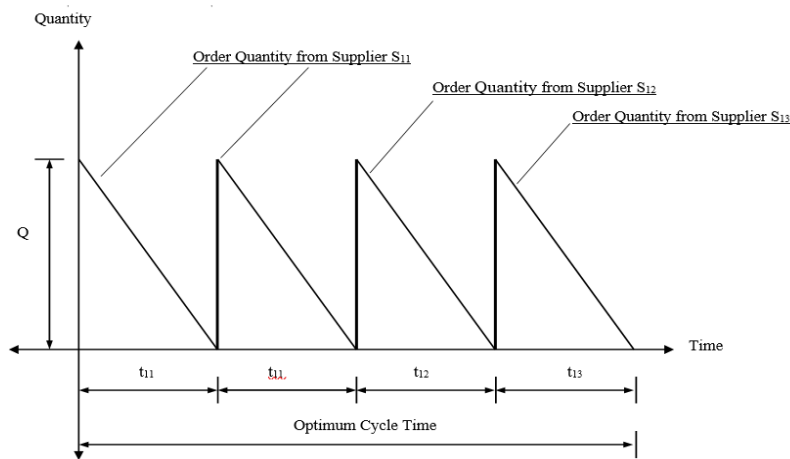
3.0 Methodology

The methodology for optimal supply network cost optimization is shown in Figure 1.

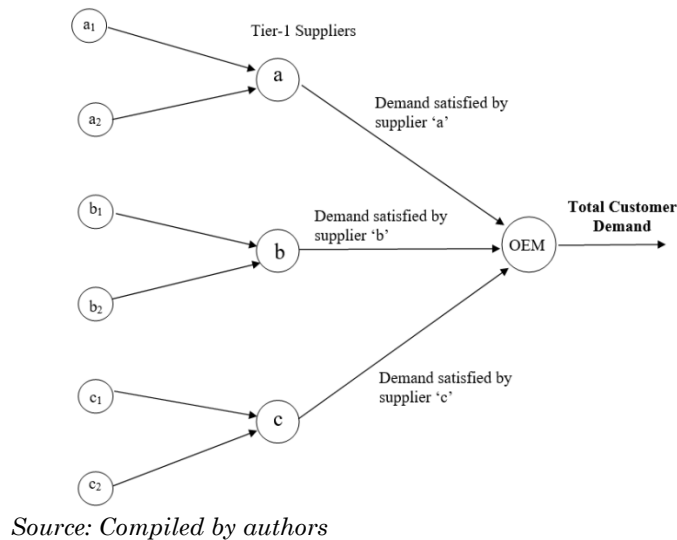
3.1 Development of the mathematical model for SS and OQA

The mathematical model developed in the study addresses supplier selection (SS) and order quantity allocation (OQA) through a structured approach that optimizes inventory costs in a multi-tier supply network. The inventory cycle for this model follows a single-stage supply system as depicted in Figure 2. This illustrates the relationship between order quantities and time periods in a simplified supply chain. For more complex networks, Figure 3 presents the multi-tier supplier system, which forms the basis of our MINLP optimization approach. The optimization process involves calculating the number of orders to be placed with each supplier based on demand and capacity as well as allocating order quantities to minimize total costs while adhering to constraints.

Figure 2: Inventory Cycle for Single Stage Supply System



Source: Compiled by authors

Figure 3: Multi-Tier Supplier System

3.2 Multi-objective optimization model

The proposed multi-objective optimization model addresses sustainability risks in supplier selection through a structured two-phase methodology:

Phase 1: Supplier Sustainability Risk Assessment: The model begins with a sustainability risk assessment of potential suppliers. This involves evaluating suppliers based on economic, environmental, and social criteria to determine their sustainability risk levels. Each supplier is assigned a Supplier Sustainability Risk Score (SSRS), which quantifies the sustainability risks associated with each supplier.

Phase 2: Multi-objective Mixed Integer Linear Programming (MILP) Model: The SSRS calculated in Phase 1 is integrated into the MILP model as one of the objectives to minimize supplier sustainability risk. The model allows for the identification of backup suppliers, which serves as a risk mitigation mechanism against supply disruptions. This is crucial for maintaining supply chain resilience in the face of sustainability risks.

3.3 Mathematical model integrating sustainability

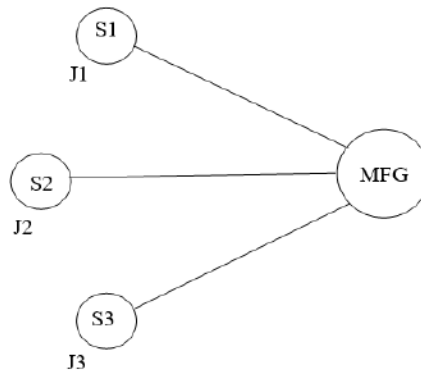
$$\text{Order cycle time for a single order} = \frac{Q}{d} \quad \dots 1$$

Quantity divided by demand gives us order cycle time.

$$\text{Order cycle time } (t_{ij}) = \sum J_i \times \frac{Q}{d} \quad \dots 2$$

The number of orders multiplied by order cycle time for a single order gives us total order cycle time. The supply network structure as shown in Figure 4 demonstrates how suppliers are interconnected in our case study.

Figure 4: Supply Network (Source: Compiled by Authors)



$$\text{Setup Cost} = \frac{\sum J_{ij} K_{ij}}{\sum J_{ij} \times \frac{Q}{a}} \quad \dots 3$$

Set up cost is the product of set up cost per order and number of orders multiplied by total order cycle time.

$$= \frac{d}{Q} \frac{\sum J_{ij} K_{ij}}{\sum J_{ij}} \quad \dots 4$$

$$\text{Carrying Cost} = \frac{Q}{2} \times a \times \frac{\sum J_{ij} P_{ij}}{\sum J_{ij}} \quad \dots 5$$

Carrying cost per unit time for an order cycle is the product of average price from all the suppliers, inventory holding rate (%) per unit time (a) and average inventory ($Q/2$).

$$\frac{aQ}{2} \times \frac{\sum J_{ij} P_{ij}}{\sum J_{ij}} \quad \dots 6$$

$$\text{Unit cost of production} = \frac{\sum Q \times J_{ij} \times P_{ij}}{\sum J_{ij} \times \frac{Q}{a}} \quad \dots 7$$

Product of quantity, number of orders and unit price of product divided by total order cycle time gives unit cost of production.

$$= d \frac{\sum J_{ij} \times P_{ij}}{\sum J_{ij}} \quad \dots 8$$

$$\text{Inventory cost} = \text{setup cost} + \text{carrying cost} + \text{unit cost} \quad \dots 9$$

Now we are adding one more element, i.e. sustainability cost to the inventory cost to develop the new model.

Sustainability cost

$$\text{Fuel consumption} = \frac{\text{distance}}{\text{mileage}} = \frac{\text{km}}{\frac{\text{km}}{l}} = l \quad \dots 10$$

$$\text{CO}_2 \text{ emission per order cycle} = \text{Fuel consumption/trip} \times \text{FEF} \times \text{Number of trips} \quad \dots 11$$

$$\sum \frac{\text{distance}_{ij}}{\text{mileage}} \times \text{FEF} \times J_{ij} \quad \dots 12$$

$$\text{CO}_2/\text{unit time (in tonnes)} = \frac{\sum \frac{\text{distance}_{ij}}{\text{mileage}} \times \text{FEF} \times J_{ij}}{\frac{Q \sum J_{ij}}{d}} \quad \dots 13$$

CO₂ emission per order cycle divided by total order cycle time gives CO₂ per unit time.

$$= \frac{d \times \text{FEF}}{Q \times \text{mileage}} \left(\sum \frac{\text{distance}_{ij} \times J_{ij}}{\sum J_{ij}} \right) \quad \dots 14$$

$$\text{Sustainability cost (in rupees)} = \text{sustainability cost} \times \text{CP} \times \text{exchange rate} \quad \dots 15$$

$$\text{CO}_2 \text{ emission} = \text{fuel consumption} \times \text{FEF (in tonnes)} \quad \dots 16$$

According to the European Energy Exchange (EEX, 2014), the cost of one emission permit (GC) is 6.19 € or 8.85 USD. According to the new model,

$$\text{Inventory cost} = \text{setup cost} + \text{carrying cost} + \text{unit cost of product} + \text{sustainability cost} \quad \dots 17$$

Our objective is to minimize this cost,

$$Z_{\min} = \frac{d}{Q} \frac{\sum J_{ij} K_{ij}}{\sum J_{ij}} + \frac{aQ}{2} \left(\frac{\sum J_{ij} P_{ij}}{\sum J_{ij}} \right) + d \left(\frac{\sum J_{ij} \times P_{ij}}{\sum J_{ij}} \right) + \frac{d}{Q} \times \frac{\text{FEF}}{\text{mileage}} \left(\sum \frac{\text{distance}_{ij} \times J_{ij}}{\sum J_{ij}} \right) \quad \dots 18$$

Where in $Z_{\min}$, the first term is setup cost; the second term is carrying cost; the third term is unit cost of production, and the fourth term is sustainability cost.

Table 1: GHG Emission Factors for Fuel Types

Fuel Type	CO ₂ emissions	
	kgCO ₂ e/kg	kgCO ₂ e/l
Diesel	3.9	3.24
Jet kerosene	3.88	3.1
Heavy Fuel Oil (HFO)	3.41	3.31

3.4 Applying the model to a real-life case study

The mathematical model is validated using a real-life case study of an Indian electric appliance company.

Table 2: Inputs for Design of Experiments (DOE) (Source: Compiled by Authors)

Variables	Supplier 1	Supplier 2	Supplier 3
Demand	80000		
Carrying Cost	120	110	112
Ordering Cost	5000	6000	7000
Distance	1000	1300	1200
Cost	400	410	406

The model is applied to this case study to determine optimal order quantities and supplier allocations, minimizing both inventory and sustainability costs. The goal is to validate the model's effectiveness in optimizing supply network costs while minimizing environmental impact. The mathematical relationships in this system are defined by above equations with key parameters summarized in Table 1 (GHG emission factors) and Table 2 (DOE input variables). The above inputs are used for the case analysis:

3.5 Sensitivity analysis using design of experiments (DOE)

The next step focuses on conducting a sensitivity analysis using Design of Experiments (DOE) to evaluate the impact of five key variables- demand, distance, ordering cost, carrying cost, and unit price, on both inventory cost and sustainability cost. Each variable is examined at three levels: the real-case scenario of a supplier, and two alternative scenarios representing $\pm 10\%$ deviations from the base values.

In this study, the dependent variable is the total supply network cost, which includes both inventory costs and sustainability costs. Design of Experiments (DOE) is used to identify which variables have the most significant impact on supply network costs, determine how these variables interact with each other and to optimize the supply network by focusing on the most influential variables.

The DOE is carried out using LINGO software, a powerful optimization tool, to design and analyse the experiments. The outcomes from the DOE were further analysed using Minitab, a statistical software, to determine the significance of each variable and their interactions. The results highlight the relative importance of each factor in optimizing inventory costs and sustainability costs, offering actionable insights for supply chain decision-making.

3.6 Optimization of the overall supply network cost

The insights gained from the Sensitivity Analysis are used to optimize the overall supply network cost. The goal is to minimize both inventory costs and sustainability costs while ensuring that the supply chain operates efficiently and aligns with global sustainability goals. Incorporating sustainability metrics into supply chain management is essential for modern businesses aiming to balance economic performance with environmental and social responsibility. In this study, sustainability metrics such as CO₂ emissions and fuel consumption are integrated into the mathematical model to optimize supply network costs while minimizing environmental impact.

4.0 Results and Discussions

The study explores not only the linear effects of these variables but also their two-way interactions, providing a comprehensive understanding of how these factors collectively influence supply chain performance.

4.1 Optimization of supply network costs

The primary objective of the study is to minimize total supply network costs, which include inventory costs and sustainability costs. The study demonstrates that centralized sourcing reduces inventory costs by approximately 1.69% compared to decentralized sourcing. This is achieved by coordinating supplier selection and order quantity allocation across multiple tiers of the supply chain. It also simplifies relationships with fewer suppliers, reduces redundancy, and improves overall supply chain efficiency. It also fosters long-term relationships with suppliers, encouraging them to participate in sustainability programs.

4.2 Hypothesis testing

It is a critical component of the sensitivity analysis conducted in this study. It is used to determine the statistical significance of key variables and their impact on total supply network costs. The goal was to determine which variables have a statistically significant impact on the total supply network cost and to understand how these variables interact with each other. The hypothesis testing process involved the formulation of null (H_0) and alternative (H_1) hypotheses, conducting statistical tests, and interpreting the results. The hypothesis testing results in Table 3 confirm that demand, carrying cost, and material cost have statistically significant effects ($p < 0.001$).

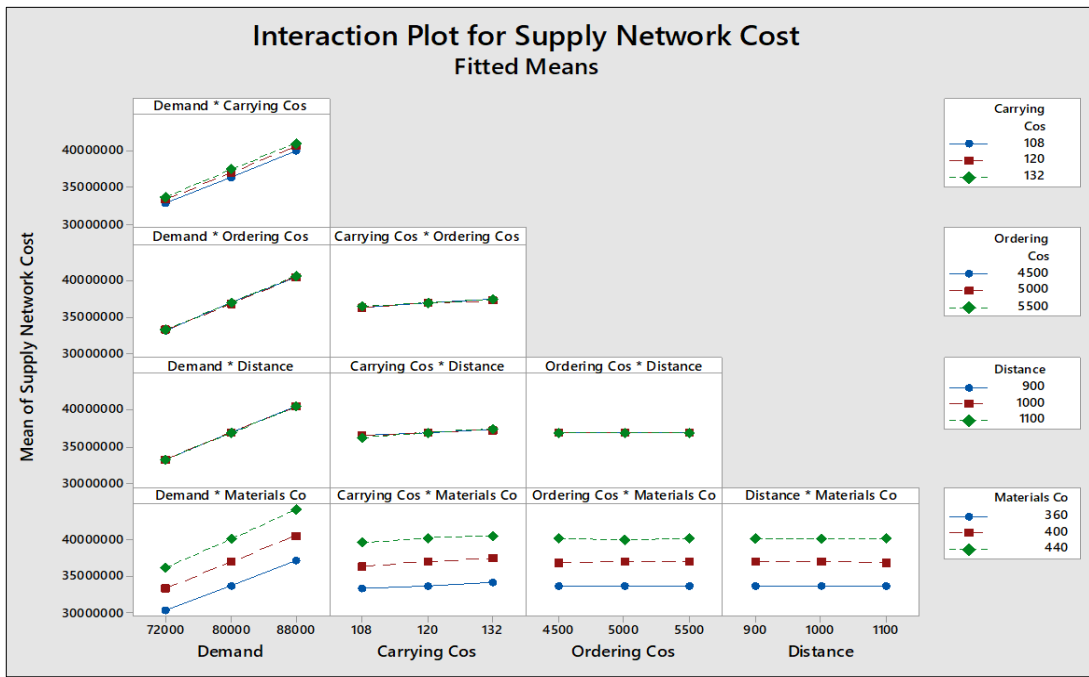
Table 3: Hypothesis Table (Source: Compiled by authors)

Variables	Null Hypothesis (H_0)	Alternate Hypothesis (H_1)	p value	Significance
Demand	Demand has no significant effect on the total supply network cost.	Demand has a significant effect on the total supply network cost.	0.000	Yes
Carrying Cost	Carrying cost has no significant effect on the total supply network cost.	Carrying cost has a significant effect on the total supply network cost.	0.000	Yes
Ordering Cost	Ordering cost has no significant effect on the total supply network cost.	Ordering cost has a significant effect on the total supply network cost.	0.266	No
Distance	Distance has no significant effect on the total supply network cost.	Distance has a significant effect on the total supply network cost.	0.398	No
Material Cost	Material cost has no significant effect on the total supply network cost.	Material cost has a significant effect on the total supply network cost.	0.000	Yes
Comparison Factor	There is no significant interaction effect between demand and material cost on the total supply network cost.	There is a significant interaction effect between demand and material cost on the total supply network cost.	0.000	Yes

4.3 Visualization of results

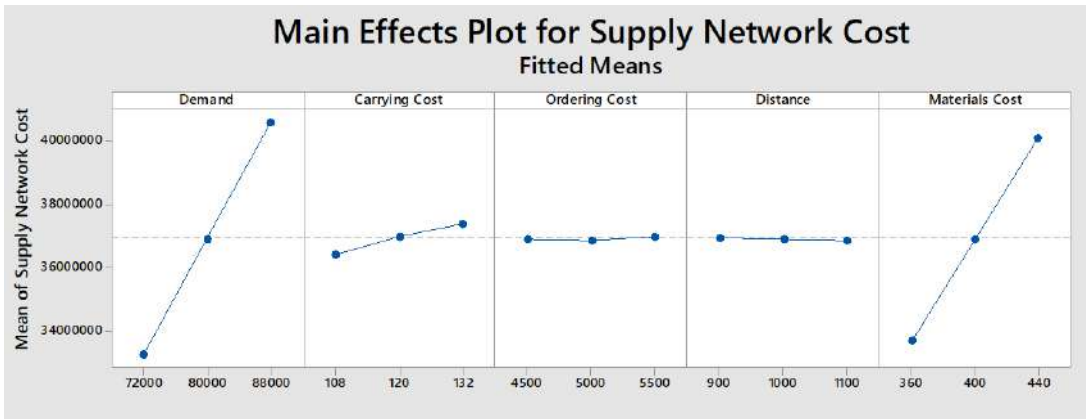
The results of the sensitivity analysis are visualized using interaction plots and main effects plots generated by Minitab.

Figure 5: Interaction Plot for Supply Network Cost



Source: Minitab

Figure 6: Main Effects Plot for Supply Network Cost



Source: Minitab

The 'Interaction plot' as displayed in Figure 5 shows the combined effect of demand and unit price on total supply network costs. The plot reveals that higher demand levels amplify the impact of unit price on costs, while lower demand levels mitigate this impact. The 'Main effects' plot as shown in Figure 6 exhibits the individual effect of each variable (demand, carrying cost, unit price, ordering cost, and distance) on total supply network costs. The plot highlights that demand, carrying cost, and unit price have the most significant impact on costs.

5.0 Implications of the Research

5.1 Theoretical implications

There was no such model existing that integrated sustainability into construction supply network optimization and we have developed such a model. The paper contributes to the theoretical framework of sustainable supply chain management (SSCM) by integrating environmental costs like CO₂ emissions into traditional inventory optimization models. This bridges the gap between economic and environmental objectives in supply network design.

5.2 Practical implications

From a real-life perspective, these findings have significant implications for supply chain managers aiming to optimize inventory costs while addressing sustainability concerns. For example, reducing carrying costs through efficient inventory management practices can lead to lower overall supply network costs and improved sustainability by minimizing waste and excess storage. Similarly, understanding the interaction between demand and material costs can help businesses better forecast and plan for fluctuations, ensuring a more resilient and cost-effective supply chain. Our findings also support (Kumar *et al.*, 2015) argument for green logistics integration.

6.0 Conclusion

The study provides a general model for reducing supply network costs by considering sustainability aspects. Employing the Design of Experiments (DOE) and advanced analysis tools like LINGO and Minitab, the study was able to determine the most influential variables—demand, carrying cost, and material cost, whose impact has a significant bearing on both inventory and sustainability cost. The study highlights the use of a centralized sourcing policy for cost reduction and sustainability enhancement, particularly in multi-tier supply chains. The use of sustainability parameters like CO₂ emissions and fuel consumption in the supply chain model further highlights the importance of green logistics practices in the construction industry. The interrelation between demand and material cost is significant, which justifies the implementation of a comprehensive supply chain optimization policy where economic as well as environmental factors are given due importance.

The developed model considers demand, distance, ordering cost, carrying cost, and unit price as parameters and does not account for other parameters such as the reliability of suppliers, geopolitical factors, and fluctuations in the market, which would affect supply chain performance. The model accounts for CO₂ emissions as a cost of sustainability, but other environmental and social aspects like water usage and labour practices are not accounted for, which are also some determinants of sustainability. While this research offers valuable insights into sustainable logistics management, there are some areas of research left open. Future research should address areas like social sustainability (Jørsfeldt *et al.*, 2016) and AI applications (Kanálíková *et al.*, 2019) to advance the triple bottom line (Lazar *et al.*, 2021). Future studies may include social cost impacts, such as labour practices and community well-being, to offer a better picture of the triple bottom line-economic, environmental, and social sustainability. Integration of new technologies such as blockchain, IoT, and AI may further enhance supply chain transparency and efficiency. Addressing these concerns, future studies can use the results of this research to create more sophisticated and integrated models for sustainable logistics management in the construction sector.

References

- Bagul, A., & Mukherjee, I. (2018). An insight into centralised sourcing strategy for enhancing performance and sustainability of multi-tier supply network. *International Journal of Intelligent Enterprise*, 5(1–2), 18–49.
- Bagul, A., & Mukherjee, I. (2022). Enhanced sourcing strategy for centralized multitier multiple suppliers network with failure risks. *International Journal of Productivity and Performance Management*, 71(1), 211–244.
- Cheng, Y., Masukujjaman, M., Sobhani, F. A., Hamayun, M., & Alam, S. S. (2023). Green logistics, green human capital, and circular economy: The mediating role of sustainable production. *Sustainability*, 15(2), 1045.
- Dey, A., LaGuardia, P., & Srinivasan, M. (2011). Building sustainability in logistics operations: A research agenda. *Management Research Review*, 34(11), 1237–1259.
- Dzwigol, H., Trushkina, N., & Kwilinski, A. (2021). Green logistics as a sustainable development concept of logistics systems in a circular economy. In *Proceedings of the 37th International Business Information Management Association (IBIMA)* [Doctoral dissertation].
- Guerlain, C., Renault, S., Ferrero, F., & Faye, S. (2019). Decision support systems for smarter and sustainable logistics of construction sites. *Sustainability*, 11(10), 2762.

Jørsfeldt, L. M., Hvolby, H. H., & Nguyen, V. T. (2016). Implementing environmental sustainability in logistics operations: A case study. *Strategic Outsourcing: An International Journal*, 9(2), 98–125.

Kanálíková, A., Behúnová, A., Mandicák, T., & Mésároš, P. (2019). New technologies for sustaining development in infrastructure, logistics and construction industry. *Acta Logistica*, 6(4), 171–177.

Kumar, A. (2015). Green logistics for sustainable development: An analytical review. *IOSRD International Journal of Business*, 1(1), 7–13.

Lazar, S., Klimecka-Tatar, D., & Obrecht, M. (2021). Sustainability orientation and focus in logistics and supply chains. *Sustainability*, 13(6), 3280.

Benmamoun, Z., Hachimi, H., & Amine, A. (2017, December). Green logistics practices. In *2017 International Renewable and Sustainable Energy Conference (IRSEC)* (pp. 1–5). IEEE.

Bagul, A., & Mukherjee, I. (2022, March). A new insight on order quantity allocation for coordinated multi-tier multiple supplier networks under demand uncertainty. In *Studies in Quantitative Decision Making: Selected Papers from XXIII Annual International Conference of the Society of Operations Management* (pp. 23–47). Springer Singapore.

CHAPTER 136

Sustainable Educational Institute Development through Green Rating Systems

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ABSTRACT

Sustainability is the need of the hour. As per India's 2030 sustainability target, India will be reducing 50% of its energy needs from non-fossil fuels. Many organizations are working towards achieving this goal, keeping this in mind, this paper explores various green rating systems. Similarly, NICMAR University Pune also has a mission to increase its energy efficiency and decrease its dependency on consumption of electricity from the main power grid. Therefore, this paper investigates the applicability of a suitable rating system for the institute to achieve its sustainability mission, promoting sustainable practices. The primary aim is to identify a suitable green rating system for transformation of the existing campus into a green campus. The required data was gathered through comparative analysis of the existing green rating systems around the world. On comparing the Indian green rating systems, i.e., GRIHA and IGBC, it was finalized that IGBC criteria were the most suitable for this campus.

Keywords: Green rating systems; Green campus; Sustainability; Educational institute; Energy efficiency.

1.0 Introduction

The world is facing increasing environmental challenges, there is an exigency of mitigating climate change emphasizing the requirement for sustainable practices. Conferences around the world starting from the first Stockholm conference i.e. United Nations Conference on Human Environment, to the Kyoto Protocol, Paris Agreement, G20 Summit and many more, have all led to an awakening for the requirement of sustainable development across various sectors, ensuring a quality life on our planet. India's commitment under these global conferences and agreements have led to constitutional provisions, amendments and legal frameworks such as incorporating Corporate Social Responsibility, several energy and climate laws leading the right to a healthy environment ensuring sustainable development in a structured approach. India's vision for 2030 is aimed to develop an environmentally sustainable nation aligning with Global Sustainable Goals. Their key focus areas being renewable energy, climate action, sustainable growth including quality education and health care (United Nations, n.d.).

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Keeping up with the changing trends, educational institutions in India are adopting various strategies and sustainable practices to minimize their ecological footprint. The integration of sustainability in educational infrastructure enhances the quality of education, human health and the climate. This further develops a culture of responsible sustainable behaviour. Creating a scope for discussion of the same among students and faculty alike, further influencing their respective fields. Green rating systems are the key drivers in implementing and promoting sustainable practices. These frameworks set clear standards which encourages resource efficiency and drives environmentally responsible construction. Two major green rating systems are followed in India, Indian Green Building Council i.e. IGBC and Green Rating for Integrated Habitat Assessment i.e. GRIHA. Each framework establishes clear guidelines to enhance energy efficiency, water conservation, waste management, and overall environmental impact in institutional buildings (IGBC, 2017; GRIHA, 2019.). GRIHA Focuses on government led initiatives while IGBC is an industry driven approach with international recognition offering more flexibility. This study concludes IGBC Green Campus Rating as a more suitable framework as per the comparative analysis done in this paper, for the assessment of an educational Institute because of its adaptability for both new and existing campuses. Despite the growing adoption of green rating systems, limited research exists on the comparative effectiveness of IGBC Certified educational campuses in India and even lesser are the comparative analysis-based studies on these green rating systems.

2.0 Green Rating Systems

2.1 Sustainability in educational institutes

Educational Institutes and similar public spaces are one of the significant consumers of energy due to their revolving occupancy patterns. With the growing environmental challenges, there is a need for these institutions to adapt sustainable practices to reduce their environmental impact.

2.2 Importance of green campuses

One of the stepping stones for any infrastructure setup to move towards sustainable development is to follow a Green Rating System. These certifications provide a detailed framework of requirements to be fulfilled to obtain their certification. These systems also encourage environmentally responsible constructions and reduction of energy consumption to reduce the carbon footprint generated from the infrastructure. Similarly educational institutions in India are opting for green building certifications.

2.3 Green rating systems around the world

These rating systems are designed frameworks that evaluate and assess building infrastructure based on their sustainability, energy efficiency and the overall impact on the environment. Some of the most prominent green rating systems followed worldwide are (see, Table 1):

Table 1: Rating Systems around the World, Used for this Study

Sr. No	Rating System	Country of Origin	Established Year	Summary
1	LEED	USA	1993	Evaluation of buildings on energy efficiency, water efficiency, indoor environment quality, materials and environmental impact.
2	BREEAM	UK	1990	Measures sustainability across the building life cycle including energy consumption, waste management, water efficiency, transportation efficiency, land use, material use, health and well-being.
3	GREEN STAR	Australia	2003	Aiming to enhance a building's overall environmental performance and occupant health. Evaluates energy efficiency, water efficiency, material selection and indoor environment quality.
4	WELL	USA	2014	Focusing on human health and wellness in built environment by assessing air quality, water quality, lighting efficiency, movement, thermal comfort, sound, nourishment, mind and community (well-being and community).
5	Green Globes	US and Canada	2000	Interactive user-friendly online platform evaluating a building's energy and water efficiency, resources, indoor environment, emission reduction and project management.
6	GRIHA	India	2007	Tailored for residential buildings' sustainability. Evaluates energy efficiency, water efficiency, site planning, waste management and occupant health.
7	IGBC	India	2001	Provision of Guidelines for building types such as residences, offices, education facilities, commercial buildings and others. Focusing on site selection, energy efficiency, water efficiency, material usage, indoor environment quality and design innovation.

Source: Compiled by authors

2.4 India's sustainability mission

India being an active participant of the sustainable development movement has made a commitment to achieve sustainability by implementing national policies and participating in global agreements. Starting from the first United Nations Conference on the Human Environment in Stockholm Declaration, 1972 to the 3rd edition of India Energy Week, 2025.

2.5 Importance of green rating systems in India

Green Rating Systems serve as essential tools in promoting sustainable infrastructure. Various States such as Pune and Hyderabad i.e. Pune Municipal Corporation and Greater Hyderabad Municipal Corporation offers 10% property tax rebate for certified buildings under

IGBC and GRIHA (Pune Municipal Corporation [PMC], n.d.; Eco-Business, 2012). Further the Maharashtra Energy Development Agency gives subsidies for rooftop solar installations in campus buildings (Maharashtra Energy Development Agency [MEDA], n.d.). Sweetening this deal Maharashtra State Electricity Distribution Company Ltd. (Maharashtra State Electricity Distribution Company Limited [MSEDCL], 2023). Also offers benefits on adopting solar power by providing net metering which further reduces the institution's electricity cost.

2.6 Green rating systems in India

All organizations should have green campuses and environmental impact reduction policies since they enhance well-being of their occupants (Rajalakshmi *et al.*, 2022). And acquiring green certifications could help a building become a leading example for sustainable development in the country (Kshetri *et al.*, 2021). A comparative analysis can be done for selecting such sustainability rating systems for campuses and evaluating sustainability indicators to identify challenges faced by Indian institutions for green certification. (Parvez & Agrawal, 2018). Green rating systems such as GRIHA and IGBC can be used in an existing campus for enhancing the prevailing systems in the campus for assessment of areas to be improved and increment of green practices or efficiency (Sharma *et al.*, 2024).

2.7 Research gap

Absence of detailed research based on the effectiveness of different green rating systems for educational campus buildings and their applicability on educational institutions, addressed region-specific measures for India.

2.8 Research question

Conduct a comparative analysis on different green rating systems to find their applicability in educational campuses, across India.

2.9 Scope and methodology

This paper will investigate the applicability of a suitable green rating system for a Maharashtra based educational institute. Further dwelling into the requirements and green rating categories to achieve the sustainability mission where data will be collected through a comparative analysis of existing green rating systems, around the world.

3.0 Comparison of the selected green rating systems

After listing out green rating systems around the world this study narrows down two rating systems applicable for Indian infrastructure. IGBC and GRIHA that are suitable for the Indian context as these align with our country's climate, available resources and sustainability goals (see, Table 2).

Table 2: Narrowing Down to IGBC and GRIHA Rating Systems

Sr. No	Suitability Factor	Reasons
1	Adapting to the Indian climatic conditions	Different from other global rating systems these two are tailored for India's diverse climate, temperature and composite regions. Emphasizing on passive cooling water efficiency, thermal comfort and climatic impact suitable for the Indian environment.
2	Focuses on resource efficiency	Prioritizes efficient water fixtures, rainwater harvesting and renewable energy integration to meet increasing energy demand and water scarcity in India.
3	Alignment with Government regulations and recognition	Validated by the Indian Government. These also align with level incentives, tax benefits and national policies such as Energy Conservation Building Code (ECBC).
4	Accessibility and affordability	Compared to International systems, these offer cost effective certifications, considering locally available resources, materials, green technology and affordable native construction practices.
5	Comprehensive sustainability	These two systems incorporate a holistic approach to sustainable development, including energy efficiency, waste management practices, biodiversity conservation and socio-economic impacts like livelihood generation.
6	Results	Since these are climate responsive, cost effective, nationally recognized rating systems, they are adaptable to Indian buildings without relying on foreign technologies, which makes them more affordable, practical in addressing India's sustainability goals.

Source: Compiled by authors

To understand these two rating systems a comprehensive study of their parameters, guidelines and requirements was conducted for educational campus buildings and addressing region-specific measures for India. The following table is the summary of this study (see, Table 3). Further the most suitable option for NICMAR University Pune campus, among the two rating systems IGBC and GRIHA will be chosen. This decision has been made by performing the following SWOT analyses (see, Table 4 & Table 5).

Table 3: Comparison of IGBC and GRIHA Parameters and Sub-parameters for Existing Campus Buildings

Sr. No	Sustainability Parameters	IGBC	GRIHA
1	Site Planning	Site Planning and Management 1. Requirement of green buildings within the campus. 2. Requirement of soil erosion control 3. Site preservation 4. Green Cover and vegetation 5. Heat Island reduction, non-roof. 6. Outdoor Light Pollution Reduction.	Site parameters: 1. Accessibility of Basic Services 2. Microclimatic Impact
2	Transportation	Sustainable Transportation: 1. Pedestrian Network 2. Bicycle	NIL

		Lanes Network 3. Access to Sustainable Transportation	
3	Water	Water Conservation: 1. Rainwater Harvesting 2. Landscape Design 3. Management of Irrigation Systems 4. Wastewater Treatment and Reuse 5. Optimise Water Use for Construction 6. Water Metering	Water: 1. Water Footprint 2. Reduction in Cumulative Water Performance
4	Energy	Energy Efficiency: 1. Energy Efficiency in Infrastructural 2. On-site Renewable Energy 3. Off-site Renewable Energy 4. Energy Metering	Energy: 1. Energy Efficiency 2. Renewable Energy Utilization
5	Material and Resource Management	Material and Resource Management: 1. Segregation of Waste, Post-occupancy 2. Organic Waste Management, Post occupancy 3. Handling of Waste Materials, During Construction 4. Local Materials	Maintenance and housekeeping: 1. Maintenance, Green procurement and Waste management 2. Metering & Monitoring
6	Health	Health & Well-being: 1. Tobacco Smoke Control 2. Basic Amenities 3. Health & Well-being Facilities 4. Universal Design 5. Basic Facilities for Construction Workforce	Human health and comfort: 1. Achieving Indoor Comfort Requirements 2. Maintaining Good IAQ (Indoor Air Quality)
7	Social Awareness	Green Education: 1. Green Education 2. Green Campus Guidelines	Social Aspects: 1. Universal accessibility & Environmental Awareness
8	Innovation	Innovation in Design: 1. Innovation in Design Process 2. IGBC Accredited Professional	Social Aspects: 2. Bonus Points for adoption and implementation of innovative strategies.

Source: Compiled by authors

4.0 Conclusion

Through the comparative analysis, it was established that both IGBC and GRIHA are suitable rating system choices for India-specific projects. It was also found that IGBC has a more detailed set of certification guidelines. After the SWOT analysis of the above-mentioned green building rating certifications, it was also established that IGBC provides more tax rebates, direct incentives, lower certification costs, quick implementation time and flexible upgradations. Therefore, IGBC is more suitable for NICMAR University Pune to help facilitate its sustainability mission, for the transformation of the existing campus into a green campus. However, choosing a suitable green rating system is based on institutes' requirements, financial capabilities, time limitations and other project specifications (see, table 6).

Table 4: IGBC SWOT Analysis

Strengths	Weakness
Fast environmental clearances: Certified green campuses receive fast approvals for modification and expansions (MPCB, 2023).	High Initial Investment: Institutions have to invest in high replacement costs to undergo retrofitting which can be difficult in case of limited budget. (IGBC, 2017)
Water saving benefits: IGBC aligns with Jal Shakti Abhiyan in Maharashtra by promoting rainwater harvesting and wastewater recycling (MoJS, 2023).	Lack of skilled workers: It is difficult to find trained working professionals to implement sustainability and IGBC guidelines. (TERI, 2022)
Energy Savings: IGBC certified buildings that have retrofitted electrical fixtures can save up to 30% to 50% payment on electricity bills also which enhances financial sustainability (TERI, 2022).	Limited Recognition: IGBC is recognized within India but for an international collaboration it lacks global recognition. (USGBC, 2021).
Adherence to Waste Management: IGBC has guidelines aligning with Maharashtra Pollution Control Board Regulations (MPCB, 2023)	Difficulty in Maintenance: Continuous monitoring and reporting is required for IGBC certified buildings that increases complexity in daily operations. (IGBC, 2017)
Property Tax Incentives: Maharashtra State Government provides property tax discounts for IGBC certified buildings, to encourage institutions to practice sustainability. (MEDA, 2023)	Limited area for rainwater harvesting: There is a limited scope for implementation of rainwater harvesting systems due to lack open of spaces in existing campuses. (MoEFCC, 2023)
Opportunities	Threats
Smart Campus Development funds: Maharashtra State Government offers funding for transforming campuses into a green campus under the smart city initiative. (MoHUA, 2022)	Revised Government Policies: Adjustments in Maharashtra's green building incentives may influence the economic viability of IGBC certifications. (MEDA, 2023)
Promotion of Renewable Energy: IGBC supports solar energy incentives by MSEDCL promoting institutions to implement net metering policies. (MSEDCL, 2023)	Competition with other rating systems: Institutions might opt for GRIHA for government projects or LEED for global partnerships over IGBC. (USGBC, 2021)
Carbon Credits: Institutions can earn carbon credits through IGBC certification which lets them generate additional revenue. (IGBC, 2017)	Slow ROI: Due to initial budget: constraints institutions may be reluctant in implementing IGBC's long term advantages. (TERI 2022)
Circular Economy Integration: IGBC guidelines encourage recycling, reducing landfill waste and promotes waste to energy innovations. (MoEFCC, 2023).	Absence of Sustainability Monitoring: Inadequate sustainability monitoring may prevent the newly certified institutions in achieving intended sustainability goals. (IGBC, 2017)
Student Awareness and Engagement in Sustainability Practices: IGBC certifications create a green learning environment which enhances student involvement in sustainability programmes. (TERI, 2022)	Climate Challenges: Increasing unforeseen heat waves and flood risks in Maharashtra requires additional preventive measures beyond IGBC guidelines. (MoEFCC, 2023)

Source: Compiled by authors

Table 5: GRIHA SWOT Analysis

Strengths	Weakness
Government Recognition: Suitable for government institutions since it is endorsed by the Ministry of New and Renewable Energy (MNRE, 2023).	Complicated Certification Process: Involves detailed documentation and third-party audits making certification process time intensive. (GRIHA, 2019)
Climate Change: Passive design strategies such as natural ventilation and daylighting enables institutions to deal with hot and humid climate. (GRIHA, 2019)	Lack of International Recognition: It is recognized in India but lacks international recognition that limits global collaboration. (USGBC,2022)
Water Efficiency: Rainwater harvesting and water reusing practices in GRIHA align with water conservation goals of government of Maharashtra. (MoJS,2023)	High Initial Investment Costs & Slow ROI: The costs of retrofitting solar panels, water conservation systems and procurement of green materials can be high for some institutions. (TERI, 2022) Additionally the ROI of GRIHA certification is slower compared to IGBC which may discourage private institutions that expect a higher ROI. (MoHUA, 2022)
Energy Efficiency: Institutions can cut electricity cost by 40% by using GRIHA guidelines that aligns with the solar energy initiatives by Maharashtra government. (MSEDCL, 2023)	Shortage of skilled professionals: Unavailability of skilled and trained sustainability professionals and consultants specializing in GRIHA compliance. (MPCB, 2023)
Carbon Footprint Reduction: It encourages use of low carbon construction material, energy-efficient retrofitting to reduce greenhouse gas emissions. (MoEFCC, 2023)	Retrofitting challenges for Urban Campuses: There can be space limitation in cities like Pune and Mumbai that makes rainwater harvesting and renewable energy system implementation difficult. (MoHUA, 2022)
Opportunities	Threats
Aligns with National Policies: GRIHA guidelines align with the national education policy focused on sustainability, enhancing education standards. (MoE,2023)	Competition from other Rating Systems: IGBC and LEED provide quicker certification processes, making them more appealing to private institutions. (USGBC, 2022)
Integrates with renewable energy schemes: GRIHA certified campuses can take advantage of Maharashtra's MSEDCL solar incentives to facilitate solar panel installation. (MNRE,2022)	Changes in Policy: Shift in government sustainability incentives may impact funding for projects under GRIHA. (MEDA, 2023)
Smart & Sustainable Development: GRIHA encourages transformation of existing campuses into smart and sustainable institutions by integrating IOT based energy monitoring systems. (MoHUA, 2022)	Delays in Implementation: Involves complicated third-party verification processes which lead to delays in obtaining GRIHA certification. (GRHIA, n.d.)
Carbon Credits: Certified campuses can generate additional revenue through selling carbon credits. (MoEFCC, 2023)	Lack of Local Sustainable Material: GRIHA guidelines demand specific materials which may be required to be imported, leading to higher costs. (MNRE, 2022)
Enhances Student Engagement: GRIHA enables student engagement in sustainability practices increasing their well-being, productivity and making them environmentally conscious by spreading awareness. (TERI, 2022)	High Cost of Maintenance: Inadequate post certification management makes it challenging for institutions to maintain GRIHA standards, affecting long-term efficiency. (MPCB, 2023)

Source: Compiled by authors

Table 6: Checklist of Criteria Requirement for IGBC & GRIHA Certifications

CRITERIA	IGBC	GRIHA
Minimal structural modifications	✓	X
Energy efficient and renewable systems	✓	✓
Rainwater Harvesting	✓	✓
Waste Management	✓	✓
Indoor Environment Quality	✓	✓
More tax rebates and direct incentives	✓	X
Lower Certification Cost	✓	X
Quick implementation time	✓	X
Flexible Upgradation	✓	X
NAAC accreditation	✓	✓

Source: Compiled by authors

5.0 Limitations and Future Scope

This study is limited to a comparative analysis of rating systems and does not dwell into the analysis of on ground sustainability measures taken by the university to promote sustainability practices.

6.0 Acknowledgement

We would like to extend our sincere gratitude towards NICMAR University, Pune, for providing us this platform to conduct research on “Sustainable Educational Institute Development through Green Rating Systems”. This would not have been possible without the invaluable guidance of our mentor Dr. Shobha Ramalingam, whom we express our heartfelt appreciation for her constant support and guidance in our research endeavours.

References

Green Building Initiative (GBI). (n.d.). *Green Globes for existing buildings*. Retrieved March 7, 2025, from <https://thegbi.org/greenglobes/existing-buildings/>

Indian Green Building Council (IGBC). (2017). *IGBC Green Campus Rating System (New & Existing) Pilot Version, January 2017*. Retrieved March 7, 2025, from [https://igbc.in/frontend-assets/html_pdfs/IGBC%20Green%20Campus%20\(Pilot%20Version%20with%20First%20Addendum%20_%20January%202017\).pdf](https://igbc.in/frontend-assets/html_pdfs/IGBC%20Green%20Campus%20(Pilot%20Version%20with%20First%20Addendum%20_%20January%202017).pdf)

Indian Green Building Council (IGBC). (n.d.). *Indian Green Building Council*. Retrieved March 7, 2025, from <https://igbc.in/>

Kshetri, M. S. B., Kadam, P., Jain, K., Urkude, N., & Shende, P. (2021). Potential retrofitting of existing campus into green buildings.

Maharashtra Energy Development Agency (MEDA). (n.d.). *Maharashtra Energy Development Agency (MEDA)*. Retrieved March 7, 2025, from <https://www.mahaurja.com/meda/>

Maharashtra Pollution Control Board (MPCB). (2023). *Annual report 2022–23*. Retrieved March 7, 2025, from https://mpcb.gov.in/sites/default/files/annual_report/2022-2023.pdf

Maharashtra State Electricity Distribution Company Limited (MSEDCL). (2023, April 28). *Commercial Circular 341 (MERC Order Case No. 226 of 2022)*. Retrieved March 7, 2025, from <https://www.mahadiscom.in/consumer/wp-content/uploads/2023/04/Commercial-Circular-341-dtd-28.4.2023-MERC-Order-Case-No.-226-of-2022.pdf>

Ministry of Education (MoE). (2023). *Annual report 2022–23*. Retrieved March 7, 2025, from https://www.education.gov.in/sites/default/files/annual_report_2022-23.pdf

Ministry of Environment, Forest and Climate Change (MoEFCC). (2023). *Annual report 2022–23*. Retrieved March 7, 2025, from <https://moef.gov.in/wp-content/uploads/2023/04/annual-report-2022-23.pdf>

Ministry of Housing and Urban Affairs (MoHUA). (2022). *Annual report 2021–22*. Retrieved March 7, 2025, from <https://mohua.gov.in/upload/uploadfiles/files/annual-report-2021-22.pdf>

Ministry of Jal Shakti (MoJS). (2023). *Annual report 2022–23*. Retrieved March 7, 2025, from https://jalshakti.gov.in/sites/default/files/annual_report_2022-2023.pdf

Ministry of New and Renewable Energy (MNRE). (2022). *Annual report 2021–22*. Retrieved March 7, 2025, from https://mnre.gov.in/img/documents/uploads/file_f-1677745689963.pdf

Pune Municipal Corporation (PMC). (n.d.). *Green rating system*. Retrieved March 7, 2025, from <https://www.pmc.gov.in/en/green-rating-system-0>

Rajalakshmi, S., Gnanamangai, B. M., Kumar, D. V., Santhya, V. S., Priya, M., Josephine, R. M., ... & Deepa, M. A. (2022). Green campus audit procedures and implementation to educational institutions and industries. *Nature Environment and Pollution Technology*, 21(4), 1921–1932.

Sharma, R., Goel, S., Lenka, S. R., & Satpathy, P. R. (2024). Energy efficiency retrofitting measures of an institutional building: A case study in eastern India. *Cleaner Energy Systems*, 7, 100111.

The Energy and Resources Institute (TERI). (2022). *Annual report 2021–22*. Retrieved March 7, 2025, from <https://www.teriin.org/sites/default/files/2022-09/annual-report-2021-22.pdf>

United Nations. (n.d.). *Sustainable Development Goals (SDGs)*. Retrieved March 7, 2025, from <https://sdgs.un.org/goals>

Eco-Business. (2012, April 26). *Tax incentives for green buildings*. Retrieved March 7, 2025, from <https://www.eco-business.com/news/tax-incentives-for-green-buildings/>

Parvez, N., & Avlokita, A. (2018, November). Review of campus sustainability rating systems for Indian campuses. In *Proceedings of the 52nd International Conference of the Architectural Science Association* (pp. 503–510). Melbourne, Australia.

Green Star. (n.d.). *Introducing Green Star*. Retrieved March 7, 2025, from https://www.gbca.org.au/uploads/91/2139/Introducing_Green_Star.pdf

BREEAM. (n.d.). *How BREEAM works*. Retrieved March 7, 2025, from <https://breeam.com/about/how-breeam-works>

GRIHA Council. (2019). *GRIHA manual: Volume 1*. Retrieved March 7, 2025, from <https://www.grihaindia.org/sites/default/files/pdf/Manuals/griha-manual-vol1.pdf>

WELL. (n.d.). *WELL v2 overview*. Retrieved March 7, 2025, from <https://v2.wellcertified.com/en/wellv2/overview>

U.S. Green Building Council (USGBC). (2021). *LEED v4.1 operations and maintenance*. Retrieved March 7, 2025, from <https://www.usgbc.org/resources/leed-v41-om>

U.S. Green Building Council. (n.d.). *LEED O+M v4.1 credit library*. Retrieved March 7, 2025, from https://build.usgbc.org/clean_om_41

CHAPTER 137

Sustainable Supply Chain Management in Agriculture

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Vishnu Kumar Avasthi¹ and Virendra Balon²*

ABSTRACT

This study evaluates the integration of sustainable practices into agricultural supply chains to enhance livelihoods, minimize environmental impact, and optimize resource utilization. By collecting primary data through surveys of producers, supply chain stakeholders, and agricultural specialists, it identifies challenges and opportunities for eco-friendly strategies. The findings emphasize the importance of sustainable practices to boost productivity, reduce pollution, and achieve ecological and economic goals, offering actionable recommendations for stakeholders. While limited by a small sample size, the study highlights the potential of sustainable supply chains to promote environmental conservation, community health, and equitable economic growth for farming communities, paving the way for long-term benefits.

Keywords: Supply chain management; Sustainable agriculture; Resource optimization; Environmental sustainability; Eco-friendly practices.

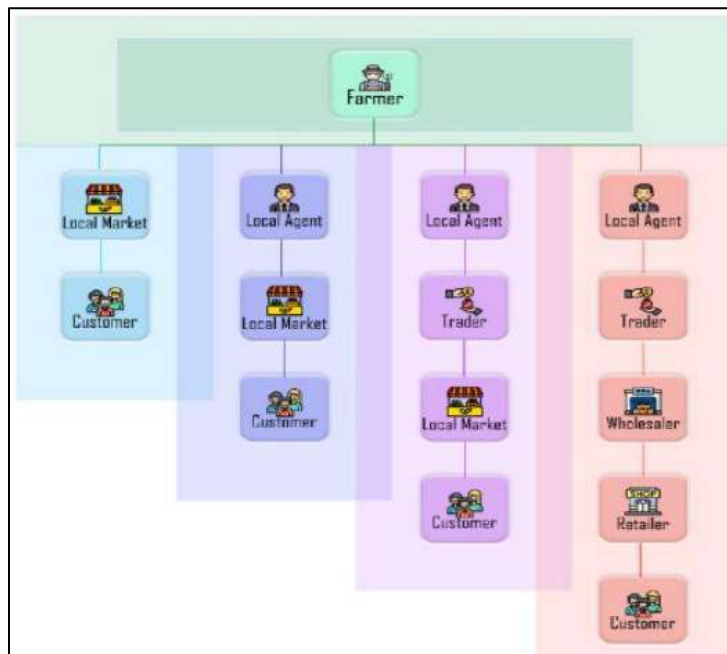
1.0 Introduction

Since it contributes to economic as well as environmental growth, Agriculture is essential to the growth of the nation or area. For most people across the globe, growing agricultural products is a daily activity and an occupation. Consequently, in most countries, agriculture is important in order to rise above poverty (Douillet, 2024). The agricultural supply chain has received much attention in recent times because of its link to social responsibility and environmental issues. Regulations that are more stringent and monitoring should be imposed on the planning as well as operation of the agricultural supply chain. This implies that to meet the growing demands of sustainability, traditional supply chain processes may be modified and altered. Knowing how a sustainable supply chain is helping agriculture is still in its infancy, even though the interest in sustainable supply chain management (SSCM) is growing in numerous directions (Toan, 2018). However, studies have shown that an SSCM's appearance is a key attribute in the agricultural sector. One of the most important problems facing the world today is sustainable agriculture as well as its supply chain. In some nations, they support the economy, society, and ecology.

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Figure 1: Traditional Agricultural Supply Chain



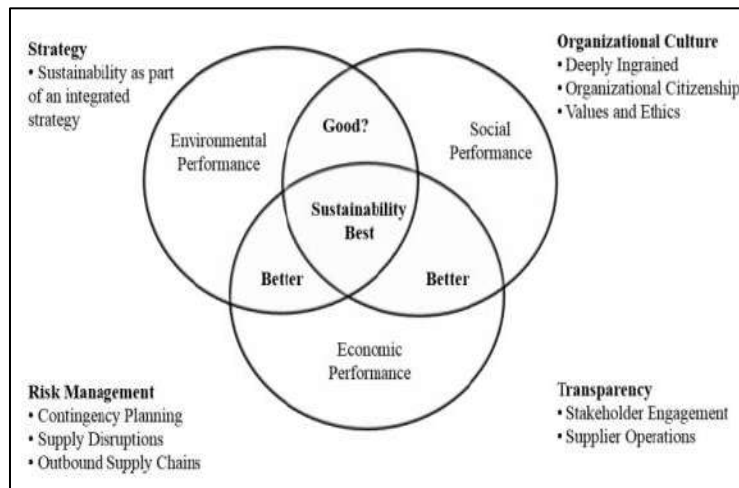
2.0 Sustainability & SSCM

From the viewpoints of corporations, governments, environmentalists, as well as social reformers, the term “sustainable development” may signify many different things. The term “sustainable” has no universally accepted meaning. “A development that satisfies current needs without jeopardizing the capacity of future generations to satisfy their own needs is referred to as sustainable development.” Researchers’ varying conceptions of sustainability concurrently emphasize three facets of social, environmental, as well as economic performance. Sustainability’s capacity to lower long-term dangers associated with pollution, waste management, product liability, resource depletion, & energy price volatility (Kalva, 2017).

“The systemic coordination of key interorganizational business processes for the improvement of the long-term economic performance of the individual company and its supply chain, as well as the strategic, transparent integration and achievement of an organization’s social, environmental, and economic goals.” Because of concerns about income inequality, corporate social responsibility, and the rapid depletion of natural resources, sustainability has grown in importance for business and practical research over the last several decades. Therefore, it is possible to identify sustainable development as a process of structural change and economic growth that upholds human potential. The sustainable growth and balance of human capabilities,

the capacity for social responsibility, and the future for future generations are so ways to approach sustainability (Carter & Rogers, 2008).

Figure 2: SSCM Objective of the Study



- To assess benefits of sustainability in agriculture.
- To identify challenges in adopting sustainable methods.
- To explore innovative solutions for sustainable agriculture.

3.0 Literature review

Sachin S. Kamble *et al.* (2020) highlighted that any solutions to these challenges should include social, environmental, and economic factors in addition to the food production process. New technologies are being used more often in agricultural supply chains. Blockchain, the IoT, and big data may enable sustainable agriculture supply chains. The agricultural supply chain is evolving into a digital, data-driven supply chain ecosystem thanks to these technologies (Kamble *et al.*, 2020). Rajabion *et al.* (2019) provide a framework for evaluating how farmers' knowledge, business practices, and urban ITS affect the effectiveness of GSCM systems for the urban distribution of agricultural products. The causal model is evaluated, and its validity and reliability are confirmed using the structural equation modeling approach. A structural equation model is also used to assess the model's consistency and validity. Smart PLS 3.0 is used for the analysis of the model and survey data (Rajabion *et al.*, 2019).

Touboulic *et al.* (2014) examine sustainable supply chain connections from a power perspective and critically evaluate buyer-supplier relationships using RDT. The RDT model is expanded using empirical data. A qualitative study of a multinational corporation and

agricultural producers in the UK food business explores power dynamics in adopting sustainable practices. To determine how relative power influences sustainable supply-management strategies, several triadic interactions between a major client and its minor suppliers are examined (Touboulis *et al.*, 2014). Rohit Sharma *et al.* (2020) determined and evaluated the interruption-related ASC risks. FLQOWA was used to analyze these risks. The findings indicate that ASC is significantly impacted by supply, demand, financial, logistical, and infrastructure risks. Managerial and operational, policy, regulatory, biological, and environmental risks also play a crucial role depending on the organization's size and scope. Many strategies have been researched for a sustainable future, such as shared responsibility, Industry 4.0 technology adoption, and supply chain collaboration (Sharma *et al.*, 2020).

Kumar *et al.* (2021) highlighted that agricultural enterprises have begun to alter their business strategies due to growing globalization and digitization. Modern technologies are being employed by agribusinesses to create a more advanced, customer-focused, and sustainable supply chain. The circular economy (CE) concept and the development of related technologies have helped the industrial sector meet sustainability goals despite challenges. This report identifies the obstacles to Industry 4.0 (I4.0) and CE adoption in India's agricultural supply chain (Kumar *et al.*, 2021). Tsolakis *et al.* (2014) noted that the growing demand for upscale, value-added, and customized agrifood products is driven by globalization, demographic changes, and evolving regulations.

As a result, contemporary management science has gained more attention in the planning, creation, and administration of effective agrifood supply chains. These trends underscore the need for robust frameworks to optimize AFSC operations (Tsolakis *et al.*, 2014). Chartzoulakis *et al.* (2015) emphasized that water is the most crucial resource for sustainable agriculture. To meet increasing industrial and domestic water needs, more land will be irrigated, and fresh water extraction from agriculture will increase in the coming years. However, irrigation efficiency is currently low, with crops utilizing less than 65% of supplied water. Responsible water usage in irrigation is essential in arid environments (Chartzoulakis & Bertaki, 2015). Movahed *et al.* (2024) stated that the growing global population and food scarcity have led to new advancements in agriculture. To enhance efficiency, artificial intelligence and the Internet of Things are used for farmland management. Advanced industrialization in agriculture has resulted in improved product quality and quantity, optimized energy usage, reduced emissions, and fewer human interventions in the manufacturing process (Movahed *et al.*, 2024).

4.0 Research Methodology

The research methodology is founded upon a primary data collection strategy whose objective is to acquire firsthand experience from the pertinent stakeholders. In a bid to ensure a comprehensive and relevant spectrum of opinions, purposive sampling was used in the selection of a sample comprising 100 respondents, namely farmers, supply chain managers, distributors,

and policymakers. Structured questionnaires were used to collect data, which consisted of close-ended questions focused on essential sustainability factors such as maximizing resource use, minimizing waste, adopting environmentally beneficial technologies, and policy framework effects. To enable respondents' geographical dispersion, the questionnaires were conducted via web-based surveys. The information was examined with the help of statistical measures to find trends, correlation, and challenges involved in adopting sustainable practices within agricultural supply chains. In addition, qualitative answers gave contextual information on the drivers and barriers to sustainability. To ensure the credibility and integrity of the research process, ethical procedures were strictly followed, including the obtaining of informed consent and maintenance of respondent confidentiality.

5.0 Data Analysis

Table 1: Age

		Frequency	Percent
Valid	Under 20	54	54
	21-30	17	17
	31-40	18	18
	41-50	7	7
	Above 50	4	4
	Total	100	100

The age distribution of a sample of 100 people is indicated in the data. The highest number (54%) is below the age of 20, 18% fall in the age group 31 to 40, and 17% fall in the age group 21 to 30. Only 4% fall in the age group above 50, as well as the lower proportion, 7%, fall in the age group 41 to 50. This indicates that the sample includes people who are mostly young.

Table 2: Gender

		Frequency	Percent
Valid	Male	67	67
	Female	33	33
	Total	100	100

The gender distribution of a sample of 100 individuals is reflected in the data. The population consists of mostly males, 67%, and females, 33%. This shows that there is a greater proportion of males in the sample.

Table 3: Education Level

		Frequency	Percent
Valid	High School	18	18
	Undergraduate	42	42
	Postgraduate	17	17
	Doctorate	23	23
	Total	100	100

The data provides the distribution of educational qualifications within a sample population of 100 individuals. Undergraduates are the largest percentage of the segment at 42%, followed by 23% who have a doctorate, 18% with an elementary high school level qualification, and 17% with a postgraduate qualification. This indicates that in the sample, the distribution is relatively level with a considerable percentage of respondents with higher education.

**Table 4: The Adoption of Sustainable Practices in Agriculture is
Essential for Long-term Growth**

		Frequency	Percent
Valid	Strongly Disagree	6	6
	Disagree	10	10
	Neutral	23	23
	Agree	32	32
	Strongly Agree	29	29
	Total	100	100

The results are an indication of what the respondents feel towards a particular statement. Generally, the sentiments are positive as a larger number of respondents agree (32%), strongly agree (29%), or remain neutral. On the contrary, 23% of respondents remain neutral, and a smaller number of respondents disagree (10%) or strongly disagree (6%). Such an observation indicates minimal dissidence and general acceptability.

**Table 5: Sustainable Supply Chain Management in
Agriculture Enhances Environmental Protection**

		Frequency	Percent
Valid	Strongly Disagree	4	4
	Disagree	9	9
	Neutral	24	24
	Agree	29	29
	Strongly Agree	34	34
	Total	100	100

The attitudes of the respondents towards a statement are reflected in the data. Most of them, either strongly agreeing (34%) or agreeing (29%), reflect a positive bias. Although a quarter of the respondents (24%) are neutral, a lesser percentage (9%) or strongly disagree (4%). This reflects that there is overall agreement with little opposition.

Table 6: The Cost of Implementing Sustainable Practices in Agriculture is too High for Small-scale Farmers

		Frequency	Percent
Valid	Strongly Disagree	7	7
	Disagree	8	8
	Neutral	22	22
	Agree	27	27
	Strongly Agree	36	36
	Total	100	100

The opinions of the respondents on a statement are what are captured in the data collected. A general positive sentiment is seen in the fact that a large majority of the respondents either agree (27%) or strongly agree (36%). On the other hand, 22% of the respondents are neutral, while a minority disagree (8%) or strongly disagree (7%). This is an indication of a general consensus with minimal dissent.

Table 7: Farmers in My Region are Aware of the Benefits of Sustainable Farming Practices

		Frequency	Percent
Valid	Strongly Disagree	5	5
	Disagree	8	8
	Neutral	24	24
	Agree	29	29
	Strongly Agree	34	34
	Total	100	100

The findings are a portrayal of the views of the respondents on a specific statement. A positive trend is indicated by the fact that most either strongly agree (34%) or agree (29%). On the dissent, 24% of the respondents are neutral and a lesser proportion disagrees (8%) or strongly disagrees (5%). This shows that there is a general assent with little dissent.

The “Case Processing Summary” reveals that the analysis had 100 valid cases, which represented 100% of the data. The study did not exclude any cases, as a 0% exclusion rate indicates. Therefore, the dataset was represented by a sum total of 100 cases that were integrated

into the analysis. This summary suggests that the analysis is based on the whole dataset, with no data omitted or discarded.

Table 8: Scale - All Variables

Case Processing Summary			
		N	%
Cases	Valid	100	100
	Excluded ^a	0	.0
	Total	100	100

Table 9: Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.901	.894	18

The results of the reliability analysis of the data are shown in the “Reliability Statistics” table. From the Cronbach’s Alpha of 0.901, it is evident that the items on the scale have a high level of internal consistency, meaning that they are highly correlated and reliable. A standardized item value of 0.894 shows that the internal consistency is strong even when the items are standardized. Examining 18 items established the reliability of the scale, which shows that it is a valid measure of the construct in question.

Table 10: ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
The adoption of sustainable practices in agriculture is essential for long-term growth.	Between Groups	23.074	4	5.768	4.863	.001
	Within Groups	112.686	95	1.186		
	Total	135.760	99			
Sustainable supply chain management in agriculture enhances environmental protection.	Between Groups	26.278	4	6.569	6.258	.000
	Within Groups	99.722	95	1.050		
	Total	126.000	99			
The cost of implementing sustainable practices in agriculture is too high for small-scale farmers.	Between Groups	31.455	4	7.864	6.426	.000
	Within Groups	116.255	95	1.224		
	Total	147.710	99			
Farmers in my region are aware of the benefits of sustainable farming practices.	Between Groups	26.655	4	6.664	6.091	.000
	Within Groups	103.935	95	1.094		
	Total	130.590	99			

Long-term development requires the usage of sustainable farming practices: The hypothesis is accepted since the p-value is 0.001, which is lower than the significance level of 0.05. Sustainable agricultural supply chain management enhances environmental conservation: The hypothesis is embraced since the p-value is 0.000, which is lower than the significance level of 0.05. Small-scale producers cannot fund the costs involved in implementing sustainable farm practices: The null hypothesis is rejected since $p = 0.000$ is less than the significance level of 0.05. The farmers in my area see the benefits of sustainable agriculture: The null hypothesis is rejected, since the p-value 0.000 is smaller than the significance level 0.05. In all cases, the p-values are smaller than 0.05, indicating that there are large differences among the groups. The null hypotheses are therefore rejected. The alternative hypotheses are therefore accepted.

6.0 Findings

The ANOVA results confirm that consumers demonstrate significant differences in their willingness to pay a premium for agricultural produce that is sourced ecologically, reflecting strong support for sustainability in their shopping habits (p-value = 0.000). However, there is no significant difference in views about the focus on minimizing waste and maximizing resources in the agricultural supply chain (p-value = 0.087), nor is there a significant difference in views about the lack of awareness and training in SSCM for agriculture (p-value = 0.143). These results suggest that customers value sustainability in consumption; however, there is less consensus when it comes to the operational aspects and the need for education in sustainable agriculture.

7.0 Conclusion

In conclusion, agricultural SSCM is fundamental for the long-term development of economic stability, environmental conservation, and social health. The report emphasizes how important sustainable farming methods are, including the application of innovative technologies, enhancement of resource optimization, and minimization of waste in the enhancement of the overall efficiency as well as sustainability of the agricultural supply chain. While there is widespread consumer acceptance of agricultural produce that is sourced sustainably, there is limited agreement on the operational areas of focus, such as resource maximization and minimization of waste. In addition, to ensure the universal application of these practices, it is crucial to solve the major education and awareness problems of SSCM. In building a resilient and accountable agricultural system, it will be crucial to have sustainable supply chain practices since the agricultural sector will continue to grapple with the impacts of climate change, resource depletion, and rising global demand.

References

Ahumada, O., & Villalobos, J. R. (2009). Application of planning models in the agri-food supply chain: A review. *European Journal of Operational Research*, 196(1), 1-20.

Akkerman, R., Farahani, P., & Grunow, M. (2010). Quality, safety and sustainability in food distribution: A review of quantitative operations management approaches and challenges. *OR Spectrum*, 32(4), 863-904.

Aramyan, L. H., Oude Lansink, A. G. J. M., van der Vorst, J. G. A. J., & van Kooten, O. (2007). Performance measurement in agri-food supply chains: A case study. *Supply Chain Management: An International Journal*, 12(4), 304-315.

Beske, P., Land, A., & Seuring, S. (2014). Sustainable supply chain management practices and dynamic capabilities in the food industry: A critical analysis of the literature. *International Journal of Production Economics*, 152, 131-143.

Boehlje, M. (1999). Structural changes in the agricultural industries: How do we measure, analyze and understand them? *American Journal of Agricultural Economics*, 81(5), 1028-1041.

Bourlakis, M., Maglaras, G., Aktas, E., Gallear, D., & Fotopoulos, C. (2014). Firm size and sustainable performance in food supply chains: Insights from Greek SMEs. *International Journal of Production Economics*, 152, 112-130.

Brandenburg, M., Govindan, K., Sarkis, J., & Seuring, S. (2014). Quantitative models for sustainable supply chain management: Developments and directions. *European Journal of Operational Research*, 233(2), 299-312.

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: Moving toward new theory. *International Journal of Physical Distribution & Logistics Management*, 38(5), 360-387.

Cassidy, A. (2025, January 24). Feed the world—but can we do it without wrecking the planet further? *The Guardian*. <https://www.theguardian.com/research-to-reality/2025/jan/24/feed-the-world-but-can-we-do-it-without-wrecking-the-planet-further>

Chartzoulakis, K., & Bertaki, M. (2015). Sustainable Water Management in Agriculture under Climate Change. *Agriculture and Agricultural Science Procedia*, 4, 88–98. <https://doi.org/10.1016/j.aaspro.2015.03.011>

Chkanikova, O., & Mont, O. (2015). Corporate supply chain responsibility: Drivers and barriers for sustainable food retailing. *Corporate Social Responsibility and Environmental Management*, 22(2), 65-82.

Christopher, M., & Peck, H. (2004). Building the resilient supply chain. *International Journal of Logistics Management*, 15(2), 1-14.

Croom, S., Romano, P., & Giannakis, M. (2000). Supply chain management: An analytical framework for critical literature review. *European Journal of Purchasing & Supply Management*, 6(1), 67-83.

Dania, W. A. P., Xing, K., & Amer, Y. (2018). Collaboration and sustainable agri-food supply chain: A literature review. *MATEC Web of Conferences*, 152, 1-7.

de Boer, L., & van Ittersum, K. (2018). Assessing the sustainability of specialty food supply chains: A European case study. *Sustainability*, 10(12), 1-16.

Desalegn, S. G., & Nadeem, S. P. (2024). The adoption of sustainable supply chain management practices on performance of agricultural sectors in Ethiopia. *Journal of World Economic Research*, 13(2), 55-72. <https://doi.org/10.11648/j.jwer.20241302.13>

Dubey, R., Gunasekaran, A., & Papadopoulos, T. (2017). Green supply chain management: Theoretical framework and further research directions. *Benchmarking: An International Journal*, 24(1), 184-218.

Elkington, J. (1998). *Cannibals with forks: The triple bottom line of 21st century business*. New Society Publishers.

Fawcett, S. E., Magnan, G. M., & McCarter, M. W. (2008). Benefits, barriers, and bridges to effective supply chain management. *Supply Chain Management: An International Journal*, 13(1), 35-48.

Fritz, M., & Schiefer, G. (2008). Food chain management for sustainable food system development: A European research agenda. *Agribusiness*, 24(4), 440-452.

Gimenez, C., & Tachizawa, E. M. (2012). Extending sustainability to suppliers: A systematic literature review. *Supply Chain Management: An International Journal*, 17(5), 531-543.

Gold, S., Seuring, S., & Beske, P. (2010). Sustainable supply chain management and inter-organizational resources: A literature review. *Corporate Social Responsibility and Environmental Management*, 17(4), 230-245.

Govindan, K., Rajendran, S., Sarkis, J., & Murugesan, P. (2015). Multi criteria decision making approaches for green supplier evaluation and selection: A literature review. *Journal of Cleaner Production*, 98, 66-83.

Grimm, J. H., Hofstetter, J. S., & Sarkis, J. (2014). Critical factors for sub-supplier management: A sustainable food supply chains perspective. *International Journal of Production Economics*, 152, 159-173.

Handayati, Y., Simatupang, T. M., & Perdana, T. (2015). Agri-food supply chain coordination: The state-of-the-art and recent developments. *Logistics Research*, 8(1), 5.

Hussain, M., & Malik, M. (2020). Prioritizing sustainable supply chain management practices in the context of Pakistani textile industry. *Sustainable Production and Consumption*, 23, 1-12.

Kalva, R. S. (2017). A Model for Strategic Marketing Sustainability (Marketing mix to Marketing matrix). *National Conference on Marketing and Sustainable Development*, 7–23.

Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2020). Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications. *International Journal of Production Economics*, 219(March 2019), 179–194. <https://doi.org/10.1016/j.ijpe.2019.05.022>

Kumar, S., Raut, R. D., Nayal, K., Kraus, S., Yadav, V. S., & Narkhede, B. E. (2021). To identify industry 4.0 and circular economy adoption barriers in the agriculture supply chain by using ISM-ANP. *Journal of Cleaner Production*, 293, 126023. <https://doi.org/10.1016/j.jclepro.2021.126023>

Kumar, V., & Singh, P. J. (2017). Coordination and responsiveness issues in the supply chain: A case study of the Indian dairy industry. *Journal of Agribusiness in Developing and Emerging Economies*, 7(1), 2-20.

Le Bao Toan. (2018). *SUSTAINABLE AGRICULTURAL SUPPLY CHAIN – A LITERATURE REVIEW*. https://www.worldwidejournals.com/global-journal-for-research-analysis-GJRA/recent_issues_pdf/2018/January/January_2018_1515151896__63.pdf

Mangla, S. K., Govindan, K., & Luthra, S. (2017). Prioritizing the barriers to achieve sustainable consumption and production trends in supply chains using fuzzy Analytical Hierarchy Process. *Journal of Cleaner Production*, 151, 509-525.

Moktadir, M. A., Rahman, T., & Rahman, M. H. (2018). Drivers to sustainable manufacturing practices and circular economy: A perspective of leather industries in Bangladesh. *Journal of Cleaner Production*, 174, 1366-1380.

Movahed, A. B., Movahed, A. B., Aliahmadi, B., & Nozari, H. (2024). Green and sustainable supply chain in agriculture 6.0. *Advanced Businesses in Industry 6.0*, April, 32–45. <https://doi.org/10.4018/979-8-3693-3108-8.ch003>

Nicolas Douillet. (2024). *Agriculture Overview: Development news, research, data* | World Bank. <https://www.worldbank.org/en/topic/agriculture/overview>

Patidar, R., Agrawal, S., & Pratap, S. (2018). Development of novel strategies for designing sustainable Indian agri-fresh food supply chain. *Sādhanā*, 43, 167. <https://doi.org/10.1007/s12046-018-0927-6>

Rajabion, L., Khorraminia, M., Andjomshoaa, A., Ghafouri-Azar, M., & Molavi, H. (2019). A new model for assessing the impact of the urban intelligent transportation system, farmers' knowledge and business processes on the success of green supply chain management system for urban distribution of agricultural products. *Journal of Retailing and Consumer Services*, 50(March), 154–162. <https://doi.org/10.1016/j.jretconser.2019.05.007>

Sharma, P., & Singh, R. K. (2019). Analyzing the barriers of green supply chain management in small and medium-sized enterprises: A case of Indian clothing industry. *Management of Environmental Quality: An International Journal*, 30(5), 1095-1114.

Sharma, R., Shishodia, A., Kamble, S., Gunasekaran, A., & Belhadi, A. (2020). Agriculture supply chain risks and COVID-19: mitigation strategies and implications for the practitioners. *International Journal of Logistics Research and Applications*, FAO. <https://doi.org/10.1080/13675567.2020.1830049>

Sonar, H., Sharma, I., Ghag, N., & Singh, R. K. (2024). Barriers for achieving sustainable agri supply chain: Study in context to Indian MSMEs. *International Journal of Logistics Research and Applications*. Advance online publication. <https://doi.org/10.1080/13675567.2024.2345359>

Touboulie, A., Chicksand, D., & Walker, H. (2014). Managing Imbalanced Supply Chain Relationships for Sustainability: A Power Perspective. *Decision Sciences*, 45(4), 577–619. <https://doi.org/10.1111/dec.12087>

Tsolakis, N. K., Keramydas, C. A., Toka, A. K., Aidonis, D. A., & Iakovou, E. T. (2014). Agrifood supply chain management: A comprehensive hierarchical decision-making framework and a critical taxonomy. *Biosystems Engineering*, 120, 47–64. <https://doi.org/10.1016/j.biosys.2013.10.014>

Yadav, G., & Desai, T. N. (2016). Lean Six Sigma: A categorized review of the literature. *International Journal of Lean Six Sigma*, 7(1), 2–24.

Zhu, Q., & Sarkis, J. (2004). Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. *Journal of Operations Management*, 22(3), 265–289.

CHAPTER 138

Synergizing Lean Construction, Building Information Modeling, and Sustainability: A Comprehensive Review and Integration Analysis in Building Construction Projects

Atharva Vatsaraj¹, Pratham Kapoor¹, Ayesha Mahapatra¹, Gaurav Wayase¹ and Deepak M. D.²

ABSTRACT

The Architecture, Engineering, and Construction (AEC) industry faces labor inefficiency, environmental issues, and productivity difficulties. To improve project outcomes, this study investigates the integration of sustainability concepts, lean construction (LC), and building information modeling (BIM). Although interest in LC and BIM separately is expanding, there is still a dearth of research on their combined use. By outlining the benefits of BIM and suggesting standard operating procedures, this article seeks to close this disparity. The study proposes to undertake a systematic literature review using the PRISMA approach. In response to this challenge, a lot of research has been carried out to ensure effectiveness and efficiency in the building industry. Consequently, this study seeks to analyze the integration of Lean Construction (LC) and Building Information Modeling (BIM) in the building industry. This systematic literature review was done using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) method to stringently identify, sort, and examine pertinent information from journals, conferences, and reports. By the integration of evidence in the systematic review of literature, this study aims to make notable contributions to diverse methods, techniques, challenges, and opportunities of integrating Lean Construction and BIM in construction.

Keywords: BIM; Lean construction; Sustainability; Bim and lean integration.

1.0 Introduction

1.1 Background

Among several industries that depend heavily on labor, the architecture, engineering, and construction (AEC) sector struggles with low productivity and inefficient labor practices. Adverse environmental effects and resource waste are also major societal issues. This indicates that it is essential to address the issue of how to maintain both competitiveness and profitability by making the best use of all their resources, including people, machinery, supplies, and technology. This is also consistent with lean thinking. A growing number of academics and government agencies are becoming interested in cutting-edge techniques and approaches like BIM project management and Lean construction management (LCM), as awareness of low-carbon development and ecological conservation grows (Ballard & Howell, 2003).

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Globally, the construction sector has been distinguished by poor productivity: between 1995 and 2015, the average growth rate of value added per person was only 1.0%, whereas the overall growth rate of the economy was 2.7% (Hei *et al.*, 2024). In contrast, the manufacturing sector grew at a rate of roughly 3.6% over the same period. This productivity disparity emphasizes the necessity of creative solutions to raise productivity and performance in the AEC sector. Despite these initiatives, research on the requirements for successfully implementing lean concepts with BIM in the AEC sector is still lacking. While earlier research has emphasized the advantages and difficulties of applying lean construction techniques to fully realize the potential synergies between BIM individually, it is necessary to investigate the integration of these two methodologies. By establishing standards for the application of lean concepts using BIM, this study seeks to close this research gap and tackle the research challenge in its entirety. (Ong & Pheng, 2021)

Given these challenges and opportunities, this research aims to develop a structured approach to integrating Lean principles with BIM, focusing on best practices, implementation frameworks, and the identification of key success factors. By exploring case studies and analyzing empirical data, this study will contribute to a deeper understanding of how Lean-BIM integration can be leveraged to enhance project efficiency, sustainability, and overall performance in the AEC sector. The findings will be valuable for construction firms, policymakers, and researchers seeking to bridge the gap between theoretical concepts and practical applications in modern construction management.

1.2 Aim and objectives

To explore the integration of Lean Construction (LC) and Building Information Modelling (BIM) through a systematic literature review to identify major benefits, challenges, and future research directions.

1.3 Objectives

- To identify research papers, and journals on the integration of Last Planner System and BIM using PRISMA.
- To analyze the theory, contextual background, characteristics, and methodologies used in the studies.

1.4 Scope

The study will encompass peer-reviewed research papers, journal articles, and conference papers sourced from online databases such as Scopus, Web of Science, and Research Gate, all written in English. The literature review will concentrate on recent publications from the past 15 years to understand the development and progress in the integration of Building Information Modelling (BIM) and Lean Construction (LC). The primary focus will be on the construction industry in India, with additional coverage of select papers from other countries to evaluate the efficiency of this integration and identify existing barriers. While the study will not propose a framework for integration, it will suggest areas for further research.

2.0 Literature Review

The AEC industry has observed significant changes in efficiency and project management skills by adopting methodologies such as Lean Construction and Building Information Modelling (BIM). Lean Construction principles, derived from manufacturing principles, focus on eliminating waste, optimizing workflows, and ensuring continuous improvement. Building information models in the AEC industry makes wonderful and efficient digital 3D models to successfully integrate and manage project management information throughout the construction project lifecycle. The integration and adaption of these two methodologies present an opportunity to enhance productivity, reduce errors, and improve overall project performance. Therefore, the potential benefits and challenges remain in effectively merging Lean and BIM into a balanced system.

2.1 Lean construction (LC)

Lean Construction (LC) is a spin-off of the lean manufacturing philosophy led by Toyota in the 1950s and codified as the Toyota Production System (TPS). The philosophy emerged again in the 1980s and was subsequently termed “lean production” by Womack *et al.* (1995). LC targets eliminating waste, streamlining workflow efficiency, and maximizing value using tools such as Percent Plan Completion (PPC) (The Lean-to-Green Evolution, 2019). Developed by the Lean Construction Institute (LCI) in 1993, LC combines the lean production philosophy with construction management to enhance the performance of a project and minimize inefficiencies.

2.2 Building information modelling (BIM)

Building Information Modelling (BIM) is a revolutionary computer program that facilitates project coordination in the Architecture, Engineering, and Construction (AEC) sector. The National Building Information Modelling Standards (NBIMS) defines BIM as a shared platform via which stakeholders can input, modify, and review data throughout the entire life of a building (Azhar *et al.*, 2012). Utilization of BIM leads to improved visualization, less design conflicts, and enhanced cost estimation, thereby resulting in higher-quality outcomes in projects. In combination with the integration of lean construction principles, BIM ensures maximum utilization of materials, workflows, and rework, which all contribute positively to overall resource management.

2.3 Sustainable development in construction projects

Sustainable construction confronts the AEC sector’s EES footprint through the motivation of natural resource utilization efficiency and minimization of negative effects on the environment. With its roots in the United Nations’ SDGs, it involves eco-similar materials, renewable energy sources, and innovative design options such as green roofs and passive cooling (Bajjou *et al.*, 2017). Standards like Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) provide guidelines for sustainable practices. Further, Building Information Modelling (BIM) and Artificial Intelligence (AI) facilitate optimal utilization of resources and life cycle assessment. However, factors like high capital expenses, change resistance, and absence of trained manpower are still preventing it from gaining widespread acceptance.

3.0 Research Methodology

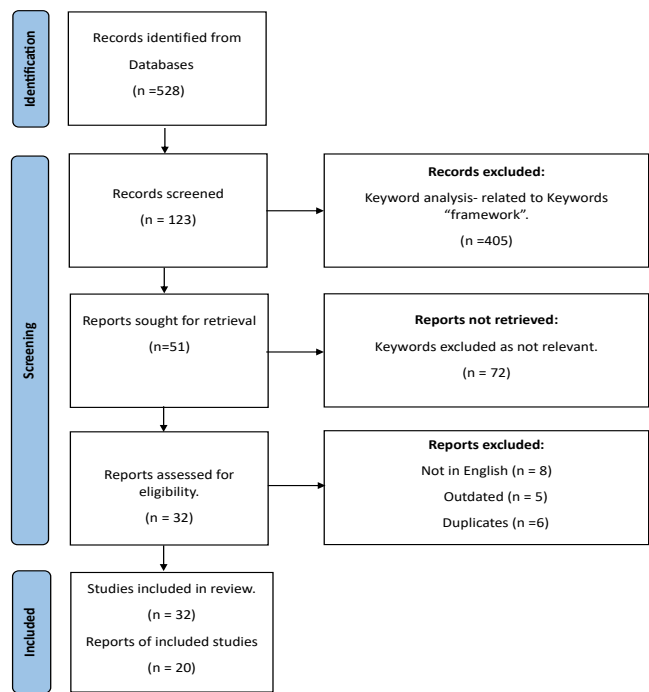
3.1 Systematic literature Review using PRISMA

The PRISMA methodology is a systematic and explicit approach that involves the collection, and evaluation of data and uses methodical procedures to identify, select, evaluate, and review relevant studies (Sharma & Laishram, 2024). To maintain methodological rigor, this study also follows PRISMA for systematic review focusing on BIM-Lean integration in the construction industry and was performed in three stages-

- Stage I – planning the review.
- Stage II – conducting the review.
- Stage III – analyzing and reporting the review

The flowchart (Figure 1) illustrates the step-by-step selection process for research studies. Initially, a total of 528 studies were identified. However, the majority (405 studies) were excluded as they did not pertain to the topic. This left 123 studies for further examination. Subsequently, 51 studies were thoroughly reviewed, while 72 were eliminated for being unhelpful. After that, 32 studies underwent scrutiny. Some were discarded because they were not in English (8), were outdated (5), or were duplicates (6). 12 Ultimately, 32 studies were selected, with 20 being the most significant. This procedure allowed for the identification of the best and most relevant studies for the research.

Figure 1: Systematic Literature Review using PRISMA



Source: Author's creation

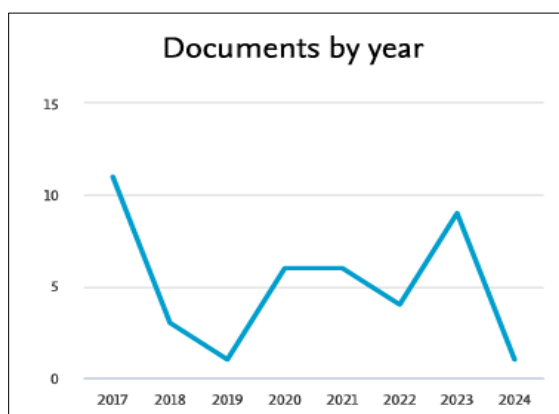
4.0 Results and Discussion

Based on the detailed method as stated in the earlier section, the results are discussed as follows: The result first addresses the bibliometric profile of the studies (i.e., publication, authorship, citation).

4.1. Publication trends over time

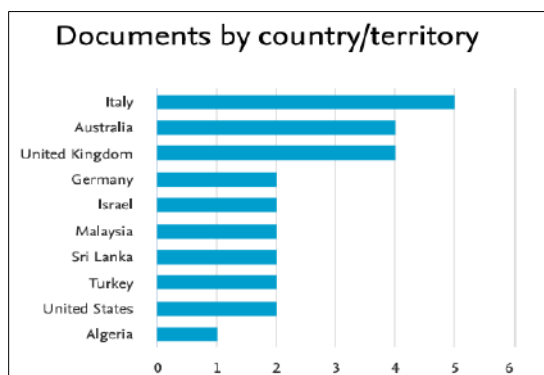
The analysis of the data showcases the distribution of published documents over the selected period, highlighting key trends in BIM, Lean Construction, and Sustainability research. The graph indicates two distinct phases of increased interest in these areas, with a significant rise in 2017 and another peak in 2023. These fluctuations reflect the growing adoption of digitalization (BIM), efficiency-driven methodologies (Lean), and environmentally conscious practices (Sustainability) in the construction industry.

Figure 2: Publication Over the Years



Source: Scopus

Figure 3: Publication by Country



Source: Scopus

4.2. Publication by country

Developed countries such as Italy, Australia, and the United Kingdom have a higher number of research publications on this topic compared to developing nations like Malaysia, Sri Lanka, and Algeria. This disparity may be attributed to various factors, with one major reason being resistance to change among stakeholders in emerging economies, which affects the adoption of new methodologies and technologies.

4.3 Keyword co-occurrence analysis

The cluster shown in Figure 3 is a network map generated with VOS viewer, illustrating the connections among key concepts associated with Building Information Modelling (BIM), Lean Construction, and their synergy within the construction sector. The nodes signify various themes, while the connecting lines depict the relationships between these subjects. Different hues presumably correspond to publication years or thematic groups, as demonstrated by the color gradient in the bottom right corner, spanning from 2020 to 2023.

Figure 4: Mapping of Co-occurrence of Keywords

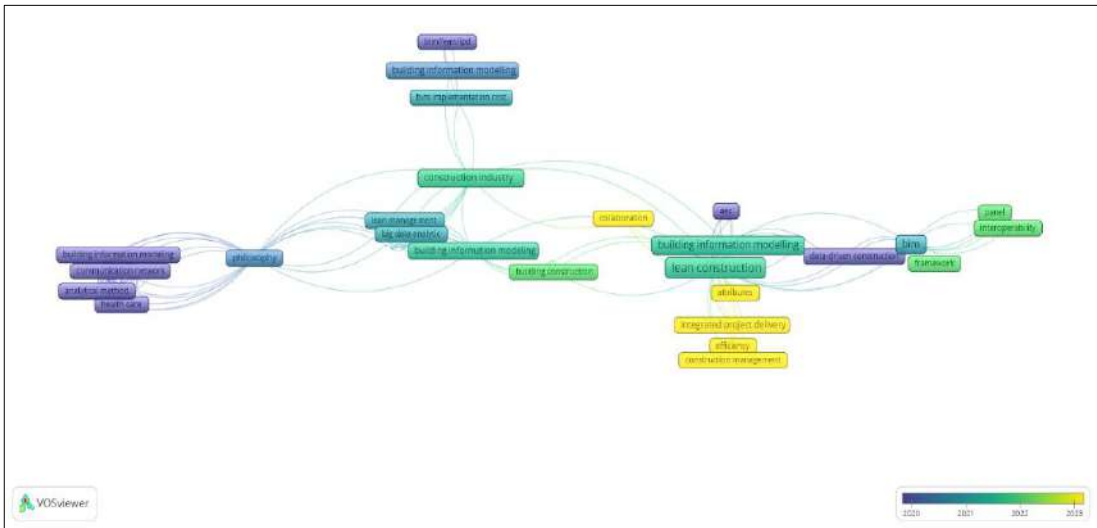
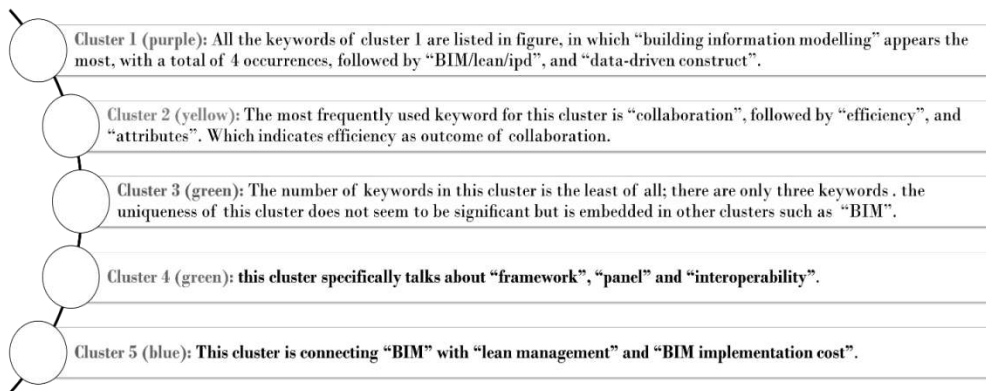


Figure 4 emphasizes the connections between BIM and Lean Construction in contemporary construction methodologies. Central themes such as efficiency, collaboration, integrated project delivery, and data-driven construction are highlighted as significant focal points. The network further investigates implementation costs, interoperability, and sustainable practices related to BIM adoption. The color change illustrates the progression of research interests over time, revealing a growing focus on framework development, construction management, and digital transformation. This map acts as a valuable representation of recent developments and research directions within the field.

Figure 5: Inferences of the Cluster of Keywords



5.0 Conclusion

This research has widely examined the intersection of Lean Construction (LC), Building Information Modeling (BIM), and Sustainability in construction projects. The results point out that although each method alone helps in achieving maximum project efficiency, minimizing waste, and enhancing sustainable practice, their application in combination has a revolutionary potential for the Architecture, Engineering, and Construction (AEC) sector. Lean Construction promotes a culture of waste reduction, resource utilization, and process improvement. BIM is a virtual facilitation technology that improves visualization, communication, and anticipatory decision-making. Sustainability norms govern that the way construction is done becomes harmonized with ecology, economy, and social harmony, enabling wiser and cleaner infrastructure. Despite these advantages, change resistance, increased cost of implementation, and professional pressure are the limiting factors toward massive application. There is a need for future studies to bridge the gaps through the integration of the framework, technological advancement in digitization, and policy-level dissemination of sustainable construction. Through assistance from technological revolutions and interdisciplinary approaches, the AEC industry has the potential for greater efficiency, cost-effectiveness, and sustainability.

References

- Ahuja, R., Sawhney, A., & Arif, M. (2017). Driving lean and green project outcomes using BIM: A qualitative comparative analysis. *International Journal of Sustainable Built Environment*, 6(1), 69–80. <https://doi.org/10.1016/j.ijsbe.2016.10.006>
- Azhar, S., Hein, M., & Sketo, B. (2012). Building Information Modeling (BIM): Benefits, risks, and challenges.

Azhar, S., Khalfan, M., & Maqsood, T. (2012). Building information modeling (BIM): Now and beyond. *Australasian Journal of Construction Economics and Building*, 12(4), 15–28. <https://doi.org/10.5130/AJCEB.V12I4.3032>

Bajjou, M.S., Chafi, A., & Ennadi, A. (2017). *Sustainable Construction: A Literature Review on Definitions, Concepts, and Practices* – Analyzes sustainable construction principles and their alignment with energy efficiency and environmental conservation.

Ballard, G., & Howell, G. (2003). Lean project management. *Building Research & Information*, 31(2), 119–133.

Bayhan, H. G., Demirkesen, S., & Jayamanne, E. (2019). Enablers and barriers of lean implementation in construction projects. *IOP Conference Series: Materials Science and Engineering*, 471(2), 022002. <https://doi.org/10.1088/1757-899X/471/2/022002>

Dave, B., Koskela, L., & Kiviniemi, A. (2013). Implementing lean in construction: Lean construction and BIM. *Construction Innovation*, 13(2), 210–225.

Joy Ong, C., & Low Sui Pheng. (2021). *Integrating lean and BIM for sustainable construction*. Springer Nature Singapore.

Moradi, S., & Sormunen, P. (2022). Lean and sustainable project delivery in building construction: Development of a conceptual framework. *Buildings*, 12(10), 1717. <https://doi.org/10.3390/buildings12101757>

Womack, J.P., Jones, D.T., & Roos, D. (1995). *The Machine That Changed the World* – Introduced the concept of “lean production” and its impact on modern industries, including construction.

CHAPTER 139

Systematic Literature Review on Quality Function Deployment in Assessing Service Quality

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ABSTRACT

This study explores the application of Quality Function Deployment (QFD) in enhancing service quality within the construction industry, with a focus on Project Management Consultants (PMCs). The construction sector in India plays a vital role in economic development; however, it faces persistent quality management challenges. These challenges often contribute to project delays and can be broadly categorized into three areas: material deficiencies, such as substandard or delayed supplies; design-related errors stemming from inadequate planning or revisions; and poor coordination among fragmented stakeholders, which hampers communication and decision-making across project phases. Quality Function Deployment (QFD) is utilized to systematically translate client requirements into actionable quality improvements. The methodology combines Quality Function Deployment (QFD) and integrates established quality management frameworks such as Total Quality Management (TQM) and Service Quality (SERVQUAL) to prioritize critical service quality factors. Key factors identified include timeliness, accuracy, communication, and responsiveness, which are assessed at corporate, project, and product levels to create a holistic quality performance index. By aligning stakeholder expectations with technical and operational project requirements, this approach provides a structured framework for Project Management Consultancy (PMC) to benchmark service quality, increase client satisfaction, and achieve continuous improvement. The findings highlight the importance of adopting advanced quality management practices that promote collaboration, transparency, and technological innovation. This Quality Function Deployment-based model establishes new quality standards, contributing to more efficient project execution and delivering greater stakeholder value, ultimately addressing critical gaps in the construction industry's management practices.

Keywords: Quality function deployment; Project management consultant; Service quality; Construction industry; Design build.

1.0 Introduction

Overview: The construction business in India plays a crucial role in economic expansion, infrastructure advancement, and job creation.

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According to “Deloitte, India economic outlook, January 2025. Deloitte Insights”, the country’s Gross Domestic Product (GDP) growth is projected to range between 6.5% and 6.8% for the fiscal year, with the construction sector being one of the key contributors to this growth. However, quality assurance in building projects remains challenging. Quality in construction is determined by factors like materials, craftsmanship, adherence to standards, safety measures, and final project delivery. Ensuring quality results in reliability, safety, and long-term cost savings while enhancing a company’s reputation. Despite its importance, quality management in Indian construction faces challenges such as insufficient knowledge of standards, small-scale firms, cost-cutting tendencies, inconsistency, and blame-shifting. This chapter explores the role of quality in construction, the use of Quality Function Deployment (QFD) in Total Quality Management, and solutions to quality-related issues.

Background: Quality in construction has evolved over centuries, from meticulous craftsmanship in ancient structures to standardization during the Industrial Revolution. Modern advancements emphasize sustainability, lean principles, and digital management. However, challenges like cost pressures and labor shortages persist. Unlike manufacturing, construction errors are costly and impact safety, making comprehensive quality management crucial. It involves design, materials, workmanship, and inspections to ensure safe, durable, and high-quality structures.

Role of quality in construction: Quality ensures safety by reducing the risk of accidents and structural failures. It enhances durability, minimizes maintenance costs, and promotes sustainability. Furthermore, quality workmanship contributes to client satisfaction and strengthens a company’s reputation—both essential for securing future projects and maintaining competitiveness in the construction industry. However, quality-related issues such as material deficiencies, design errors, poor workmanship, and lack of customer satisfaction frequently led to project delays and inefficiencies.

Total Quality Management (TQM) offers a comprehensive approach to overcoming these challenges by promoting continuous improvement, fostering stakeholder involvement, and embedding quality into every stage of the construction process. By doing so, TQM helps reduce cost overruns, ensures regulatory compliance, and improves coordination among teams.

Within the TQM framework, specific tools are employed to translate its principles into actionable practices. One such tool is Quality Function Deployment (QFD), which plays a crucial role in aligning construction outcomes with client expectations. QFD facilitates the systematic identification and prioritization of customer requirements and integrates them into design and construction planning. This not only improves communication among project teams but also supports continuous quality enhancement throughout the project lifecycle. Implementation Challenges in Quality Management challenges include fragmented supply chains, evolving project requirements, and regulatory changes. Cultural barriers like resistance to change and hierarchical structures hinder implementation. Overcoming these requires leadership commitment, employee training, and fostering a quality-driven culture. Technologies

like BIM, drones, and sensors improve transparency and accountability. A holistic approach addressing technical, cultural, and organizational aspects ensures high-quality project delivery.

2.0 Literature Review

2.1 Introduction to literature review

The reviewed documents explore the application of Quality Function Deployment (QFD) in construction and design/build projects, highlighting its effectiveness in translating client expectations into technical solutions. Researchers have proposed enhanced QFD methodologies that integrate stakeholder theory, allowing for a more structured approach to identifying, categorizing, and prioritizing the diverse needs of stakeholders. This approach is particularly relevant for Project Management Consultants (PMCs), who are responsible for aligning the interests of clients, contractors, designers, and end-users throughout the project lifecycle. Furthermore, the integration of QFD with utility theory—especially through advanced weighting systems—has shown promise in improving occupant satisfaction in office environments. PMCs can leverage utility theory to objectively evaluate and balance competing stakeholder priorities, ensuring design and construction decisions are aligned with overall project value and user satisfaction.

Models developed for evaluating service quality in design/build projects employ QFD at both corporate and project levels. These models link customer requirements to technical attributes and quality management practices, supporting PMCs in monitoring and enhancing service delivery. At the project level, ten key service quality factors are identified, with importance weights transferred from the corporate model. These are closely tied to the three core quality management components—planning, assurance, and control—which PMCs are often tasked with implementing and overseeing.

By analyzing the relationships between service factors and quality system processes, these models generate a quality performance index that PMCs can use for performance tracking and continuous improvement. At the product level, users' needs (performance, usability, aesthetics) are mapped to functional, technical, and behavioral attributes, resulting in a total quality performance index. This enables construction firms, under the guidance of PMCs, to conduct self-evaluations and benchmark their performance against industry standards.

2.2 Literature survey using preferred reporting items for systematic reviews and meta-analyses (PRISMA) approach

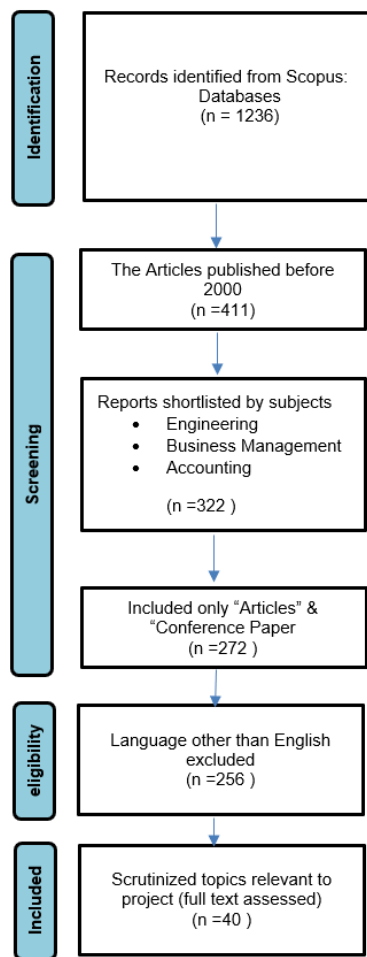
A Scopus search was conducted using the keywords: “Quality,” “Quality Function Deployment,” “QFD,” “Construction,” and “Construction Industry” within the subject areas of Engineering, Business Management, and Accounting.

The initial search yielded 1,236 results from various disciplines. Irrelevant articles were screened out based on the above criteria.

Table 1: Criteria for Screening Literature for Quality Function Deployment

Sr. No	Criteria	Rationale
1	Language	Only English articles were selected.
2	Publication Year (2000-2023)	Articles before 2000 were excluded as QFD research gained momentum after 2001.
3	Publication Source	Only peer-reviewed journal articles were considered.
4	Repetitions	Duplicate articles were screened out.
5	Title and Abstract Screening	Articles focusing on Quality, Quality Management, and QFD were included.
6	Full-Content Analysis	Articles unrelated to QFD were excluded after full-text analysis.

Figure 1: PRISMA Approach Followed for Literature Survey



Chang-His *et al.* (2012) proposed an enhanced QFD methodology incorporating stakeholder theory. A case study on Taiwan's No. 5 National Highway demonstrated its effectiveness in prioritizing project designs based on stakeholder concerns. Mostavi *et al.* (2019) integrated QFD with utility theory weighting systems to improve occupants' satisfaction in office environments. A structured three-phase approach was used to gather occupant requirements, evaluate utility functions, and rank strategies for workplace enhancements. Pheng *et al.* (2001) studied QFD in design/build projects, emphasizing customer satisfaction and competitive benchmarking. The research highlighted the industry's limited awareness of QFD benefits and advocated for structured implementation. Arditi *et al.* (2010) developed a QFD-based model to assess the service quality performance of design/build contractors. The model integrates corporate and project-level quality performance indices to benchmark firms and rank them based on service quality.

Lee *et al.* (2010) implemented a database system for QFD using Excel-based process matrices to evaluate quality performance. The study introduced a structured methodology for ranking design/build firms based on customer-driven metrics. Lee *et al.* (2006) expanded on QFD's role in total quality performance assessment in design/build projects. The model integrates corporate, project, and product-level indices to evaluate construction quality comprehensively. Parasuraman *et al.* (1988) developed the SERVQUAL model to measure service quality based on five dimensions: reliability, responsiveness, tangibles, assurance, and empathy. The framework assesses service gaps and provides diagnostic insights for improvements. Zeithaml *et al.* (1985) conceptualized service quality as the gap between customer expectations and perceptions, identifying five critical service quality gaps and their impact on customer satisfaction. Prakash *et al.* (2017) empirically validated a service quality framework for the Indian architectural sector, identifying five key dimensions: design quality, project administration, communication, relationship management, and dependability.

Numerous studies have examined the application of Quality Function Deployment (QFD) in various settings, particularly within the construction industry and design/build projects. Researchers have advanced QFD methodologies by integrating stakeholder theory to classify and rank stakeholder groups, as well as incorporating utility theory weighting systems to enhance occupant satisfaction. Various models have been developed to assess service quality at corporate, project, and product levels, leveraging QFD to align customer expectations with technical attributes and quality management strategies. Research has demonstrated QFD's capability in addressing diverse customer requirements, guiding decision-making, and improving workspace conditions. The integration of quality indices across different levels has led to the development of a total quality performance index, enabling construction owners to objectively evaluate design/build firms.

To further refine the identification and measurement of customer expectations, many studies have incorporated the SERVQUAL model alongside QFD. SERVQUAL, which assesses service quality based on five key dimensions—tangibles, reliability, responsiveness, assurance,

The thematic analysis in Table 2 shows that research has predominantly focused on areas such as contractor selection, customer satisfaction, risk management, and QFD in design/build projects. These reflect the industry's efforts to enhance efficiency, meet client expectations, and manage uncertainties. Emerging themes like green and sustainable construction highlight a growing interest in environmental responsibility. However, topics like after-sales service, project communication, and sustainability are noticeably underexplored, despite their importance in ensuring long-term project success and client satisfaction.

These gaps suggest potential directions for future research. Limited studies on post-construction performance, evolving stakeholder needs, and integration of digital tools like Building information modeling (BIM) or Artificial intelligence (AI) with QFD models reveal opportunities for more comprehensive and adaptive quality frameworks. Further exploration of these areas could improve real-time decision-making, client engagement, and overall service quality across the construction lifecycle.

3.0 Conclusion and Future Research Directions

Evaluating service quality in Project Management Consultants (PMCs) remains a crucial aspect of construction management, with research emphasizing the need for structured frameworks to assess and enhance service performance. The literature review confirms the effectiveness of Quality Function Deployment (QFD) in prioritizing service quality factors, improving stakeholder engagement, and systematically aligning client expectations with technical and managerial outcomes. Studies have demonstrated successful applications of QFD in diverse domains such as design/build projects, renewable energy product development, and corporate service quality evaluation, showcasing its versatility.

However, analysis of recent literature also reveals that while QFD has been effectively utilized across various construction contexts, a dedicated and specialized model tailored specifically for PMCs is yet to be fully realized. Additionally, the integration of QFD with established service evaluation frameworks like SERVQUAL has reinforced the importance of structured, multi-level service quality analysis across corporate, project, and product levels. Despite these advancements, key areas remain underexplored, particularly in benchmarking tools and client feedback systems tailored to PMCs.

The identified research gaps point to the necessity for a comprehensive and context-specific service quality model for design/build projects, a robust QFD-based assessment framework focused on PMC operations, and deeper analysis of QFD's role in renewable energy product development. Addressing these gaps could lead to more effective and scalable models for service quality measurement, contributing to improved project outcomes and stronger client relationships in PMC-led projects. Future research should focus on developing an integrated QFD-based assessment model that incorporates critical service quality parameters, dynamic client feedback mechanisms, and performance benchmarking tools. However, implementation

may face practical challenges such as resistance to change, lack of awareness, limited technical expertise, cultural misalignment, and poor integration with existing digital tools. Recognizing and addressing these barriers through leadership support, capacity building, and adaptive frameworks will be essential to ensure successful adoption. A structured yet flexible approach to quality evaluation would ultimately enable PMCs to enhance service delivery, increase client satisfaction, and drive long-term efficiency in construction project management.

References

Arditi, D., & Lee, D.-E. (2010). Assessing the corporate service quality performance of design-build contractors using quality function deployment.

Arditi, D., & Lee, D.-E. (2010). Service quality performance of design/build contractors using quality function deployment.

Chang-Hsi, Y., Chen, C.-K., Chen, W.-H., & Chang, H.-C. (2012). Developing a revised QFD technique to meet the needs of multiple-customer groups: A case of public policy analysis.

Deloitte. (2025, January). *India economic outlook, January 2025*. Deloitte Insights. <https://www2.deloitte.com/in/en/pages/about-deloitte/articles/india-economic-outlook.html>

Lee, D.-E., & Arditi, D. (2006). Total quality performance of design/build firms using quality function deployment.

Mostavi, E., Asadi, S., & Boussaa, D. (2019). Development of an integrated quality function deployment and utility theory weighting system to improve occupants' satisfaction.

Parasuraman, A., Zeithaml, V. A., & Berry, L. L. (1988). SERVQUAL: A multiple-item scale for measuring consumer perceptions of service quality. *Journal of Retailing*, 64(1), 12–40.

Pheng, L. S., & Yeap, L. (2001). Quality function deployment in design/build projects.

Prakash, A., & Phadtare, M. (2017). Service quality for architects: Scale development and validation ISO 9001:2015- Quality Management System.

Zeithaml, V. A., & Berry, L. L. (1985). A conceptual model of service quality and its implications for future research. *Journal of Marketing*, 49(4), 41–50. <https://doi.org/10.1177/002224298504900403>

CHAPTER 140

The Evolving Landscape of Construction Migrant Labor: Identifying and Overcoming Key Industry Challenges

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Swapnajeet Nayak² and Naman Singh Bhadouria²*

ABSTRACT

In India's burgeoning construction industry, migrant laborers are essential yet frequently undergo difficult living and working environments. Although many arrive with the expectation of a better future, in reality, they are confronted with low pay, high-risk working conditions, miserable housing, and questionable legal status. Along with tackling financial difficulties, they face job insecurity, workplace harassment, and restricted access to social security and healthcare, which makes day-to-day living difficult. In this study, a dual research approach—doctrinal and non-doctrinal—is adopted to fully understand their struggles. Analyzing current labor regulations and collecting direct testimonies through survey forms, interviews, and in-person observations of around fifty construction workers. The outcomes reveal that innumerable workers encounter unsafe working conditions and unstable earnings, which badly affect their overall well-being. A lack of proper safety training increases workplace hazards, while discrimination against female workers remains a notable issue to date. This study suggests skill-enhancing programs, stern laws, and unbiased policies to acknowledge the contribution of migrant workers, which will serve as solutions to these challenges. The study highlights the importance of establishing a more sympathetic yet equitable workplace; it also emphasizes the importance of public support programs to create an unbiased work environment. The country is significantly growing from the contributions of migrant laborers, yet their hardships go unnoticed. To protect their dignity and livelihoods, this research calls for comprehensive policy reforms, stressing the need for immediate legal changes to improve their working conditions and ensure a better future.

Keywords: Interstate migration; Construction industry; Migrant worker challenges; Labor laws; Socio-economic impact.

1.0 Introduction

1.1 Background

Construction in India relies significantly on manual labour since it is less expensive, and other reasons include the fact that construction work in the country relies less on automation.

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The labor force accounts for 60-80% of the overall construction workforce in India, and is hence regarded as the backbone of the sector. Maharashtra have long been a place of aspiration looked up to by migrant labours seeking better prospects. Cities such as Mumbai and Pune, with their flourishing construction sector, have attracted skilled and unskilled workers from all over the country. This migration has massively influenced the state's politics, economy and demographics as the years inched on. The workers in hope for stable jobs, quality education and better living conditions migrate across states right from Gujarat, Andhra Pradesh, Madhya Pradesh, Bihar, Rajasthan, Karnataka each with a migration story seeking for better living conditions. In addition to the specific obstacles that migrants across state lines encounter in their hour of need, these individuals are also subject to a number of challenges and problems that prevent them from integrating and thriving. Despite their significant contributions to the business, they are denied all basic rights, are frequently exploited by contractors, their safety is jeopardized, they are denied social security and benefits, and are discriminated against based on gender, among other issues. This eventually takes its toll on their physical and emotional health. In addition to the specific obstacles that migrants across state lines encounter in their hour of need, these individuals are also subject to a number of challenges and problems that prevent them from integrating and thriving.

The global organisations like for instance the ILO which aims to create laws that maximize the benefits of labour migration for everyone involved. However, the COVID-19 lockdown highlighted the harsh realities migrant workers face. With no jobs and no financial support, many were forced to rely entirely on their contractors' goodwill just to survive. They also struggled with limited access to social benefits, long periods of separation from their families, and constant anxiety about their loved ones' well-being back home. These issues have taken a toll on their mental and physical health but remain largely overlooked in policy discussions (Blan 2020), "Public Private Partnership in India Database, Ministry of Finance, Govt. of India, (2019)", (*mahades.maharashtra.gov.in*). Even though there are policies in place to help workers in India, they are often unaware of their rights and fail to contact departments such as Labour and Employment, which are established to understand their problems and provide them with the best possible solutions. In this research study, we sought to comprehend the gap that keeps expanding between the labours and their rights and propose solutions to uplift the labor sector in the country.

1.2 Objectives

This study will have following broad objectives:

- To identify issues and challenges related to inter-state migrant labours in Maharashtra, India: Explore the socio-economic factors driving migration and examine the difficulties workers face.
- To understand daily struggles and working conditions of migrant workers.

- To analyze the relation between migrant workers, contractors, and employers, highlighting issues of exploitation and unfair practices.
- To make recommendations with practical solutions for change to help policymakers and employers better support and protect migrant workers.

2.0 Literature Review

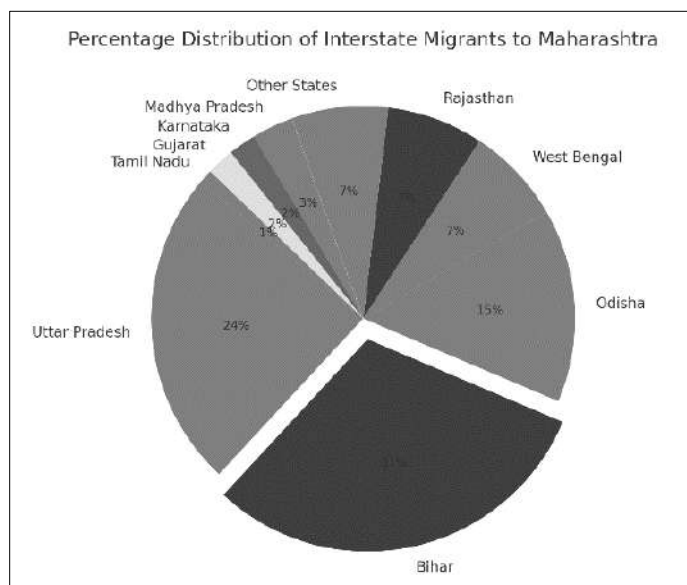
Worldwide construction Industry functions as biggest employer of inter-state migrant workers particularly in India where unskilled and semiskilled workers depend on this industry to find jobs. Studies continuously demonstrate that migrant workers in these conditions experience dangerous working conditions which include substandard pay along with unstable job positions and social isolation and restricted legal protection (Mukherji 2020). Male dominance persists within the industry while research indicates that inclusivity of women would diversify employees and enhance productivity. Research by Husam (2015) demonstrates that inclusive workplaces among construction companies create more efficient operations yet women continue to face barriers because of gender discrimination.

Safety challenges represent a significant problem that threatens migrant workers during their construction work. Based on their systematic review Peiró (2021) determined that migrant workers face elevated workplace risks because they receive insufficient safety training while working in dangerous job environments. Such acute deficiencies in existing safety instruction for unskilled workforce members produce extensive workplace injuries. Choi and Lee (2021) establish that unsafe workplace conditions continue mainly because of insufficient compliance with safety regulations. The combination of cognitive and behavioral safety training leads to substantial construction site accident prevention but migrant workers fail to access these programs because employers lack financial responsibility and training costs prove expensive. These work-related conditions inflict substantial mental strain on affected workers. Work pressure together with financial stress and hazardous working environments drive up the levels of anxiety and depression among construction workers according to the research by Rouhanizadeh & Kermanshachi (2020). Migrant workers go through significant life experiences which are strongly affected by their social circumstances alongside their safety and economic challenges. Women migrants in India struggle with dual discrimination because of the combination of gender bias and general workplace limitations coupled with insufficient maternity protection as Sengupta (2021) demonstrates. According to Aggrawal (2021) the reforms of labour code through streamlining regulations did not satisfy the unique requirements of informal workers especially in construction jobs. Saini (2009) points out that several labour laws exist but poor enforcement capabilities allow construction workers to face ongoing exploitation. The advance of stronger labour rights along with legal protections for workers has progressed at a slow pace whereas experts suggest adopting a comprehensive system to solve the labour laws' systematic inequalities.

3.0 Research Methodology

This study is based on primary data obtained from several work-sites, largely in Pune and Maharashtra, since the state has roughly 31% from Bihar, 24% from Uttar Pradesh, and the balance of the labor force from other north-eastern states, according to Census India 2011 statistics. As part of a study on migrant labourers working in the construction industry, an interview was conducted with a group of workers at a construction site. The primary objective was to understand their working conditions, wages, safety measures, and awareness of legal rights. The interview was carried out under the supervision of their contractor, which may have influenced the responses of the workers, as they might have felt apprehensive about speaking freely.

Figure 1: According to the 2011 Census Data, Maharashtra Attracted Approximately 2.44 million Net Migrants from Other states, Making it one of the Top Destinations for Interstate Migrants in India



Source: ipc2021.popconf.org, statista.com

3.1 Data collection

We obtained data from approximately fifty skilled and unskilled workers. First and foremost, individuals interviewed came from all districts in numerous states, illustrating the range of migrant laborers' experiences in the construction industry. The majority of them spent varying lengths of time on the construction site, ranging from a few months to several years.

Their principal responsibilities included manual labor such as bricklaying and scaffolding, among others. When asked about workplace issues, employees were cautious to provide specific responses, most likely due to the presence of the contractor. However, some have complained that the positions are too physically demanding, and there are insufficient sanitation and drinking water facilities. The workers' general worries were never detailed, and other issues, such as mistreatment and wage problems, did not appear to disturb them enough to warrant raising them.

Figure 2: Flow Chart of Migration Process by Bernard Attha & Angan Sengupta (2024)

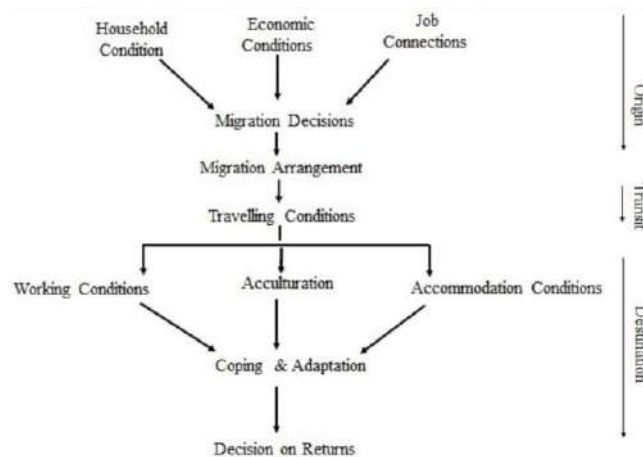
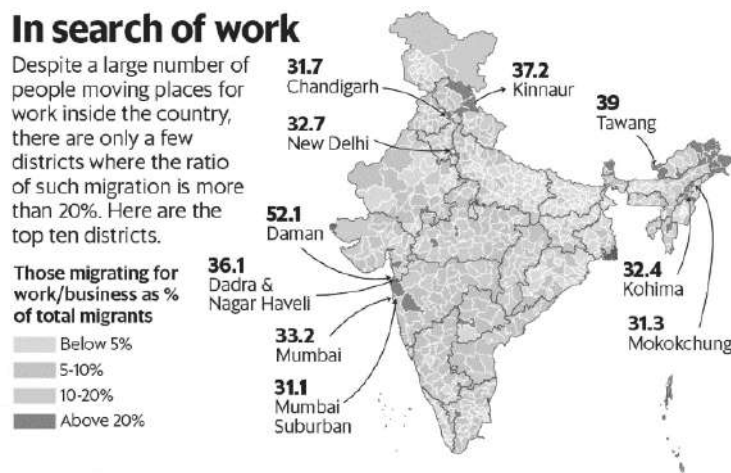


Figure 3: Percentage of Migrants in States with Proportion more than 20% in India



Source: dhrishtiiias.com

- Key Source States: Uttar Pradesh, Bihar, Rajasthan, Madhya Pradesh, Andhra Pradesh, Chhattisgarh.
- Key Destination States: Delhi, Maharashtra, Gujarat, Haryana, Punjab and Karnataka.
- Internal Migrants in India constitute a large population of 309 million internal migrants or 30 percent of the population (Census of India 2001).

4.0 Analysis and Discussion

The interview revealed several concerning aspects of the lives of migrant construction labourers, including low awareness of legal rights and inadequate social security provisions. The workers' lack of information about their rights, along with their hesitation to speak openly in front of the contractor, emphasizes the need for increased awareness and empowerment of interstate-migrant labourers in construction sector. It will not only better be working conditions, but also assurance that workers are well-informed of their legal rights and have the means to express themselves without fear of reprisal.

Considering the data from the research conducted by various authors the major issues and challenges faced by the migrants labours in construction industry are related to low wages and discrimination this is one of the most important challenges in the Indian construction sector is the pitiful pay obtained by laborers, personnel, and workers. Many of them are struggling to make ends meet, living hand to mouth despite their best efforts. The lack of solid job contracts adds to their problems, leaving them in a constant state of worry about their future. Urgent reforms are required to secure equitable compensation and job security for these dedicated workers.

The lack of social security provisions exacerbates the difficulties encountered by workers, staff, and employees. Many of them do not qualify for benefits like health insurance, retirement programs, or provident funds. This lack of support makes them financially vulnerable during times of crisis, hence it is critical that industry and government work together to implement comprehensive welfare programs for these workers.

Exploitation and discrimination are unfortunately frequent in the construction sector. Contractual workers are frequently exposed to unfair treatment, with limited access to essential services and amenities. Furthermore, the industry's labor is frequently separated by class, caste, and gender, exacerbating the marginalization of particular populations.

Eliminating discriminatory practices and ensuring equitable treatment for all should be the main goal. The Indian construction industry is primarily based on unskilled and semi-skilled workers. This maintains a cycle of low earnings and limited career opportunities for workers. Encouraging skill development and training programs can help laborers, workers, and employees improve their talents, potentially leading to better career opportunities and higher earning potential.

The major categories can be classified as mention in the table as shown below:

Table 1: Factors Influencing Migration of Workmens
drishtias.com Humam Migration in India

Push-Factors State of Origin	Migrants	Pull-Factors State of Destination
Population growth, young age structure, Inadequate educational institution, medical care and social security	Demographic factors and social infrastructure	Stable population, population decline' demographic ageing, Welfare state benefits, educational institutions, medical, scoail security.
Unemployment , low wages, poverty, low consumption and living standard	Economic Factors	Labour demand, high wages, welfare, high consumption and living standards.
Dictatorships, shadow democracy, bad governance, political upheaval, Confilcts	Political Factors	Democracy, rule of law, pluralism, political stability, peace, security, protection of human and civil rights.
Ecologic disaster, desertification, lack of natural, resources, water shortage, soil errosin, lack of environmental policy	Ecological Factors	Better environment, protection of natural resources and environmental protection.
Decesions of the family clan, Information flows	Migrant flows and migrant stocks	Diaspora, ethenic community, information flow, media

The surveys were conducted in cities like Pune, Mumbai, Nagpur, and Chandrapur of Maharashtra state to study the socio-economic conditions of interstate-migrant labours, especially in the state of Maharashtra, who have relocated from states like Uttar Pradesh, Bihar, West Bengal and Rajasthan. The interviews were conducted via forms, questionnaires, and video interviews to understand the living conditions of the labours, to examine if they have been denied basic facilities or accommodation. During the interviews, the workers provided structured responses that were insufficiently persuasive. One important likely explanation was the presence of a sub-contractor during the interviews, and it appeared that they were under pressure to provide answers.

One case from the Chandrapur area of Maharashtra (2014) had young children working on a construction site who had allegedly developed the habit of sniffing turpentine. This was merely a breach of the Child Labour (Prohibition and Regulation) Act. This scenario was brought to light by the Office of Labour Welfare Chandrapur Division. The children were rescued, taken to rehabilitation centres, and returned to normalcy. Another case was regarding an incidence from a well-known construction company in Mumbai, Maharashtra of death of a worker due to falling from height in a metro project and justice was denied for nearly two years due to the ongoing COVID situation, the Sion branch of Labour Welfare Association barged in and made sure the family was compensated as per the rule set by the government, and justice was delivered. Hearing sessions are established in labour offices at the district level, where the Assistant Labour Commissioner/Labour Welfare Commissioner acts as a judge, hearing both parties' arguments and passing judgment to expedite and facilitate the resolution process.

4.1 Key issues

- The major issue was identified that there was no data available for the migrant workers after 2011 considering all the research studies.
- The consequence of which being no tracks available in number of people those who have left their homes to find better opportunities
- Another issue recognized was that labourers do not know about their rights. While no respondent interviewed said that he has ever faced legal complaints, the unconscious nature of unawareness is critical.
- The better workers are informed, the quicker they get to identify and deal with potential violations such as unfair wage practice, unsafe working conditions, and discrimination.
- The systems fails altogether when it comes to take responsibility of these workmen who are the backbone of the construction industry yet are treated like cattle stocks

5.0 Conclusion and Recommendations

5.1 Conclusion

A holistic approach through legal education, structural changes in the process of communication, and cultural changes in the workplace would address these gaps. With these recommended strategies in place, stakeholders can develop a more informed, empowered, and engaged workforce that can help make the construction industry safer and more equitable. For the construction sector to thrive, there are large numbers of interstate migrant laborers that Maharashtra establishes to be a key destination for. Yet, like any other population, these workers encounter very painful aspects such as insecurity of their job, poor living conditions and lack of social security. The aim of the introduction is to pinpoint the gap of policies that do not deal with their vulnerabilities and urgent need for better mechanisms of integration. The analysis shows that migrant labourers in Maharashtra find their work difficult conditions and do not even know their rights. A large number are underpaid, have no means of social security and work long hours without the adequate measures in place. Their quality of life should be improved through tougher government policies and tougher employer responsibility.

Construction labourers are indispensable in the constantly changing construction sector, and thus their challenges should be understood and addressed to create better working conditions and increase productivity. Recent interviews with construction labourers have opened a window of understanding their lives, especially relating to legal rights awareness and possibly communication problems at the supervisory level. Lack of awareness reduces the chances for taking recourse to legal action. Dependent on Informal Networks: Labours seek information from peers, which creates the circulation of myths. Another important point that was noted here is that employees may not raise their concerns without hesitation because the supervisors are watching them all the time. Thus, the attendance of supervisors at the interview time may have curbed the effective communication as they might fear getting sacked, fewer working hours, or bad treatment.

5.2 Recommendations

Several initiatives can be used to help migrant laborers overcome the challenges they encounter. Strengthening legal literacy is critical, and it can be accomplished through regular workshops and training programs led by legal specialists to educate workers about their rights. Additionally, issuing concise, bilingual brochures outlining the most essential legal provisions might help raise awareness. Collaborating with worker unions to assist awareness campaigns is also important for reaching a larger audience. Another critical step is to promote open communication by developing anonymous feedback channels like as suggestion boxes or digital platforms where employees can raise problems without fear of being identified. Independent interview sessions without supervisors present can promote open communication, whilst supervisor training programs can assist them in creating a more supportive and non-threatening work atmosphere.

References

- Bhattacharya, D. (2024). *Child labour in India: A socio-political problem*.
- Deshingkar, P., & Sandi, R. (2011). Migration in India: Challenges and opportunities for human development.
- Deshingkar, P., & Shaheen, A. (2009). *Human development and migration in India* [Working paper]. United Nations Development Programme.
- Husam, A., (2024). Migrant labour in construction engineering: Industry impact and risk factors.
- Mukherji, R. (2020). *Impact of migrant labor on worker rights: A study of the economic and social conditions of migrant workers*.
- Peiró, J. M., (2020). A cross-cultural study on migrant labor: Social and economic determinants of well-being.
- Rajan, S. I., & Bhagat, R. B. (2022). Internal migration in India: Social security and labor rights perspectives.
- Rajan, S. I., & Sivakumar, P. (2020). Uneven economic development and internal migration in India.
- Rajan, S. I., Sivakumar, P., & Bhagat, R. B. (2020). The COVID-19 pandemic and migration disruption in India.

Rouhanizadeh, B., & Kermanshachi, S. (2020). Organizing labor for migrant workers: Case studies in construction and domestic work in India's National Capital Region.

Sengupta, A. (2020). Anthropology of migrant labor in India. *Anthropology of Work Review*, 41(1).

Sengupta, S. (2020). Migrant labor in the Indian labor market. *Indian Journal of Labour Economics*, 63(4),

CHAPTER 141

The Role of Leadership in Enhancing Project Delivery Performance through Citizenship Behavior

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ABSTRACT

The delivery performance of Megaprojects serves as a key measure of their overall success, reflecting how well projects meet their objectives in terms of time, cost, and quality. However, the successful delivery of megaprojects is often hindered by inherent complexities, including stakeholder diversity, resource constraints, and dynamic environments. This research delves into the role of Transformational and Authoritarian leadership styles, assessing their influence on enhancing megaproject delivery performance (MDP), focusing on the mediating role of Complexity. Using a structured model, the research examines the interrelationships between leadership styles, project complexity, and megaproject citizenship behavior (MCB). It includes a comprehensive literature review and is supported by empirical data gathered via a questionnaire circulated among experienced professionals in the construction industry. The findings create a detailed framework for enhancing delivery performance through leadership-driven behavioral dynamics. This study offers valuable insights for both academic and practical purposes, deepening the understanding of how leadership plays a crucial role in the success of megaprojects.

Keywords: Leadership styles; Megaproject delivery performance; Complexity in megaprojects; Construction industry; Megaproject citizenship behavior.

1.0 Introduction

Leadership has a significant contribution to make in improving megaproject delivery through promoting citizenship behavior discretionary behavior beyond contract requirements to enhance teamwork, initiative, and problem solving. Great leaders generate a culture of collective responsibility, motivation, and collaborative effort, which enhances project success. Megaprojects, through high-value investments, intricate stakeholder engagement, and substantial impact on society, call for more than task-level leadership but the vision shaping, motivation sustenance, and coherence of various groups. Transformational leadership, where inspiration and personal support are at the core, is most suitable to promote pro-social behavior in raising project performance.

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Megaproject management is fraught with its own set of challenges, such as scope creep, stakeholder management, resource coordination, and risk management. Megaprojects tend to have cost overruns, delays, and regulatory issues because of their complexity and long gestation periods. To make matters worse, there are cultural and organizational dissimilarities, technological developments, and sustainability issues. Leadership plays a crucial role in addressing these challenges, effective decision-making, aligning stakeholders, and developing a robust project culture that instills accountability and high performance.

1.1 Key challenge: Stakeholder coordination

Coordination of diverse stakeholders, such as government institutions, private companies, contractors, suppliers, and local populations, is among the most daunting megaproject management challenges. Mis-alignment between these varied parties may cause delays, conflicts, and litigation. Effective leadership ensures clear communication, conflict management, and objective alignment to ensure that the project is kept on track and that desired results are realized.

1.2 Objectives

This research seeks to investigate the correlation between various leadership styles and Organizational Citizenship Behavior (OCB) in megaprojects, evaluating the impact of Organizational Citizenship Behavior (OCB) on project delivery performance. The research also investigates how the behaviors of leaders contribute to the success of megaprojects through the promotion of organizational citizenship behavior as an intervening variable. Through the analysis of these interactions, the study hopes to shed light on effective leadership approaches that improve teamwork, motivation, and project performance.

2.0 Literature Review

Effective leadership is paramount for the success of megaprojects, those large-scale ventures with significant budgetary and stakeholder considerations. Several studies emphasize the importance of strong leadership, with transformational leadership emerging as the most influential style for driving organizational performance. This style focuses on inspiring and motivating teams, as opposed to relying solely on participation or consensus-building. Research has also delved into specific leadership characteristics and behaviors that contribute to success in complex environments like Building Information Modeling (BIM)-based construction projects. These studies highlight the multifaceted nature of effective leadership, encompassing not only behaviors like commitment and tolerance but also communication skills and personality traits like conscientiousness. Furthermore, the project manager's role in the pre-construction phase of sustainable construction projects is crucial, with communication, planning, team building, and conflict management skills identified as essential for laying a strong foundation for long-term success.

2.1 TCCM (Theory, Context, Characteristics, and Methodology)

TCCM (Theory, Context, Characteristics, and Methodology) is a structured approach that helps researchers analyze and organize academic studies effectively. It acts as a guiding framework to ensure that research is built on strong theoretical foundations, considers relevant real-world settings, identifies key features, and follows a sound research methodology.

- Theory refers to the core ideas and established knowledge that form the basis of a study. It helps ensure that research is not just based on assumptions but is grounded in well-accepted concepts and frameworks.
- Context is all about understanding where and how a concept or theory is applied. This includes factors like geography, industry, culture, and economic conditions that can influence the research outcomes.
- Characteristics focus on the defining elements of the study, things like important variables, relationships between factors, and any unique aspects that make the research stand out.
- Methodology is the approach used to conduct research, whether it's qualitative (exploring ideas and experiences), quantitative (using numbers and statistics), or mix of both. The chosen method should align with the research goals to ensure reliable and meaningful results.

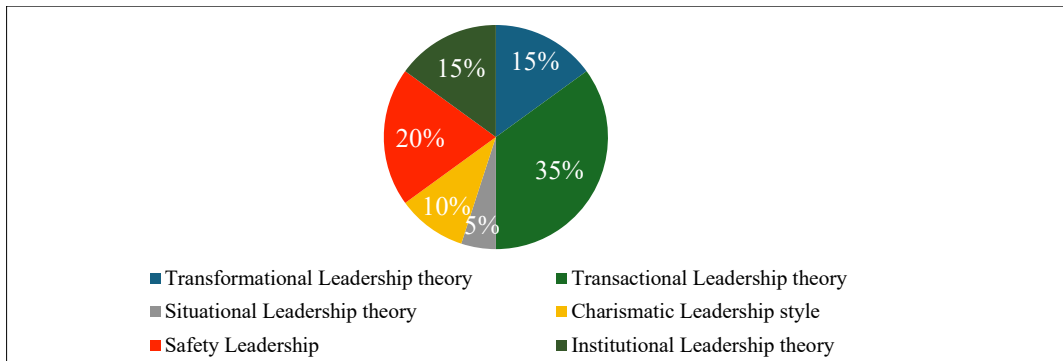
2.1.1 T-Theory

Several studies have explored the importance of leadership in the success of megaprojects. One approach examines how leadership theories can be used to assess potential sponsors (Louw *et al.*, 2018). This research investigates how theories like transformational, transactional, and situational leadership can inform the development of instruments to evaluate a sponsor's leadership style and its suitability for a megaproject.

Another strand of research employs qualitative methods to understand leadership in megaprojects. For instance, a study adopted an explorative qualitative approach using thematic analysis of interview data to gain insights into leadership practices within construction organizations (Alshehhi *et al.*, 2023). This approach can provide valuable real-world perspectives on leadership within complex project environments.

Furthermore, research has explored the link between leadership styles and project innovation. A study identified four innovation leadership styles – charismatic, instrumental, strategic, and interactive – and examined their influence on process and product innovations in construction projects (Omer *et al.*, 2022). Understanding these styles can help project leaders foster a culture of innovation within their megaprojects. Finally, other research papers delve into the specific competencies required for successful megaproject leadership (Zaman *et al.*, 2023). Research suggests that the optimal configuration of leadership skills and project complexity plays a crucial role in achieving positive outcomes (Latiffi & Zulkiffli, 2022). This highlights the need for leaders to adapt their approaches based on the specific characteristics of each megaproject (Damayanti *et al.*, 2021)

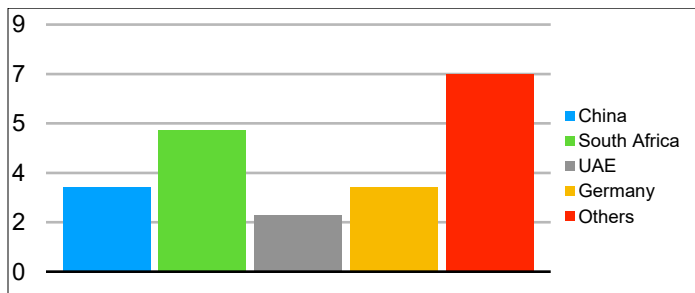
Figure 1: Pie Chart Representing Types of Leadership Theories



2.1.2 C - context

As per (Wan *et al.*, 2020), context pertains to the conditions or environment in which a particular study was conducted. The table below presents the context, focusing on the countries and sectors where leadership affects the Megaprojects that have been explored in the extant literature. Despite the diversified and fragmented nature of research in the domain, researchers were able to arrive at a few conclusions. It was observed that most of the studies in the sample were conducted in a single-country context rather than multicountry. Furthermore, multiple studies explored the context (Latiffi & Zulkiffli, 2022) & (Liu *et al.*, 2021) compared to larger established firms, which may be attributed to our emerging countries context. In terms of continents, the researchers find most countries covered in South Africa, followed by Australia, Germany, and China. In terms of countries, most studies were conducted in South Africa (Africa, 2018; Journal & December 2017), followed by Australia (Oswald & Lingard, 2019). In terms of industries, multiple studies focused on the public construction sector (Lühr & Wagner, 2023). A few under-explored industries were identified, such as Oil, gas, and petrochemicals (Alshehhi *et al.*, 2023) and the Telecommunications sector (Akhwaba *et al.*, 2020). Future studies can be conducted based on multi-country samples focusing on the Middle, Oceania, Southeast Asia, and emerging countries.

Figure 2: Bar Chart Depicting Country's Context



2.1.3 C - Characteristics

This conclusion of research work implicitly demonstrates that leadership in successful megaprojects is meant to be very a complex one. The research not only talks about sponsorship as it plays a crucial part but shows an involvement of leadership style within sponsor's role, and management style to work these large-scale endeavors (Louw *et al.*, 2018) Doubling down the studies try to identify the specific traits that positively impact a project success. In the construction projects grounded on Building Information Modeling (BIM), tolerance, commitment, and reliability are the foremost temperaments needed to create and cultivate a congenial working environment (Omer *et al.*, 2022). On the other side of the coin, intolerant leadership conduct can give rise to countless challenges.

The project managers on the crew of the megaproject must learn to navigate the complexity as well. Communication, planning, setting goals, team building, and conflict management are the traits that are found to be most crucial among all, and they are particularly mentioned by much of the research as the factors that have significant influence at the beginning of the construction phase (Latiffi & Zulkiffli, 2022) Concerning teams alongside the hard skills, it is the leadership styles themselves that also have an impact. The study looks into the state of leadership via the lens of transformational, transactional, charismatic, and democratic models (Dossick & Neff, 2010). Further, trait theory focuses on the inherent qualities that are involved in the success of the leadership and analyses the effectiveness and the emergent properties as traits (Dossick & Neff, 2010). The careful study of the projects gives deep insight into the leadership style corresponding to the field of project management. Collaborative, as well as vertical and horizontal leadership styles are equally significant in this literature.

Such outcomes make clear that a leadership style without a mix of elements is not distinguishable in megaprojects. The “contingency hypothesis” suggested in one study focuses on the interaction of project-avoidable influences with leadership effectiveness, and it is predicted that if the interaction of these factors is satisfactory, the project execution will succeed (Akhwaba *et al.*, 2020).

2.1.4 M - Methodology

Table 1 outlines the research methodology, data collection methods, and sample data analysis techniques employed in the reviewed studies. Notably, all the research studies were conceptual or theoretical approaches, prioritizing the collection and analysis of real-world data over purely empirical approaches. In terms of research design, a quantitative approach, emphasizing non-numerical data and a wider range of research techniques, was the dominant choice. Qualitative and mixed methods design, which encompass numerical data and statistical analysis, were implemented less frequently.

The most prevalent methods for data collection were surveys and questionnaires. The second most common method was case studies and interviews. Using a statistical model called Partial Least Squares Structural Equation Modeling (PLS-SEM), one can comprehend and

determine potential relationships between multiple variables. Structural Equation Modelling is an extension of factor analysis and multiple regression analysis (Majumdarr *et al.*, 2023). Purpose, content analysis and thematic analysis were also utilized, although to a lesser extent. The authors propose that future research could benefit from incorporating qualitative alongside alternative data collection methods like case studies and observations. These approaches have the potential to yield novel and distinct findings. The authors further suggest that Delphi techniques, fuzzy-set qualitative comparative analysis (FSQCA) could provide valuable enhancements to data analysis.

3.0 Future Scope

- We intend to construct a hypothetical model of leadership in megaprojects.
- To gather insights from industrial professionals, we propose circulating a questionnaire aimed at resolving their perspectives on leadership in this context.
- We will conduct an analysis of the data gathered from the questionnaire to extract insights and draw conclusions.

Table 1: Methodologies

Sr. No.	Research Methodology	Number
1	Conceptual	29
2	Empirical	11
Research Design		
1	Quantitative	24
2	Qualitative	13
3	Mixed	3
Data Collection		
1	Survey	10
2	Questionnaire	14
3	Interview	8
4	Case Study	6
5	Document Review	2
Data Analysis		
1	Partial Least Squares Structural Equation Modeling (PLS-SEM)	10
2	Type of Regression	19
3	Fuzzy-set Qualitative Comparative Analysis (FSQCA)	2
4	Others	9

4.0 Conclusion

This research highlights the leadership role in defining the delivery performance of megaprojects by promoting a culture of organizational citizenship behavior (OCB). It shows that

transformational leadership, with its focus on vision, motivation, and individual encouragement, greatly improves teamwork, both of which are important in overcoming the complexities involved in megaprojects. On the other hand, authoritarian leadership, although effective in some organized settings, might not be able to provide comparable amounts of citizenship behaviour or cooperation. The study also reveals how project complexity serves as a mediating factor, determining the strength and direction of leadership's influence. Drawing on empirical data and synthesizing available literature, this paper builds a robust framework that combines leadership style, project complexity, and citizenship behavior to forecast and enhance megaproject delivery performance. Hierarchies and encourage joint responsibility, ultimately leading to sustainable project success.

References

Jankelová, N., Némethová, I., Dabić, M., & Kallmuenzer, A. (2024). *Enhancing organizational citizenship behavior towards the environment*.

Luo, L., Yang, Y., Wu, G., Zheng, J., & Liu, D. (2023). Effects of organizational leadership on project citizenship behavior and management performance in complex construction projects. *Buildings*, 13(1), Article 259. <https://doi.org/10.3390/buildings13010259>

Nauman, S., Basit, A. A., Munir, H., & Iqbal, M. S. (2024). When and how servant leadership leads to megaproject success: The roles of project governance and interpersonal trust. *Project Management Journal*, 55(3), 297–312. <https://doi.org/10.1177/87569728231216897>

Saleem, F., Zhang, Y., Gopinath, C., & Adeel, A. (2020). Impact of servant leadership on performance: The mediating role of affective and cognitive trust. *SAGE Open*, 10(1). <https://doi.org/10.1177/2158244019900562>

Wang, G., Locatelli, G., Zhang, H., Wan, J., & Chen, Y. (2023). Playing the cards right: Exploring the way leadership influences organizational citizenship behavior for the environment in megaprojects. *Engineering, Construction and Architectural Management*, 30(2), 623–646. <https://doi.org/10.1108/ECAM-01-2021-0093>

Yang, D., Zhu, J., Cui, Q., He, Q., & Zheng, X. (2021). The diffusion mechanism of megaproject citizenship behavior: The role of institutional isomorphism. *Sustainability*, 13(15), Article 8123. <https://doi.org/10.3390/su13158123>

Yang, Y., Huang, J., Wu, P., Zheng, X., Lin, H., & Ji, S. (2022). Responsible leadership and project citizenship behavior: A cross-level investigation. *Frontiers in Psychology*, 13, Article 960290. <https://doi.org/10.3389/fpsyg.2022.960290>

CHAPTER 142

Thematic Literature Review of Unplanned Settlement around Integrated Townships

Sanjay Pathak¹ and Rani R. Patil²

ABSTRACT

Rapid urbanisation in India has manifested in two extremes: “Planned integrated townships on the one end and Unplanned settlements on the other”. This poses several challenges, such as infrastructure, economics, and socio-cultural factors. Integrated townships showcase sustainable urban development with housing and job opportunities. However, the success of such IT lures migration, which has led to further unplanned growth around such townships. These areas attract low-income workers from the unorganised sector who work in IT because of the low rent. These settlements, which may be called “underdeveloped settlements,” appear to have issues with basic physical & social infrastructure, thus damaging the urban systems and adding to the existing socio-economic differences in the metropolitan area. A thematic analysis of existing literature supports this research by identifying key concepts related to urban planning and unplanned settlement. These insights will form the basis for bridging the divide between the plans and the realities in which such unplanned settlements sit, surrounding integrated townships.

Keywords: Integrated townships; Unplanned settlement; Sustainable urban development; Socio-economic differences; Urban planning.

1.0 Introduction

The proportion of urban population of India, according to the 2001 Census, reportedly rose from 27.7% to a ratio of 31.1% (377.1 million) according to the 2011 Census, at an annual growth rate of 2.76 percent (Kapur & Anees, 2024). Increasingly, urbanisation transforms cities and metropolitan areas, determining land use, housing patterns, and socio-economic structures. The ‘Housing for All Mission 2022’ represents a challenge that must be met by all while addressing the entire matrix of complex issues that beset the real estate industry in India (Nandu, 2023). Among the various urban planning models, integrated townships have emerged as a catalyst for urban growth management.

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Integrated Townships are planned, self-sufficient living environments that offer choice in various housing types, good infrastructure, safety, amenities, and community spaces, which provide comfort and sustainability with a good quality of life (Kumar & Katyal, 2023). Integrated Township is a mixture of residential, commercial, educational, institutional, healthcare and physical infrastructure with road connectivity. An Integrated Township is a ‘city within a city’ (Nandu, 2023). Perfectly suited integrated townships for ‘walk-to-work’ lifestyle, shopping complexes, leisure, and entertainment facilities typically have all the elements a customer desires (Ahire *et al.*, 2020).

1.1 Concept of settlements

Settlements are categorized into 2 categories, mainly planned and unplanned settlements. Planned settlements are a human-made work that governs human lives in small areas and also govern human interactions and relationships with nature. Thus, planned settlements are a bid for modernism in their lives (Novitasari *et al.*, 2021). On the other hand, unplanned settlements in their punitive conditions of existence, depending on the character of housing and limited access to infrastructure, may also pose a threat to the quality of life in the long run (Hitayezu *et al.*, 2018). Both permanent or semi-permanent and temporary structures line the city drains, railway tracks, low-lying flood-prone areas, agricultural land, and green belts in and around the city (Kapur & Anees, 2024). As integrated townships grow, they create a demand for labour in construction, domestic work, retail and services, attracting low-income workers who cannot afford to live within the planned township limits.

This results in the spontaneous development of settlements on the periphery, vulnerable infrastructure, restricted access to basic services and uncertain land tenure, among others. There are many aspects composed of lack of proper infrastructure, limited access to basic services, as well as uncertainty in land tenure. Despite the increasing prevalence of this issue, research on the relationship between integrated townships and adjacent unplanned settlements remains Fragmented. The adverse impacts, challenges, and repercussions of the expansion itself become apparent and the insidious fallouts of such a stateless development, thus making the unpremeditated coverage of this area a serious one (Rai, 2012). Understanding how integrated townships contribute to the growth of unplanned settlements and the socio-spatial dynamics that emerge from their coexistence is crucial for developing inclusive urban policies.

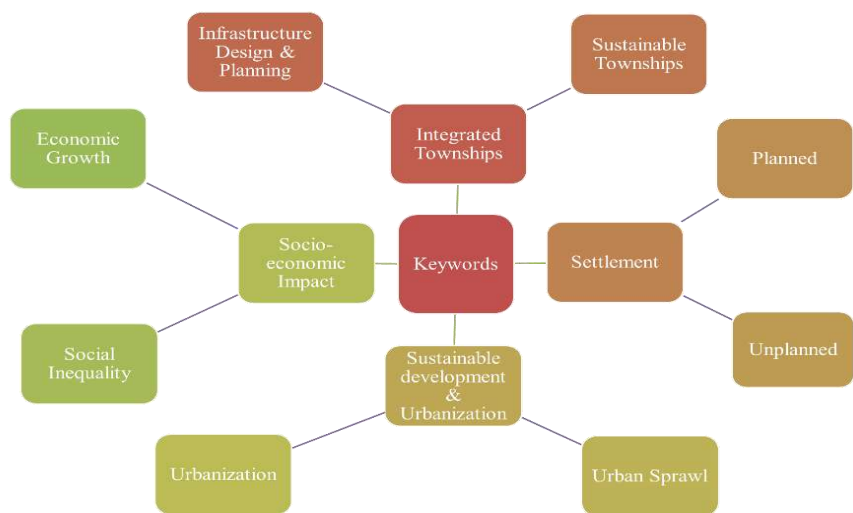
1.2 Methodology for literature selection

The systematic literature search is conducted through two online databases (Scopus & Google Scholar). The following keywords have been used to search the datasets:

Filters were set to search only for:

- Peer-reviewed journal articles on urban planning, informal housing, and real estate development.
- Case studies of integrated townships and their surrounding settlements in India and globally.
- Conference proceedings discussing informal urbanization trends.

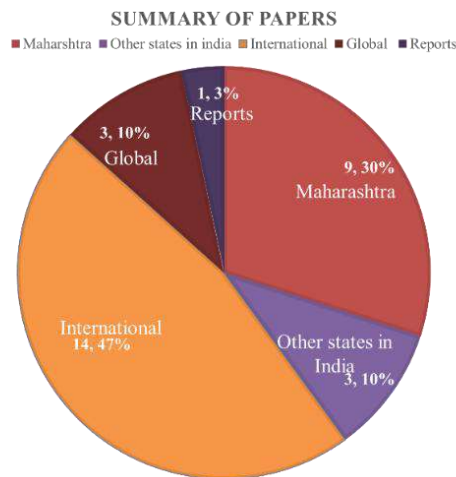
Figure 1: Keywords used to Extract the Datasets



Source: Compiled by authors

From 2005 to 2024. This time frame was selected because the special township policy was historically introduced in 2005. A literature review on unplanned settlements around integrated townships forms the basis for this research work, considering important factors that fuel their growth and the socio-economic, spatial and governance problems that emerge. 159 papers were extracted from Scopus and Google Scholar, out of which 30 literature papers have been used for this thematic analysis. The categorization of papers according to their location is as follows:

Figure 2: Summary of Literature Papers



Source: Compiled by authors

Such themes considered include Urban Void Management and Settlement Monitoring, Urban Planning and policy frameworks, Integrated Townships and Sustainable Urban Development, Slum Upgrading and Informal Settlement Solutions. Through peer-reviewed articles, case studies, government reports, and policy documents, this research seeks to fill knowledge gaps and propose knowledge for urban policies, governance frameworks and sustainable development strategies to everyone. The findings are important to policymakers, urban planners and developers for balancing urban growth within diverse urban settings.

2.0 Thematic Review of Literature

Urbanization triggers and creates mixed use communities in townships, the planned settlements-to-absorb population growth and stem economic activities-today end up creating unplanned settlements at the edge by affordability constraints, migration patterns, and poor urban governance. This literature review pursues a thematic agenda to bring together existing studies to examine the major drivers, hindrances, and policy gaps regarding unplanned settlements into the realm of integrated townships.

2.1 Urban Void management and settlement monitoring

Unplanned and underused spaces, also called urban voids, are magnets for the disorganised growth of informal settlements. Monitoring such organic growth increasingly relies on advanced technologies like spatial metrics, remote sensing, and the Urban Void Assessment Index (UVAI). Their effectiveness in tracking changes from land use to morphologies of cities from the onset of development has been proved through various studies. Case Study examples include Akurdi (PCMC), Dar es Salaam, and New Delhi, illustrating how we apply spatial analysis techniques to identify areas vulnerable to informal occupation. Remote sensing and GIS mapping have been particularly effective for monitoring the urban voids and recording the trajectory of settlement patterns.

According to (Raisoni *et al.*, 2024), a Special Purpose Vehicle (SPV) is needed to coordinate urban void management, a Land Bank should be created, and leases should be revised according to UVAI rankings. This new quantitative-qualitative framework will enhance decision-making by enabling the best possible distribution of resources and flexible policy recommendations for urban regeneration. Further to the (Omar & Saeed, 2019) The relevant research finally develops a framework pertaining to the reuse and development of voids within a system to upgrade the operation of a city and help planners and designers improve on existing mechanisms for maximizing efficiency in urban void reuse. The study of (Kuffer & Joana, 2011) develops a spatial metric-based tool that aids in identifying unplanned settlements through VHR images of Dar es Salaam and New Delhi. Metabolically, this includes correlated extensive morphological differences, i.e., size, density and layout between planned and unplanned areas, thus producing an Unplanned Settlement Index for making settlement monitoring and land-use

analysis better. Such three papers fall into the category of Urban Void Management and Settlement Monitoring, which is rightly complementary as to the research title, to how unplanned settlements evolve around integrated townships.

2.2 Urban planning and policy frameworks

The debate surrounding the governance of unregulated settlements is that of jurisdictional overlaps among township developers, municipalities, and state authorities. Then, the policy to officialise unregulated settlements, such as Singapore's Special Township Policy, creates a question mark regarding the impact on unplanned settlements. How the last cities compare concerning India and the little extent of adoption of global best practices is so little unlike many cities taking strides with inclusive urbanization.

Indeed, the analysis of (Moghayedi *et al.*, 2023) is to demonstrate the considerable impact of household socioeconomic status, housing conditions and neighbourhood safety on the wellbeing and resilience of people living in South African townships. The study also points to the necessity for data-driven and localised strategies for improvement in the micro (housing) and macro (neighborhood) contexts towards sustainable development. According to (Patel & Padhya, 2021), Magarpatta City is perhaps the best example of the neighbourhood concept as most defined in urban planning. It has several governing principles of being self-sufficient, mixed-use, and accessible, meaning that the resident should be able to achieve an activity without the effort of going beyond his doorstep for all.

Some Characteristics that Magarpatta has as a Neighbourhood:

- *Mixed-use development:* A blend of residential, commercial, educational, and recreational spaces.
- *Walkability:* Promotes walk-to-work and walk-to-school lifestyle, thus reducing dependence on private vehicles.
- *Green and sustainable planning:* Consists of public parks, boulevards, and waste management programs.
- *Social and economic inclusivity:* Different income groups are provided housing, jobs within the township itself.
- *Infrastructure and services:* A great urban living facility, with well-made roads, public transport access, hospitals, and malls.

The case brief named as (Can peri-urban development choose partnerships over displacement?, 2016) Examines whether communities can engage in urban development without displacing populations already there. The Magar community group of farmers in Maharashtra together changed their land into a new town, Magarpatta City in Pune. Rather than sell their land to an outsider developer, the Magars got together to develop the area, ensuring their participation in the process of urbanization. This establishes an alternative to the practice of displacing local communities and demolishing their houses for the sake of urban development. By tapping into their social and political networks, the Magars held on to their land and

livelihood, demonstrating a model in which development is beneficial for the original inhabitants. This research of (Prakash *et al.*, 2022) Focuses on land pooling as an alternative for sustainable urbanization and includes case studies to understand alternative urban development practices in India.

- Land Pooling/Readjustment (LP/R): Hence, this is the arrangement under which landowners pool their lands to urbanize them. It is not that the government compulsorily acquires land; the landowners voluntarily pooled their land and would develop that to return parts of that developed land to them. Such an approach to riverbanks development needs, along with that protection of the landowners.
- Amaravati, Andhra Pradesh: Andhra Pradesh government devised a pooling scheme to develop the new capital city. The voluntary nature of pooling involved persuading around 25,000 farmers to pool around 30,000 acres of farmland in 60 days. This voluntary approach minimized disputes and ensured that landowners became stakeholders in the process of urban development.

This paper indicates how pooling land could be an approach that would be fair and justly inclusive from the urban policies. Direct involvement of landowners with proper consent may create this kind of urbanization that can go well together with the sustainable protection of the rights and livelihoods for the original landholders.

This study of (Hayek *et al.*, 2010) Regulates the question of urban sprawl in Switzerland and examines potential future settlement developments for the year 2030. A series of parameters are adopted to measure sprawl, while different growth scenarios are evaluated considering economic and social factors. The study emphasizes the importance of planning policy in curbing urban growth and protecting landscapes. The research underlines the importance of boundaries on growth, regionally, but specifies none. Different scenarios show that Economic growth does not inherently mean densification; balanced regional development can also limit consumption of land. 3D visualization and additional indicators are recommended for developing understanding and future landscapes' planning.

According to (Novitasari *et al.*, 2021) The domains of ekistics are found in both planned and unplanned settlements, though the two differ in many respects such as governance, infrastructure, and social structure. Planned settlements have their infrastructure built in advance; the topography of the land is followed; rules and regulations dictate the planning policies; such settlements often house the elites. The unplanned settlements develop spontaneously, whether inward-oriented to nature or outward-oriented for economic opportunities, trade being the main one. In planned areas, culture is imported by elites, whereas the unplanned settlements have tremendous diversity in socio-cultural dynamics.

Based on (Sharma *et al.*, 2015) Study, the attempt must be taken to generate self-sustained employment, generating economic centres and direct their connection towards townships to assist in guiding such strategic suburban growth. It ensures the affordable housing of EWS/LIG along with planned infrastructure and does not provide purely profit-oriented

flexibility to private developers. EWS/LIG housing and economically active development must be mandated from policies, and incentives should be made available for attracting private investment into the housing sector.

2.3 Integrated townships and sustainable urban development

Integrated townships have emerged on the scene in Pune and Uttar Pradesh; while self-sufficient, they also lead to peri-urban growth and displacement. Although mixed land-use planning is inclusive, some townships worsen the economic situation of others. Studies must advance toward governance and sustainability aspects of township-led urbanization concerning balanced development. The authors (Ahire *et al.*, 2020) Research is on comparing the Mahalunge-Man integrated township to the other townships in Pune regarding their sustainability and effectiveness. The paper identified integrated townships as self-sustaining communities which to some extent exert less pressure on the urban environment, promote the well-known “walk to work” lifestyle, and improve quality of life. The comparative studies are in line with the concept of sustainable development, since they emphasize the proper planned growth of an urban area, efficient infrastructure provision, and reduced congestion.

Moreover, (Rai, 2012) The author explores the challenges posed by rapid urbanization in developing nations and offers integrated townships as an avenue towards sustainable urban development. Self-sufficient townships are being built that contain residential, commercial, retail, and recreational areas of the same land, in addition to their own infrastructures and resource management systems. The “walk to work” concept, along with public-private partnerships, would therefore decrease pressure on urban centers, reduce environmental impact, and enhance the quality of life for its residents. The article speculates that some Indian states, like Maharashtra, Gujarat, Karnataka, and Rajasthan, have put in a Special Township Policy to promote the development of these sustainable communities.

From the point of view of (Nayak, 2017) The causes, effects, features and contributions towards the sustainable development are as follows

- *Causes:* Migration from rural areas to urban centers for better employment and living conditions. Industrialization encourages labour movement to urban areas.
- *Effects:* Overcrowding in the city, leading to the possibility of infrastructure collapse. Environmental degradation occurring in cities due to pollution and waste.
- *Satellite townships:* A self-sufficient township consists of various residential, commercial, and recreational areas. All urban infrastructure encompasses transportation, water supply, and waste disposal. Environmental policies embody environmental sustainability through green area creation and eco-friendly practices.
- *Contributions towards sustainable development:* Alleviates urban congestion by decentralizing population and economic activities. Promotes balanced regional growth, preventing heavy reliance on major cities. Enhances the quality of life through planned urbanization and efficient resource use.

In short, the study reinforces the point that satellite townships are a major remedy for the problems brought forth by urbanization and hence contribute to sustainable urban development. According to (Bello *et al.*, 2016) A study has been carried out to identify the challenges related to rapid urbanization in Ogun State, proposing integrated township development as a sustainable remedy. According to the authors, most developing countries such as Nigeria experience heavy-population influxes towards urban centers because of concentration in materials and opportunities, causing overcrowding and haggling among existing infrastructure. Evolving this kind of problem, Ogun State Government undertakes transformations of rural places into urban locations by making them statewide infrastructurally dotted. The paper addresses the issues of citizens' involvement to ensure acceptance and sustainability in development initiatives. Housing and social amenities provision will be an important element in successfully developing integrated townships, in this regard to the sustainable urbanization goals.

As stated by (Haspe & Deshmukh, 2016) The integrated townships conceptualized as self-sustaining communities that provide a mix of residential, commercial, recreational, and other public amenities all within one development. These townships create a platform for balanced and sustainable urbanism via the provision of ample housing and facilities. This allows the authors to hold forth about a collaboration between the public and private sectors in developing affordable housing within these townships, highlighting that partnership among the parties is central to achieving sustainable urban development. In a nutshell, the paper argues in favour of integrated townships and sustainable development by promoting planned and self-sufficient communities as a means of addressing the challenges of urban existence via proper infrastructure and amenities; thus, making for more sustainable and liveable cities. The paper by (Kumar & Katyal, 2023), discusses the integrated townships' influence on urban developments in Uttar Pradesh. Some of the featured integrated township projects of the state include

- Wave City in Ghaziabad,
- Eldeco City in Lucknow,
- Gaur City in Greater Noida,

The paper also provides an in-depth critical analysis of the challenges posed by integrated townships in terms of the possibility of socio-economic disparity in development and the need for engaging policies that would allow equitable development. The authors argue that while integrated townships offer an effective tool for urban development through provision of orderly as well as sustainable living environments, issues regarding proper planning and implementation of policies would need to be tackled before establishing mutual benefit for wider populations. The paper of (Patel & Gandhi, 2019) Discusses the concept of self-sustaining integrated townships as solutions to various challenges that arise due to urbanization. It states the most natural practice in building such entities: waste management, Revenue Collection, water conservation, renewable energy consumption, among all components partaking in the process of a sustainable environment. Further, those characteristics tend to improve the quality

of life of township residents while reducing the ecological footprint is at par with developments made in the principles of sustainable development. The (Kumar, 2019) Article on integrated townships considers ‘Club hood,’ as applicable in the case of Lavasa and Magarpatta. Detailed in the study are how integrated townships serve as exclusive communities upholding club goods by providing shared amenities to a select group of participants. Notable Observations of these Integrated Townships as Club Goods:

- Integrated Townships as a Club Good: The amenities provided here are exclusively for residents, thus enhancing community and exclusion.
- Lavasa conceived as a private city and burdened with several drawbacks, such as environmental issues and financial problems, now suffers from development stalling.
- Magarpatta, on the other hand, was built by pooling agricultural land from local farmers. The township has emerged as a successful model of sustainable urban development, integrating residential, commercial, and recreational uses.

Overall, the paper indicates that integrated townships would assure a very high-potential service and infrastructure supply but accept some complexity regarding social divides and governing these townships. As per (Nallathiga *et al.*, 2021) Examines the progression of township development in Pune, highlighting a shift from traditional satellite townships to modern smart townships.

2.4 Key points

- *Satellite townships*: Initially developed as peripheral settlements to alleviate urban congestion, these townships functioned as ‘counter magnet settlements’ to the main city.
- *Integrated townships*: Over time, the focus shifted toward self-sustaining communities that incorporate residential, commercial, and recreational facilities, embodying the concept of sustainable development.
- *Smart townships*: The latest phase involves the adoption of smart technologies and principles of new urbanism, emphasizing efficient resource management, environmental conservation, and enhanced quality of life.

This progression underscores the importance of integrating sustainability into urban planning, aligning with the broader theme of sustainable development. The paper of (Khare & Thakur, 2020) examines the growing integrated townships across Pune with the aid of remote sensing and GIS technologies. Further, it reveals a major suffrage in the urbanscape especially as fringed by township development. This research has discovered the conversion from agricultural use to residential and commercial use, necessitating an immediate call for formulation strategies for sustainable urbanization-integration of development and environmental conservation. The article of (Yu *et al.*, 2021) Presents a framework for constructing an information management service platform for township administrations. The platform aims to improve administrative efficiency and service delivery by integrating multiple information systems and resources. The key elements are as follows:

- **Integrated Data Management:** The system supports combining different data sources under one umbrella for easier management and sharing across different departments.
- **Modular Design:** Functions can be added or modified in accordance with changing administrative requirements, allowing for the necessary level of flexibility and scalability around which the system will be built.
- **User-Focused Services:** The platform intends to deliver user-friendly and efficient public services for township residents to improve citizen satisfaction.
- **Use of Advanced Technology:** The application of GIS and similar technologies assisted in analyzing spatial data and making decisions.

This framework seeks to achieve the general goal of incorporating sustainable development principles into township-level planning and management. Information technology is used in the platform to conserve resources, enhance service efficiency, and ensure transparent governance, which are vital for the sustainable urban development agenda.

2.5 Slum upgrading and informal settlement solution

According to research done in Zanzibar, Egypt, and Kigali, unplanned settlements are linked with land tenure security, migration, and unaffordable housing. The example of Jakarta emphasizes self-evident governance in informal settlements, notwithstanding weak controls. The sustainable upgrade into improved living conditions can thus be facilitated by integrating urban planning with community participation with concurrent tenure formalization. The project (Africa) Takes an integrative approach to upgrading informal settlements and focuses on the equity distribution of public space, the safety of that space, as well as the public provisioning for basic services such as water, sanitation, and waste management. The SDGs focused on are 6 and 11: about sustainable urban development and good living conditions. It hence aligns with the commitment of the New Urban Agenda in social inclusion, poverty alleviation, and inclusive urban prosperity through the housing upgrade into economic and social opportunities that make informal settlements resilient and liveable. The study entitled “The Dynamics of Unplanned Settlements in the City of Kigali” by (Hitayezu *et al.*, 2018) Goes deep into the informal settlements of Kigali and puts forward critical notes for slum upgrading and informal settlement approaches. The study notes that about 79% of the population in Kigali has been settled in the unplanned pockets due to rapid growth of urbanization, which is beyond the pace of infrastructure and housing development. Some of the key findings of the study included:

- **Migration Patterns:** An estimated 65% of adult inhabitants in these settlements are internal migrants in search of employment opportunities.
- **Employment and Mobility:** Limited by the high costs of commuting, low-income families are forced to live close to their workplaces.
- **Housing and Services:** Residents often face challenges to housing quality and basic services.

The study recommends a gradual and integrated redevelopment focusing on attracting economic activities and enhanced public transport to ameliorate living conditions. This supports

sustainable urban development goals through the recognition of informal settlement upgrading as being unique and case specific. This report of (Mahabir *et al.*, 2016) Investigates slums as a social and physical construct, drawing attention to hindrances such as insufficient data and informal economies, while also finding gateways, for instance, geospatial technologies and participatory mapping. In conjunction with slum upgrading, it promotes an interdisciplinary approach to understand and improve informal settlements. The present study (Charman & Petersen, 2015) Investigated the spatial distribution of informal enterprises in the Cape Town townships and found that 75% operate within residential areas rather than commercial concentrations, suggesting the need for policies that support such embedded businesses and to facilitate strategies directed at integrating informal economies into urban planning.

The study of (Ali & Sulaiman, 2006) Evaluates the informal settlements in Zanzibar resulting from rapid urbanization, weak land policies, and poverty, with more than 70% of the urban population represented. These impacts manifest themselves in terms of environmental degradation and limitation of access to basic services, calling for improvement in urban planning and policy reforms. This paper of (Nurgandarum *et al.*, 2019) Examines how self-organizing processes shape unplanned neighbourhoods in Jakarta, stressing their organic processes of development. In this regard, it has been argued that the processes of understanding the formation and transformation of settlements will rather be the basis for more context-sensitive interventions in slum upgrading.

The paper titled “Unplanned Settlements in Saudi Arabia: The Case of Al-Sabeel District, Jeddah,” written by (EL-SHORBAGY, 2020), investigates Al-Sabeel’s characteristics and challenges, an unplanned settlement in Jeddah. The research makes clear that Jeddah has more than 54 unplanned settlements that together house more than a million residents, accounting for about one-quarter of the city. Al-Sabeel District, located near the city centre, is characterized by narrow streets crowded with buildings, many of which are in deteriorated condition. On this basis, there is a need for community participation and government intervention to make such districts liveable.

(Foster, 2009) is looking at informal housing settlements in developing countries through the eyes of the “commons” framework in her essay “Urban Informality as a Commons Dilemma.” She believes that these settlements display characteristics of common-pool resources. The actions of individual users lead to challenges at the collective level, including overcrowding and insufficient infrastructure. Foster argues that some form of collaborative governance and empowerment of stakeholders to manage their communities is essential if these problems are to be managed for sustainable urban development.

3.0 Key Findings and Research Gaps

The below discussion highlights significant insights categorized into four themes, which are Urban Void Management, Slum Upgrading, Urban Planning Policies, and Integrated

Townships. Each theme presents a different viewpoint regarding urbanization and settlement pattern combinations.

Table 1: Key Findings, Research Gaps, and Contradictions in Urban Planning and Settlement Studies

Theme	Key Findings	Research Gaps	Contradictions
Urban Void Management & Settlement Monitoring	- Urban voids attract informal settlements (Akurdi, Dar es Salaam, New Delhi). - UVAI & remote sensing help track growth. - SPVs & land banks can reclaim urban voids.	- Lack of policy-driven urban void repurposing. - Need real-time monitoring integrating land-use policies.	Some studies claim urban voids lead to slums, others argue they can be reclaimed for public use.
Slum Upgrading & Informal Settlement Solutions	- Participatory slum upgrading improves outcomes (Dharavi, Amanora models). - Land tenure security encourages housing investment.	Insufficient studies on integrated townships driving slum formation. Need comparative studies across economic zones.	Some research sees slum upgrading as effective, others highlight its limited long-term impact without economic inclusion.
Urban Planning & Policy Frameworks	- Magarpatta & Amaravati demonstrate successful land pooling. - Weak regulatory enforcement fosters unplanned settlements.	Limited long-term studies on land pooling's impact on sustainability.	Debate on whether land pooling is scalable beyond specific socio-political contexts.
Integrated Townships & Sustainable Development	- Townships shape urbanization but displace low-income groups. - Mixed-use policies mitigate urban sprawl.	- Unclear impact of integrated townships on regional economic disparities. - Need research on governance structures ensuring inclusivity.	Some claim integrated townships promote economic growth, others argue they worsen affordability & exclusion.

Source: Compiled by authors

While major findings disclose that planning instruments, governance, and spatial monitoring would be the main tools within reach, research gaps indicate the absence of longitudinal studies and policy-led interventions. Conflicting arguments existed among proponents regarding the effectiveness of land pooling, the sustainability of slum upgrading, and integrated townships' impact on affordability and exclusion.

4.0 Conceptual Framework for Future Research

A coherent approach will provide direction in urban void management, slum upgrading, planning policies, and integrated townships. This framework incorporates aspects of spatial

analyses, governance models, socio-economic impacts, and sustainability matters.

Urban Void Management & Settlement Monitoring

- Real-time GIS-based spatial tracking for informal growth monitoring.
- Draft policy frameworks for urban voids repurposing through Special Purpose Vehicles (SPVs) or community land trusts.

Solutions for Slum Upgrading & Informal Settlements

- Investigate participatory governance models for sustainability in upgrading.
- Research economic mobility after upgrading with a further focus on employment and tenure security.

Urban Planning & Policy Frameworks

- Examine the scalability of the pooling of land beyond cases that have worked.
- Assess the role of enforcement through regulation in curbing urban sprawl and informal settlements.

Integrated Townships & Sustainable Development

- Study the economic spillover effects of these integrated townships on regional disparities.
- Evolving inclusive planning models that are affordable to lower-income groups.

This is a framework that brings existing research gaps closer, new technological innovations, and policy reforms complemented by socio-economic assessments contribute to sustainability in the urbanization process as well as inclusiveness.

5.0 Conclusion

The study of unplanned settlements around integrated townships has revealed some big urban challenges such as poor land utilization, poor governance, and inequalities among the populace. Findings include that urban voids always attract informal settlements; slum upgrading will help in stabilizing housing; integrated townships draw the affordability issue closer but also pattern urbanization; and land-pooling models like Magarpatta bring forth new forms of urbanization with not too much study in their long-term sustainability.

This is, therefore, a matter of extreme relevance to future urban planning because as cities expand, in future they will be called upon to strike a balance between planned versus unplanned development and inclusive growth. Without attention to unplanned settlements, then these will continue to grow and grow, including urban sprawl, hence unsustainable infrastructures, and the poor are excluded socioeconomically. They will jeopardize the goal of sustainable development. The need for governance mechanisms regulating informal growth but integrating at-risk communities under urban planning is a significant takeaway from the findings for policymakers. Planners should also embrace real-time monitoring tools (e.g., remote sensing, UAVI) for the planned establishment of affordable military mixed use. The accountability of the developer extends to guiding the planned development and infrastructure measures within the township, taking cognizance of compliance with relevant regulations, as well as to mitigate

probable negative externalities. In addition, where an integrated township is sanctioned, the environment should also be developed in a systematic manner to avoid sporadic settlements and facilitate uniform urban development. Researchers have more work to do in establishing the causal linkages about integrated townships and informal settlements, taking the long-term impact assessments of land pooling, and looking at scalable models towards inclusive urbanization. Mitigation of unplanned settlement growth and resilient, equitable urban futures requires a multi-stakeholder approach-combining innovative governance, planning, and empirically grounded research.

References

Africa, S.-S. (n.d.). *Empower, an integrated development approach to informal settlement upgrading*. Urban Agenda Platform.

Ahire, H., Salunke, H., & Mane. (2020). Comparative analysis of integrated township development in Pune region. *International Journal for Research Publication and Seminar*, 7.

Ali, M. H., & Sulaiman, M. S. (2006, October 13). Informal settlements: Policy, land use and tenure. In *Shaping the Change*, XXIII FIG Congress, Munich, Germany.

Bello, I. K., Solanke, P. A., & Arowosegbe, O. S. (2016, June). Managing a sustainable integrated township for urbanization development in Ogun State, Nigeria. *International Journal of Research in Business Studies and Management*, 3(6), 56–62.

Charman, A., & Petersen, L. (2015, March). The layout of the township economy: The surprising spatial distribution of informal township enterprises. *Econ3x3*. Retrieved from <http://www.econ3x3.org>

El-Shorbagy, A. M. (2020, February 3). Unplanned settlements in Saudi Arabia: The case of Al-Sabeel District, Jeddah. *Journal of Settlements and Spatial Planning*. <https://doi.org>

Foster, S. R. (2009, February). Urban informality as a commons dilemma.

Haspe, A. A., & Deshmukh, P. S. (2016). Comparative evaluation of integrated townships. *IJARIE*, 2(3).

Hayek, U. W., Jaeger, J. A., Schwick, C., Jarne, A., & Schuler, M. (2010, June). Measuring and assessing urban sprawl: What are the remaining options for future settlement development in Switzerland for 2030? *Springer*. <https://doi.org/10.1007/010>

Hitayezu, P., Rajashekar, A., & Stoelinga, D. (2018). The dynamics of unplanned settlements in the city of Kigali. *Laterite Ltd*. International Growth Centre, London.

Indian Institute for Human Settlements (IIHS). (2016). *Can peri-urban development choose partnerships over displacement?* (The IIHS Case Method No. 1-0006).

Kapur, D., & Anees, U. (2024, May 1). Informal and unplanned urbanisation—Welcome to the new urban India. *Down to Earth*, 1.

Khare, U., & Thakur, P. (2020, September). Integrated townships in Pune: A temporal study using remote sensing techniques. *IBP*, 9(12). Retrieved from <http://www.ibp.world>

Kuffer, M., & Barros, J. (2011). Urban morphology of unplanned settlements: The use of spatial metrics in VHR remotely sensed images. In *1st Conference on Spatial Statistics 2011, Mapping Global Change* (pp. 152–157). Elsevier Ltd. <https://doi.org/10.1016/027>

Kumar, L. (2019). Development of integrated townships as club good: The case of Lavasa and Magarpatta. *JETIR*, 6(4). Retrieved from <http://www.jetir.org>

Kumar, R., & Katyal, S. (2023, June). Integrated townships and their role in impacting the development scenario in Uttar Pradesh. *International Journal of Novel Research and Development*, 8(6). Retrieved from <http://www.ijnrd.org>

Mahabir, R., Crooks, A., Croitoru, A., & Agouris, P. (2016, September 22). The study of slums as social and physical constructs: Challenges and emerging research opportunities. *Regional Studies, Regional Science*. <https://doi.org/10.1080/21681376.2016.1229130>

Moghayedi, A., Mehmood, A., Michell, K., & Ekpo, C. O. (2023, May). Modeling the neighborhood wellbeing of townships in South Africa. *MDPI*. <https://doi.org/10.3390/542>

Nallathiga, R., Tewari, K., Saboo, A., & Varghese, S. (2021, February). From satellite townships to smart townships: Evolution of township development in Pune, India. *JSTOR*, 16(1), 86–106.

Nandu, G. (2023, March 8). Integrated townships in Maharashtra. *Mondaq*, 1.

Nayak, N. (2017). Study of urbanization, causes and effects in India & some important features of satellite townships. Department of Geography, University of Rajasthan. *Universal Research Reports*.

Novitasari, V., Hardiyati, & Miladan, N. (2021). Ekistics in planned and unplanned settlement. *IOP Conference Series: Earth and Environmental Science*. IOP. <https://doi.org/10.1099/778>

Nurgandarum, D., Inavonna, & Ischak, M. (2019, November). Understanding unplanned settlement structure as a result of self-organization in Jakarta. *International Journal of Scientific & Technology Research*, 8(11).

Omar, N. A., & Saeed, E. H. (2019, September). Urban voids as potential resources for the city development. *Journal of Engineering Sciences, Assiut University Faculty of Engineering*, 47, 585–600.

Patel, J. H., & Gandhi, Z. H. (2019, December). A review on self-sustainable integrated township. *International Research Journal of Engineering and Technology (IRJET)*, 6(12).

Patel, M., & Padhya, H. (2021). The neighbourhood planning in India: A case study of Magarpatta City. *International Journal of Research in Engineering and Science (IJRES)*, 9(1), 29–33. Retrieved from <http://www.ijres.org>

Prakash, P. B., Rao, P. C., & Yasaswi, M. K. (2022, November). Land pooling practices in India: A case study of Amaravathi and Magarpatta. *International Journal of Engineering Research & Technology (IJERT)*, 11(11).

Rai, P. T. (2012). Townships for sustainable cities. In *International Conference on Emerging Economies—Prospects and Challenges* (p. 10). Elsevier Ltd. <https://doi.org/10.1016/307>

Raisoni, H., Verma, T., & Petkar, A. (2024, July 28). Unveiling urban void potential: The development of an Urban Void Analysis Index (UVAI) for city section revival: A case study of Akurdi, PCMC, India. *International Review for Spatial Planning and Sustainable Development A, Planning Strategies and Design*, 12, 28. <https://doi.org/10.14246/132>

Sharma, S. S., Diwan, G. R., & Petkar, A. S. (2015). Evaluation of special township policy—Case study of Pune Metropolitan Region. *Indian Journal of Regional Science*, 47.

Yu, Z., Pei, Q., Liyuan, X., & Xitao, H. (2021). The framework design of the construction of a comprehensive information management service platform at the township. *Journal of Physics: Conference Series*. IOP. <https://doi.org/10.1088/182>

CHAPTER 143

To Examine Impact of Urban Mobilization on Urban Development in Case of Pune City

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ABSTRACT

The study investigates how urban mobilization influences Pune city's development, examining the complex relationship between traffic dynamics, infrastructure, and the urban environment. The findings reveal a strong public concern regarding the city's ability to address traffic congestion, road safety, and the environmental consequences of rapid urban growth. Many residents are dissatisfied with the current state of road networks, public transportation systems, and traffic management, which directly impact daily commuting experiences and quality of life. The research highlights the need for sustainable construction methods and regular policy evaluations to address these challenges effectively. A lack of public awareness and inconsistent policy implementation emerged as significant barriers to progress. Additionally, issues such as environmental degradation, rising vehicular emissions, and unchecked real estate expansion call for immediate attention and well-structured strategies to mitigate their effects. By achieving its objectives, the study emphasizes the crucial role of traffic management and urban mobilization in shaping the city's future. Recommendations include adopting sustainable practices, improving public involvement in urban planning, and ensuring stronger enforcement of policies. These steps are vital to creating a sustainable and livable Pune, balancing growth with environmental preservation. The research provides actionable insights for policymakers and urban planners working to address the challenges of urbanization while enhancing the city's long-term resilience and livability.

Keywords: Pune city; Urban development; Urban mobilization; Policy implementation; Infrastructure development; Traffic management; Sustainability.

1.0 Introduction

Over the course of three decades, Pune's population has increased by 73.36%, and the city has grown from 146 square kilometers. Due to the consolidation of 43 villages that encircle the city under the Pune Metropolitan Region Development Authority (PMRDA), to 331 sq.km as of right now.

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Pune is located on the banks of the Mula and Mutha rivers at an elevation of 570 meters, between the Sahyadri hills. The city benefits from the neighboring mountains' excellent natural ambience and year-round mild climate. Pune, also referred to as the Oxford of Maharashtra, is a rapidly developing industrial and IT hub in India with multiple highly regarded universities in a wide range of subjects. Pune was ranked among the 111 cities in India that are the most livable.

Mobility has a direct impact on the economic efficiency of cities and the well-being of urban residents. The effectiveness of a city's transportation networks, or the efficiency with which people and products are moved across the city, is crucial to its efficiency. Pune has consistently been one of the fastest-growing cities in the Asian-Pacific region. From 1991 and 2001, the city expanded by 40%, reaching 1.6 million to 2.5 million people. Pune's decadal rate of growth has averaged nearly 40% for the past 40 years, and it is anticipated that the population would reach 5.6 million by 2031 if the above situation continues. (Gawade 2021) As a result, Pune has grown to become one of the state's major cities, attracting engineering firms and car manufacturing. It has quickly attracted a lot of interest from the communication and InfoTech industries as well. Because to the increasing urbanization, there has been a large-scale migration from all over the nation. The fast urbanization has affected the urban development of the city. Examining the relationship between urban growth and mobilization is the aim of this research.

1.1 Research problem and question

This research aims to answer following research questions -

- What are the main forms and modes of urban mobilization found in Pune City?
- Who are the main stakeholders participating in urban mobilization activities in Pune, and what do they do and why?
- What particular urban development issues or projects have been shaped by urban mobilization in Pune, and how?
- To what degree does urban mobilization help shape urban policies, plans, and governance institutions in Pune?
- What are the perceived advantages and drawbacks of urban mobilization for stakeholders in urban development in Pune?

1.2 Research objectives

This research aims to examine the impact of urban mobilization on urban growth by evaluating the effectiveness of urban development plans and their influence on infrastructure, connectivity, and physical expansion. It analyzes the role of government policies and regulations in shaping urban mobility and sustainable growth while also assessing the accessibility, efficiency, and integration of public transit in driving economic development and managing urban sprawl. Additionally, the study explores the effectiveness of traffic management strategies, including congestion control and intelligent traffic systems, in improving mobility. It investigates the role of Intermediate Public Transit (IPT) in bridging gaps between formal public

transport and last-mile connectivity. Furthermore, the research delves into the effects of urban mobility on existing settlements, focusing on land use changes, population density, and real estate development.

2.0 Literature Review

After analyzing 80 research papers related to urban mobilization of the various cities around the globe out of which 40 were screened and shortlisted for further investigation and we found a research gap that highlighted the role of urban mobilization in city growth. Economic development, policy interventions, and technological progress are the primary drivers, but these are slowed down by bottlenecks such as poor last-mile connectivity and increased vehicle dependency. While existing studies identify multimodal transport integration and sustainable measures, they do not explicitly make the connection between urban mobilization and urban development. An investigation into this link is crucial in appreciating how mobility initiatives shape urban growth, infrastructure, and socio-economic growth and, hence, offers valuable inputs towards better planning and policymaking for Pune.

Table 1: Literature Review Table

Sr. No.	Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Planning																				
1.1	Road Width																		✓		
1.2	Footpath slash cycle way																				
1.3	Improper road networks	✓	✓																✓		✓
1.4	Improper junctions and intersections	✓																	✓		✓
1.5	Unappropriated Parking	✓													✓						
1.6	Land use planning	✓	✓	✓																	
	Zoning regulation																				
	Sustainable land use																			✓	
	Urban density														✓				✓	✓	
1.7	Community Engagement		✓	✓											✓						
	citizen participation																				

	Feedback mechanism																		
2	Traffic Management																		
2.1	Lack of signals								✓								✓		
2.2	Traffic flow optimization	✓	✓						✓			✓	✓				✓		
2.3	Lack of signage's and markings	✓														✓			
2.4	Traffic Monitoring	✓	✓						✓			✓	✓				✓		
2.5	Traffic regulations and enforcement	✓		✓								✓							
	Speed limit															✓			
	Parking regulations												✓			✓			
	Real time traffic information												✓						
2.6	Public awareness	✓	✓	✓					✓							✓			
	Education on safe driving	✓																	
	Promotion on public transport	✓																	
3	Public Transit																		
3.1	Modes of transit	✓											✓			✓			✓
3.2	Accessibility & Coverage		✓														✓		✓
3.3	Affordability	✓																	✓
3.4	Integration of mode	✓	✓	✓							✓						✓		
3.5	Quality of services			✓							✓								✓
3.6	Promotion of sustainable practices																✓		✓
3.7	Public awareness campaign	✓	✓	✓															
4	Private Transport																		
4.1	Modes of transit	✓	✓	✓		✓		✓			✓				✓				
4.2	Growth of private vehicle		✓					✓			✓								

	ownership																			
4.3	Insufficient public transit and rising reliance on private vehicle					✓														
5	Rapid Urbanization																			
5.1	Traffic congestion and infrastructure strain	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓		✓				✓	
5.2	Adverse impact on existing road networks	✓		✓		✓		✓				✓		✓						
5.3	Inadequate public transport infrastructure		✓		✓		✓		✓		✓									
5.4	Environmental impact on rapid urbanization								✓	✓		✓								
5.5	Improper land use and uncontrolled real estate development	✓		✓		✓		✓	✓	✓	✓	✓	✓							
6	Sustainability																			
6.1	Environmental degradation	✓		✓			✓	✓	✓			✓			✓					
6.2	vehicular emission & waste management		✓					✓					✓							
6.3	Green Construction practices	✓					✓	✓												
7	Policy Implementation and monitoring																			
7.1	Various policies related to urban development are not implemented in full swing		✓	✓							✓				✓					
7.2	Lack of monitoring policy execution		✓					✓		✓	✓				✓					

7.3	lack of public awareness about the government policies		✓			✓		✓									✓					

Sr. No.	Parameters	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Total
1	Planning																					
1.1	Road Width				✓	✓				✓												4
1.2	Footpath slash cycle way				✓					✓												2
1.3	Improper road networks	✓			✓	✓				✓												8
1.4	Improper junctions and intersections	✓				✓				✓												6
1.5	Unappropriated Parking					✓				✓												4
1.6	Land use planning				✓	✓	✓	✓	✓	✓	✓			✓	✓							12
	Zoning regulation					✓		✓			✓				✓							4
	Sustainable land use					✓	✓	✓	✓	✓	✓			✓	✓							9
	Urban density				✓		✓	✓	✓		✓	✓	✓	✓								11
1.7	Community Engagement						✓					✓										3
	citizen participation											✓										1
	Feedback mechanism											✓										1
2	Traffic Management																					
2.1	Lack of signals																					2
2.2	Traffic flow optimization	✓		✓																		8
2.3	Lack of sing ages and markings																					2
2.4	Traffic Monitoring	✓		✓																		8
2.5	Traffic regulations and enforcement	✓																				4
	Speed limit																					1
	Parking regulations																					2

[illegible]

5.4	Environmental impact on rapid urbanization																			3
5.5	Improper land use and uncontrolled real estate development																			9
6	Sustainability																			
6.1	Environmental degradation																			7
6.2	vehicular emission & waste management																			3
6.3	Green Construction practices																			3
7	Policy Implementation and monitoring																			
7.1	Various policies related to urban development are not implemented in full swing																			4
7.2	Lack of monitoring policy execution	✓																		6
7.3	lack of public awareness about the government policies	✓																		5

2.1 Research method

This study will adopt a mixed-methods approach, integrating both qualitative research techniques to comprehensively examine the effects of urban mobilization on urban development in Pune.

3.0 Methodology

This flowchart outlines the research process in a clear and structured way. It begins with identifying the core problem, which sets the direction for the study. A literature review follows, helping to understand existing research and gaps in knowledge. Based on this, a research design is created to define the study's approach. The next step is data collection,

relying on secondary sources like government reports and studies. Once the data is gathered, it is analyzed to identify key patterns and insights. The findings are then discussed in detail, leading to meaningful conclusions and practical recommendations to address the research problem.

Figure 1: Research Methodology Flowchart



4.0 Urban Development and Mobilisation

A review of the literature was done to look at how urban mobilization affects urban development. To identify the gaps or deficiencies, a thorough evaluation of the literature has been conducted using content analysis of secondary data sources, including research papers, articles, reports, and databases pertaining to urban development and urban mobilization in the context of Pune city. A few reports from commissions or government agencies are also available, and these aid in understanding the field of study. This review of the literature is helpful in determining the elements that contribute to urban growth and are associated with urban mobilization. Urban mobilization in the context of Pune city has gained significant attention in the field of urban studies, as the city faces rapid growth, urbanization challenges, and evolving infrastructure needs. A comprehensive review of existing literature reveals insights into how urban mobilization has influenced Pune's urban development across various dimensions, such as infrastructure, transport, social inclusion, and sustainability. Below is a detailed literature review based on various studies, theoretical perspectives, and case studies related to urban mobilization in Pune.

- What is urban mobilization?

Urban Mobilization is all of the movement of both people and goods that occur in City via public or private Transportation.

- What is urban development?

Urban planning includes techniques such as: predicting population growth, zoning, geographic mapping and analysis, analyzing park space, surveying the water supply, identifying transportation patterns, recognizing food supply demands, allocating healthcare and social services, and analyzing the impact of land use.

4.1 Pune's urbanization trends

Pune, once a relatively small city, has rapidly transformed into one of India's key metropolitan areas due to its economic growth, booming IT industry, educational institutions, and migration trends. According to a study by the Pune Metropolitan Region Development Authority (PMRDA, 2019), the city's population is expected to grow substantially in the coming decades, which will significantly impact urban infrastructure and planning. This growth has been accompanied by increased demand for housing, transportation, and public services, making urban mobilization crucial to addressing these demands effectively.

4.2 Challenges and limitations of urban mobilization in Pune

Despite the successes, urban mobilization in Pune faces several challenges:

- **Political and Bureaucratic Hurdles:** Implementation delays, political interference, and lack of coordination between different governmental bodies have slowed the progress of urban mobilization efforts (Satterthwaite, 2005).
- **Equity and Inclusivity:** The benefits of urban mobilization often fail to reach marginalized and low-income communities. This issue has been particularly apparent in housing and public service delivery, where wealthier areas have seen more rapid development compared to underdeveloped regions (Patil & Shinde, 2018).
- **Infrastructure Bottlenecks:** Despite efforts to improve infrastructure, rapid population growth continues to outstrip the capacity of existing systems, leading to persistent problems in areas such as waste management, water supply, and sanitation.

5.0 Data Analysis

This chapter provides a comprehensive assessment of how urban mobilization impacts urban development in Pune. The research highlights patterns and trends from primary data, offering insights into the causes, challenges, and outcomes of urban mobilization. It serves as a foundation for evaluating the success and implications of these initiatives for future urban policies.

Secondary data collection

- *Urban development plans & policies:* Analysis of government reports, policy papers, master plans, and mobility plans to evaluate implementation and effectiveness.
- *Traffic & mobility data:* Analysis of transport department reports, census statistics, and GIS-based studies to measure urban transit efficiency.
- *Qualitative analysis:* Thematic analysis of interview transcript and review to policy to explain why stakeholder believe certain policy.

6.0 Conclusion

This study highlights the deep connection between urban mobilization and Pune's development. Findings reveal widespread concern over traffic congestion, road safety, and

environmental impacts due to rapid urbanization. Many respondents expressed dissatisfaction with road networks, public transport, and traffic management, which affect daily life and mobility. There is a strong call for sustainable construction, regular policy reviews, and greater public participation in urban planning. Key concerns include environmental degradation, vehicle emissions, and uncontrolled real estate expansion, emphasizing the need for comprehensive strategies. Overall, the study underscores the importance of effective traffic management, sustainable development, and proactive policies to ensure Pune's growth remains balanced and livable.

7.0 Suggestion

- There is a pressing need to expand and enhance the existing road networks, particularly in densely populated areas. Creating more lanes and improving road width can alleviate traffic congestion and improve mobility.
- City planners should prioritize the development of well-maintained footpaths and cycle ways. Promoting walking and cycling can not only ease traffic but also contribute to environmental sustainability.
- Additional traffic signals, better road signage, and improved design of junctions and intersections should be implemented to ensure better road safety for all road users, especially pedestrians and cyclists.

References

- Bari, P. (2018, March). PMC lacks proper and effective administration, says town planner Ramchandra Gohad. *Hindustan Times*. <https://www.hindustantimes.com>
- Rocky Mountain Institute. (2018, August). *An introduction to Pune City's mobility ecosystem: Urban Mobility Lab*.
- Mangire, A. J. (2021, April). *Determining mode priority on shared streets: A key solution for Pune City's sustainable mobility development*.
- Gawade, P. S. (2021, November). *A study on Pune urban transportation crisis and approach toward sustainable transportation*.

CHAPTER 144

To Study the Difficulties Faced by Organization in Managing Over-Allocated Resources

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ABSTRACT

In the construction industry, there are large challenges in resource allocation and project scheduling. Construction projects, generally associated with inefficiencies, cost overruns, and project delays, need methods more sophisticated than just the Critical Path Method (CPM) and Resource Leveling, which, although useful, tend to be quite inadequate to cope with complex workloads and uncertainties inherent in construction projects. The paper presents a novel approach to integrating artificial intelligence into traditional project management techniques to make better decisions to optimize resource usage. With Artificial Intelligence (AI) algorithms, the project manager would be able to achieve better accuracy in forecasters, effective adjustment in critical paths, and improve resource leveling to avoid risks of over allocation and bottlenecks. The study thus has put a lot of focus on the user-friendly interface between AI-driven insights and project managers for practical application in real-world scenarios. This paper provides a comprehensive analysis on the integration of AI into project management to provide a framework for improving project outcomes in terms of time, cost, and overall effectiveness, to improve construction management practices.

Keywords: Microsoft projects; PRIMAVERA; Resource management; Critical path method; Resource leveling.

1.0 Introduction

The construction industry is vital to global economic development, driving infrastructure growth and employment. However, inefficiencies in project scheduling and resource management persist, causing delays, cost overruns, and resource wastage. Traditional scheduling methods, such as the Critical Path Method (CPM) and Resource Leveling, rely on static assumptions and struggle to adapt to dynamic project conditions. Artificial Intelligence offers advanced capabilities in predictive analytics, optimization, and decision-making, addressing the limitations of traditional scheduling.

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AI-driven models enable real-time adaptability, improved forecasting, and optimized resource distribution, reducing human errors and enhancing efficiency. This research aims to improve construction project scheduling by integrating AI-driven solutions to optimize timelines, enhance resource allocation, and improve efficiency. It evaluates the limitations of traditional methods and explores AI-based models' practical applications in project management tools like Microsoft Project (MSP) and Primavera.

The study examines AI techniques such as predictive analytics, machine learning-based optimization, and automated decision-making for construction scheduling. It assesses AI model efficiency in resource allocation, timeline adjustments, and risk management while evaluating their integration feasibility with existing project management tools. Despite AI's potential, challenges include access to high-quality project data, computational demands, and stakeholder trust in AI-driven decision-making. Smaller firms may face integration and scalability issues due to limited technological resources. This paper analyzes traditional scheduling methods, AI advancements, and a proposed AI-based scheduling framework. It explores AI integration with MSP and Primavera and assesses its impact on project timelines, resource utilization, and cost efficiency. The study concludes with key findings, future research directions, and AI adoption implications in construction scheduling, bridging the gap between theoretical advancements and practical implementation for more efficient project management.

2.0 Literature Review

The construction industry is a crucial driver of economic development, contributing to infrastructure expansion and employment generation. However, inefficiencies in project scheduling and resource management continue to hinder project success, leading to delays, cost overruns, and wasted resources. Traditional scheduling techniques, such as the Critical Path Method (CPM) and Resource Leveling, rely on static assumptions that struggle to accommodate dynamic project conditions (Khan *et al.*, 2024). These methods lack flexibility, making them ineffective in responding to uncertainties such as weather disruptions, labor shortages, and supply chain delays. AI-driven approaches offer a solution by enhancing predictive analytics, optimization, and decision-making, enabling real-time adaptability and improved forecasting accuracy (Egwim *et al.*, 2022). This research investigates the potential of AI-driven solutions to optimize project timelines, resource allocation, and efficiency while evaluating their feasibility in project management tools like Microsoft Project (MSP) and Primavera.

Traditional scheduling methodologies have been widely utilized for decades. (Kelley, 1961) introduced the Critical Path Method (CPM), a technique that determines project timelines based on deterministic task durations and precedence relationships. While CPM is effective in identifying critical activities that directly influence project completion, it lacks the ability to accommodate real-time changes. This rigidity often results in scheduling inefficiencies when unforeseen disruptions occur. Similarly, the Program Evaluation and Review Technique (PERT)

was developed to address project scheduling complexities by incorporating probabilistic time estimates. However, its reliance on estimated task durations still poses challenges in handling highly dynamic project environments. Shen *et al.* (2022) highlight that traditional scheduling methods, including CPM and PERT, struggle to adapt to uncertainties in construction projects. These techniques assume fixed task durations and static precedence relationships, which fail to capture real-world variations. Projects often experience unforeseen changes due to labor shortages, fluctuating material availability, and environmental factors, necessitating a more adaptive scheduling approach. This study emphasizes the need for AI-driven models that integrate real-time project data to optimize scheduling decisions dynamically.

Hegazy & Menesi (2010) examine the effectiveness of Resource Leveling, a scheduling technique designed to balance resource allocation across project activities. While Resource Leveling seeks to prevent resource overuse and inefficiencies, it frequently results in suboptimal scheduling decisions due to its inability to incorporate real-time project conditions. The authors argue that AI-based optimization models can address these limitations by continuously analyzing project constraints and adjusting schedules accordingly. Mayer (2002) discuss the impact of unexpected delays in construction projects. They identify factors such as adverse weather conditions, labor shortages, and supply chain disruptions as common causes of scheduling inefficiencies. Traditional methods like CPM and PERT fail to accommodate these uncertainties due to their static nature. The authors suggest that AI-powered predictive analytics can enhance scheduling accuracy by learning from historical project data and forecasting potential risks.

Johannsen (2021) argue that traditional scheduling methods are insufficient for managing probabilistic project elements. They note that CPM and PERT rely on fixed-duration task estimates, which do not reflect the inherent variability of construction activities. By leveraging machine learning and deep learning techniques, AI-driven scheduling frameworks can model uncertainties more effectively and provide adaptive scheduling recommendations. Egwin *et al.* (2022) explore the role of predictive analytics in construction scheduling. Their study demonstrates that AI models can analyze historical project data to predict potential delays and optimize resource allocation. AI-based forecasting techniques improve decision-making accuracy, enabling project managers to take proactive measures to mitigate scheduling risks. The authors conclude that integrating AI into project management tools like MSP and Primavera enhances real-time adaptability and scheduling efficiency.

Asghari *et al.* (2022) investigate the application of reinforcement learning in dynamic scheduling adjustments. Their research shows that AI models can continuously learn from evolving project conditions and refine scheduling strategies in real time. Reinforcement learning techniques allow AI-driven scheduling systems to adapt to unexpected changes, making them more effective than traditional static methods. Egbedian *et al.* (2021) analyze the impact of AI-driven scheduling frameworks on resource allocation accuracy and project completion times. Their study reveals that machine learning-based optimization techniques, such as genetic

algorithms and neural networks, significantly improve scheduling efficiency. By automating the resource allocation process, AI reduces human errors and enhances overall project performance.

Khosrowshahi & Arayici (2012) discuss the integration of AI-based scheduling tools into construction project management software. They highlight the advantages of AI-driven models embedded in Primavera and MSP, including real-time adaptability and predictive insights. The authors argue that AI-enhanced scheduling tools offer superior performance compared to traditional methodologies by continuously analyzing project data and adjusting schedules accordingly. Regona *et al.* (2023) examine the challenges associated with AI adoption in construction scheduling. They identify data availability as a major barrier, as AI models require extensive historical project data for training. Many construction firms lack structured datasets, making it difficult to implement AI-driven scheduling solutions effectively. The authors recommend developing standardized data collection practices to facilitate AI integration in the industry. This study aims to bridge the gap between theoretical AI advancements and practical applications in construction scheduling. By analyzing traditional scheduling methods, AI innovations, and a proposed AI-based scheduling framework, it evaluates AI integration with MSP and Primavera. The research assesses AI's impact on project timelines, resource utilization, and cost efficiency, concluding with key findings, future research directions, and implications for AI adoption in construction scheduling.

3.0 Proposed Methodology

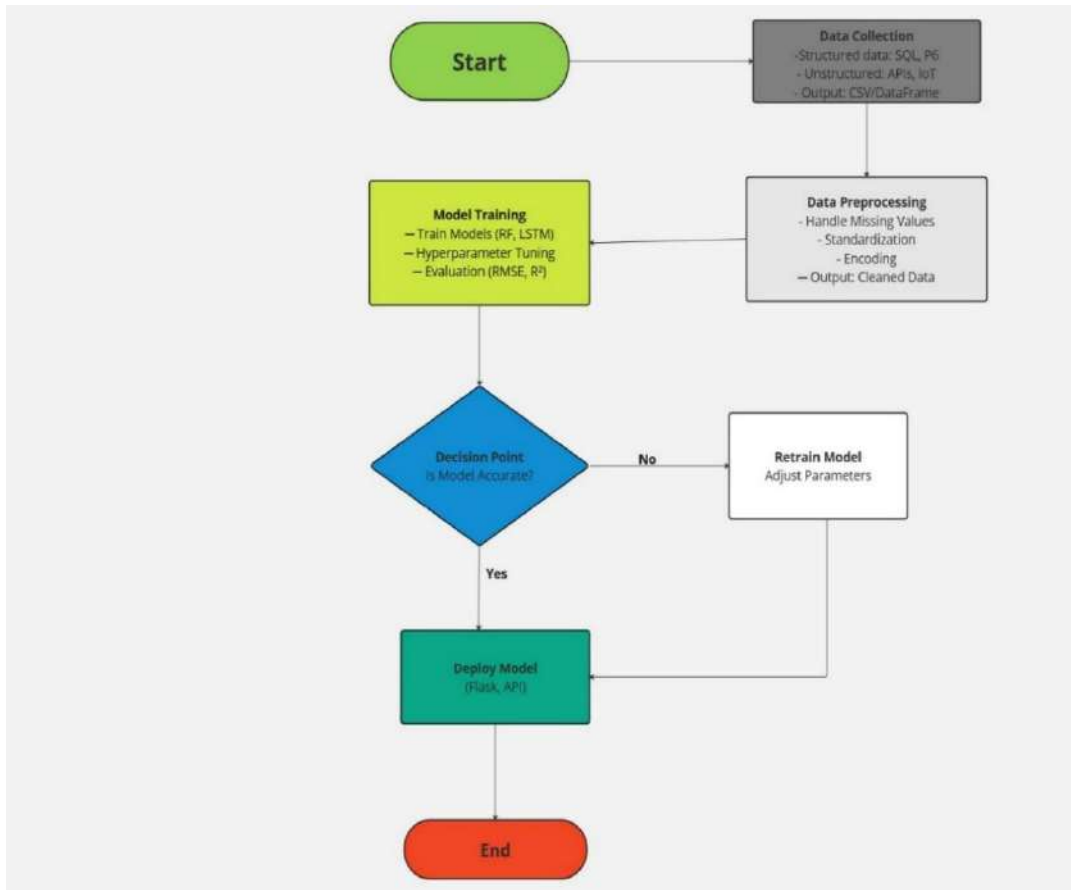
The Proposed Methodology focuses on integrating AI into construction scheduling to enhance efficiency and decision-making. It involves four main steps: data collection, AI model development, integration with scheduling software, and performance evaluation. Historical project data, including task durations and resource allocations, will be gathered and preprocessed to ensure accuracy. AI techniques, such as machine learning and optimization algorithms, will be used to predict project timelines and optimize scheduling. The AI system will be integrated with MSP and Primavera P6 using APIs (Application programming interface), plugins, or cloud-based solutions for real-time updates. Finally, the system's performance will be evaluated based on accuracy, efficiency, scalability, and usability, with comparisons to traditional scheduling methods and feedback from industry professionals to refine the model.

3.1 Data collection implementation

Data collection implementation involves various tools and techniques to extract structured and unstructured project data efficiently. SQL (Structured Query Language) queries are used to retrieve structured data such as task schedules and dependencies from relational databases like MS Project's SQL Server. APIs, such as those provided by Primavera P6 and MS Project, automate real-time data extraction, minimizing manual effort and enabling seamless integration with AI models. In cases where APIs are unavailable, web scraping tools like

Python's BeautifulSoup and Selenium help extract project logs and reports. IoT sensors and edge computing technologies, including MQTT (Message Queuing Telemetry Transport) and AWS (Amazon Web Services) IoT (Internet of Things), facilitate real-time tracking of workforce efficiency and equipment availability, improving the accuracy of AI-driven analyses.

Figure 1: Flowchart of Implementation (Workflow Architecture)



The implementation of these methods involves using SQL queries to connect to databases, extract relevant project details, and store the data for machine learning processing. APIs require authentication, HTTP (Hypertext Transfer Protocol) requests, and data parsing to fetch and utilize project schedules. Similarly, web scraping involves retrieving raw HTML (Hypertext Markup Language) from webpages, extracting key information, and storing it for further analysis. These techniques collectively enhance data collection, ensuring accurate and real-time project monitoring and decision-making.

3.2 Data preprocessing implementation

To preprocess and clean data effectively, several tools and techniques are used. Pandas, a popular Python library, helps in handling missing values, removing duplicate records, and formatting data properly. It allows users to easily manipulate large datasets by filling in missing values and ensuring consistency. NumPy is another essential library that specializes in performing complex numerical operations and calculations. It is highly efficient in processing large amounts of numerical data quickly, making it useful for data analysis. Scikit-learn, a machine learning library, provides various tools for data preprocessing. The Imputer function helps fill in missing values, ensuring that incomplete data does not cause errors in analysis. Standard-Scaler is used to normalize and standardize numeric data, making sure that all values are on a similar scale, which improves the performance of machine learning models. Label-Encoder converts categorical data into numerical values, allowing machine learning algorithms to process them efficiently. These tools work together to clean, organize, and transform raw data into a structured format that can be used for analysis and AI applications.

Table 1: Data Before Preprocessing

Task ID	Task Name	Task Duration	Task Cost (\$)	Task Status	Task Dependencies
1	Task A	5 days	10000	InProgress	Task B, Task C
2	Task B	NaN	8000	Completed	Task A
3	Task C	7 days	10000	InProgress	Task B, Task C
4	Task D	10 days	NaN	Not Start	Task A

Table 2: Data After Preprocessing

Task ID	Task Name	Task Duration (scaled)	Task Cost (\$) (imputed)	Task Status (encoded)	Task Complexity
1	Task A	0.7	10000	1	High
2	Task B	0.6	8000	0	Medium
3	Task C	1.0	9000 (mean)	2	Low

3.3 Model training implementation

To make accurate predictions in project management, different machine learning models are used based on the complexity of the data and forecasting requirements. Linear Regression (LR) is a simple, yet effective model used to predict task completion time. It works by analyzing past data and identifying relationships between task duration and influencing factors, making it useful for estimating timelines. Random Forest (RF) is a more advanced model that can handle complex project dependencies. Since construction and engineering projects involve multiple interdependent tasks, Random Forest considers various factors at once

and predicts possible delays more accurately than simpler models. XGBoost is a powerful and optimized machine learning algorithm designed to improve accuracy in forecasting project duration. It works better than many traditional models because it efficiently processes large, structured datasets and minimizes errors. Long Short-Term Memory (LSTM), a type of Recurrent Neural Network (RNN), is used for analyzing time-series data, meaning it can learn from past project trends to predict future outcomes. This is particularly useful in identifying sequential dependencies, such as how previous project delays might affect upcoming tasks. Together, these models help project managers make better decisions by predicting risks, estimating completion times, and optimizing schedules based on historical data.

3.4 Integration with scheduling software

The integration of AI models with scheduling software like Microsoft Project or Primavera P6 enhances real-time decision-making and dynamic scheduling. This process involves API-based integration, plugin development, and cloud-based synchronization to create a seamless connection between AI systems and project management tools. API-based integration starts with authenticating with scheduling software using credentials like OAuth (Open Authorization) tokens, followed by retrieving project data through HTTP GET requests to access schedules, task dependencies, and resource allocations. AI-generated insights, such as optimized schedules and risk alerts, are then sent back via HTTP POST requests, allowing automatic updates to project schedules based on AI-driven predictions.

Another approach involves developing custom plugins that embed AI functionalities directly into MSP or Primavera P6. This process requires designing an intuitive user interface to display AI insights, ensuring real-time data retrieval from the AI system, and dynamically updating project schedules based on AI recommendations. Cloud-based integration further enhances scalability by deploying AI models on platforms like AWS, Azure, or Google Cloud, with secure data transfer via HTTPS or MQTT protocols. Real-time synchronization ensures that any updates in the scheduling software reflect AI-driven adjustments. Additionally, AI-powered data visualization and reporting tools, such as Tableau and Power BI, help generate insights through Gantt charts and resource heat-maps. Customizable reports highlight key project metrics, including predicted completion dates, resource utilization, and risk assessments, with export options in formats like PDF and Excel for stakeholder presentations. Integrating AI with scheduling software significantly improves efficiency by enhancing forecasting accuracy, optimizing resource allocation, and minimizing project risks, making it a crucial advancement in construction project management.

4.0 Result and Performance Evaluation

Evaluating the AI-integrated system ensures its effectiveness in construction project management. Key metrics include accuracy, efficiency, usability, and scalability. Accuracy

measures AI predictions against actual outcomes, while efficiency assesses reductions in delays and costs. Usability evaluates user satisfaction, and scalability tests performance on large projects. Comparative analysis benchmarks AI against traditional scheduling methods like Critical Path Method and Resource Leveling to quantify improvements. Simulation and testing validate adaptability by analyzing AI responses to real-world scenarios like delays and resource shortages. The system's ability to dynamically adjust schedules is assessed. User feedback from project managers helps refine AI models, focusing on visualization and processing speed improvements. Performance reports summarize key metrics, comparative analysis, and user feedback, demonstrating AI's benefits and justifying further investment.

5.0 Recommendations and Future Scope

In order to enhance forecasts for project schedules and resource allocation, future research in AI-driven construction scheduling should focus on boosting the accuracy of machine learning models by using larger and more diverse datasets. Real-time data collecting, decision-making, and transparency can be further improved by integrating AI with innovative technologies like blockchain, the Internet of Things (IoT), and Building Information Modeling (BIM). It's also critical to make AI-integrated scheduling tools more user-friendly so that construction industry experts easily understand and utilize AI-generated insights. Implementation issues will be resolved with additional validation through pilot projects and real-world case studies, which will offer useful insights into the efficacy of AI-driven scheduling. Future studies should also look into ethical and regulatory issues to make ensure AI solutions satisfy industry requirements.

References

- Abeyasinghe, M. C., Greenwood, D., & Johansen, E. (2001, January). An efficient method for scheduling construction projects with resource constraints. *International Journal of Project Management*, 19(1), 29–45. [https://doi.org/10.1016/S0263-7863\(00\)00024-7](https://doi.org/10.1016/S0263-7863(00)00024-7)
- Asghari, V., Wang, Y., Jahanbiglari, A., Hsu, S.-C., & Tang, P. (2022, November). Reinforcement learning in construction engineering and management: A review. *Journal of Construction Engineering and Management*, 148(11). [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0002386](https://doi.org/10.1061/(ASCE)CO.1943-7862.0002386)
- De Meyer, A., Loch, C., & Pich, M. (2002, January). A framework for project management under uncertainty. *IEEE Engineering Management Review*, 30(1), 60–70. <https://doi.org/10.1109/EMR.2002.1032403>

Egbedion, G. (2024, August). Examining the security of artificial intelligence in project management: A case study of AI-driven project scheduling and resource allocation in information systems projects. *International Research Journal of Engineering and Technology (IRJET)*, 8, 486–497. <https://www.irejournals.com/paper-details/1706160>

Egwim, C. N., Alaka, H., Toriola-Coker, L. O., Balogun, H., & Sunmola, F. (2021). Applied artificial intelligence for predicting construction projects delay. *Machine Learning with Applications*, 6, 100166. <https://doi.org/10.1016/j.mlwa.2021.100166>

Hegazy, T., & Menesi, W. (2010, October). Critical path segments scheduling technique. *Journal of Construction Engineering and Management*, 136(10), 1078–1085. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0000212](https://doi.org/10.1061/(ASCE)CO.1943-7862.0000212)

Kelley, J. E. (1961). Critical-path planning and scheduling: Mathematical basis. *Operations Research*, 9(3), 296–320. <https://doi.org/10.1287/opre.9.3.296>

Khan, A. A., Bello, A. O., Arqam, M., & Ullah, F. (2024). Integrating building information modelling and artificial intelligence in construction projects: A review of challenges and mitigation strategies. *Technologies*, 12(10), 185. <https://doi.org/10.3390/technologies12100185>

Marshall-Ponting, A., Arayici, Y., Khosrowshahi, F., & Mihindu, S. (2009, May). *Towards implementation of building information modelling in the construction industry*. <https://doi.org/10.13140/2.1.3776.6080>

Putri, K., Jiang, Z., Shen, X., & Barati, K. (2022, November). Dynamic construction scheduling and resource planning based on real-time project progress monitoring. *ResearchGate*. <https://www.researchgate.net/publication/366423156>

Regona, M., Yigitcanlar, T., Xia, B., & Li, R. Y. M. (2022). Opportunities and adoption challenges of AI in the construction industry: A PRISMA review. *Journal of Open Innovation: Technology, Market, and Complexity*, 8(1), 45. <https://doi.org/10.3390/joitmc8010045>

CHAPTER 145

Traid Harmony: Integrating Time, Cost and Quality in Civil Retrofitting Projects

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ABSTRACT

Most Retrofitting projects are prone to cost overruns and delays that can significantly impact their profitability and quality. Identifying the root causes of these issues is critical to finding practical solutions. It was found that project parameters like time, cost, and quality are managed separately in retrofitting projects. Greenfield construction projects have simpler approaches to planning, scheduling, controlling and managing the projects. In the case of retrofitting projects, many unseen problems surfaced during the repairs and rehabilitation work, thereby completely collapsing the planned things. This study focuses on the different construction retrofitting projects in India and identifies the main factors that lead to cost overruns and delays in construction retrofitting projects. This study will also focus on challenges in integrating time, cost, and quality in the project planning, execution, and monitoring phases. The data collection would be done through a live project, which has already been executed, and an interview with the top management would be done to understand the key reasons for time, cost, and quality errors. The study would then give insights into the Integration plans to prevent and mitigate cost overruns, delays, and quality issues.

Keywords: Retrofitting projects; Integration; Construction repairs; Construction challenges.

1.0 Introduction

In contemporary civil engineering practices, the efficient management of retrofitting projects has become increasingly paramount. Retrofitting projects aim to upgrade existing structures to meet modern standards, whether for safety, functionality, or sustainability. However, the successful execution of such projects relies on a delicate balance between time, cost, and quality management. This project endeavours to explore the integration of these crucial aspects – time, cost, and quality – in the context of civil retrofitting projects, under the framework termed “Triad Harmony.” This compartmentalized approach often leads to conflicts, delays, budget overruns, and compromised quality.

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Recognizing this challenge, the concept of Triad Harmony seeks to harmonize these elements, ensuring that adjustments made in one area do not adversely impact the others. Projects that are executed within budget (cost), schedule (time), and of acceptable quality are said to be successful. By integrating time, cost, and quality management, Triad Harmony aims to enhance project efficiency, effectiveness, and overall success.

2.0 Objectives

The primary objective of this project is to develop a comprehensive understanding of Triad Harmony principles and their application in civil retrofitting projects. Specifically, the objectives are to investigating existing methodologies and practices in time, cost, and quality management within the context of civil retrofitting. Additionally, analysing the interdependencies and potential conflicts between time, cost, and quality objectives in retrofitting projects. Even to propose a framework for integrating time, cost, and quality management to achieve Triad Harmony in civil retrofitting projects.

3.0 Problem Definition

The traditional approach to managing civil retrofitting projects often results in inefficiencies and compromises in project outcomes. The main problems in traditional approaches to project delivery have been in extensive delays in the planned schedules, cost overruns, serious problems in quality, and an increase in the number of claims and litigation associated with construction projects [1]. Issues include difficulty in balancing competing objectives of time, cost, and quality. Even, lacks integration between project planning, execution, and monitoring phases. Mainly, inadequate mechanisms for addressing changes or deviations during project implementation. Due to limited tools or frameworks for evaluating the holistic impact of decisions on project performance. Addressing these challenges requires a paradigm shift towards integrated management approaches such as Triad Harmony.

4.0 Brief Methodology

Relevant and necessary data were collected through questionnaires and through scheduled interviews with top management executives who are into civil retrofitting project or have worked on complex retrofitting projects. Before preparing questionnaires ample amount of literature review was carried out by referring more than 50 research papers, which included research about management of time, cost and quality in civil engineering projects in different countries. The questionnaires were distributed to chief executive officer (CEO's), vice president, general managers, project managers, senior project engineers, planning engineer, site engineers, project co-ordinator and many more industry experts. These professionals had mixed

understanding of operations across clients, consultant and contractor firms. The questionnaires were prepared with both closed and open-ended questions, where personnels had full independence to share their experiences and tackles which they encountered at their projects. These professionals were then interviewed to grasp more information about how they manage retrofitting projects at their respective firms. The interviewed people were experts in retrofitting jobs, as well had worked in contracting firm, consulting firm and client organizations. Interviewee we questioned on how they implement management techniques at their respective firm and what are special techniques they use at their respective firms. Compiling all the data which is collected to understand the importance and methods of integration of management techniques in retrofitting projects.

5.0 Limitations of the Study

The project's scope may be limited by resource constraints, access to data, and time constraints. The proposed framework may require further refinement and validation in real-world applications. External factors such as regulatory changes or market conditions may influence project outcomes.

6.0 Scope of Work

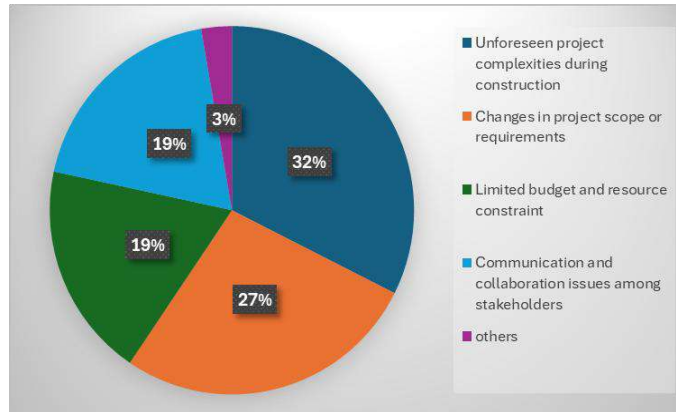
This project focuses specifically on the integration of time, cost, and quality management in civil retrofitting projects. It will primarily explore conceptual frameworks and theoretical principles, supplemented by case studies or simulations. However, the project does not aim to provide exhaustive guidance on project management practices or address broader issues beyond the scope of Triad Harmony integration.

7.0 Time, Cost and Quality Integration in Civil Retrofitting Projects

Integration of Time, Cost and Quality in retrofitting projects in the India have always been a tedious work, due to many factors. Managing time, cost and quality in a retrofitting project as a separate entity is more practical and achievable. This is what all project stakeholders believe and are practicing. But many projects fail due to this harmonic disbalance that is it causes either a time overrun, or a cost shuts up. If in case both cost and time is managed the quality of the project gets hindered. Similarly, if the project stakeholder tries to deliver a quality work, then they compromise on time. If a project is of time is an essence, then to manage the time of completion, the cost of the project is compromised, and the contractor bares losses. As per our study 80% of the projects in India, fail to balance all the three factors. In our study we have listed out all the factors which affect this harmony and create project profit losses. Also, the key influence factors which have adverse effects. As per our survey and interviews few of the challenges that a civil retrofitting project face are (see, Figure 1):

- Unforeseen project complexities during construction
- Changes in project scope or requirements
- Limited budget and resource constraints
- Communication and collaboration issues among stakeholders

Figure 1: Challenges in Civil Retrofitting Projects: A Pie Chart Analysis



The above pie chart shows the percentage of industrial experts who agreed upon the challenges they faced.

7.1 Key factors which affect project time of completion

Time is always viewed as an important factor since it is very important in gauging the success of the project. Time of completion is directly linked with the profits earned. If the project time increases it is directly linked with the expenses to be incurred due to the increase in project duration, in most of the cases if there is increase in project duration, the contractor is bound to pay the liquidity damages as per contract terms. As per survey among top industrial professional, it was evident that complexity in project execution is the main criteria that affects project time and schedule. By complexity it means the method of retrofitting jobs and challenges faced to execute the job. It was also found that there was a repetitive change in the scope of project and methodology of execution. To execute all these complex jobs, it was evident that there was a lot of delays in material delivery at site locations. Once, materials were deployed at site there would be huge challenge in the availability of skilled manpower and machinery. During the project planning stage, complete project budget is fixed, having a fixed project budget would restrict any extra expenses to incur at site level, thus would restrict the site professionals to have a free hand in taking new and innovative ideas. Knowledge about the scope of project plays an important role in project completion. Many a times the site professionals are unaware about the scope of the project. During execution of the project the

project professionals should incorporate a good functional communication system among there sub ordinates to have proper communication. In case of improper communication there would be a lot of delays in project schedule. A proper analysis of project risk that is project risk identification and assessment of risk which are possible to occur is to be forecasted. So that a mitigation plan is ready to tackle the problems. In many projects the quality inspection, approvals and authorization get delayed since the client engineers take time for processing all those.

7.2 Key factors which affect project cost

Cost is a vital factor on which the entire project success depends on. Cost of project depends upon the size, quality and location of the project that is higher the quantity higher is the project cost and vice versa. Cost of project includes material, manpower, machinery and other resources. Cost fluctuation is bound to happen in an ongoing project; the most probable cost changes is due to the escalation of material cost. Material availability and demand for the material also increases the cost of materials, thus shoot-up the cost of material and thus escalating the price. To manage the material price's escalation, in the tender document rates escalation clauses is to be incorporated to control the rate escalations that are raised by the contractors. Due to inflation in the nation and many other factors the labour cost also influences the cost of construction and the budgeted cost of project. Cost of a project also changes by the demographic influence to discuss more about demography, the cost of construction at an urban setup is usually costlier than in the rural setup where construction material is easily available, and cost of labour is comparatively lower. Due to poor management operation, at some cases the delivery of wrong material also occurs where in the cost of transportation, material packing cost and many other miscellaneous charges are to be incurred. The material wastage occurred at sites contribute a huge cost on the budget cost. It was found that at many construction siye the cost of monitoring a project is never accounted in the budget calculation. These monitoring cost have a huge impact on the budgeted cost of operation. Having trained professionals to estimate the budget of the project is necessary, the cost estimation should also be realistic and logical so that it bares all the cost incurred at the site and its expenses.

7.3 Key factors which affecting quality of retrofitting project

Quality of retrofitting projects is to be very carefully monitored as it is a very critical activity as the work carried out is for either repair, strengthening or a rehabilitation. No compromise in quality of the project is to be entertained. Construction quality is directly tied to time and cost and conversely [2]to achieve a quality product skilled manpower is at most important, because the workman ship of the workers influence the quality. A skilled workman executes work at higher quality and a better pace vice versa an unskilled workman executes work with low quality and at a slower pace. Not only the workmen who work, also the knowledge and competency of the project team also plays an important role in execution of

quality product. Use of apt machinery and tools also play a key role in attainment of quality product. The resources that are used in the product generation is to be of a good quality range that is the specification of the material is to satisfy the scope of the project. A wrong material will generate a bad quality product. Since different materials have different technical specification choosing a wrong material for execution of job will lead to non-attainment of the desired product.

7.4 Integration of time, cost and quality of retrofitting project

Based on the interviews and our survey regarding integration of time, cost and quality in retrofitting project, it was evident that to generate true harmony the change management is to be very strong, that is any change that a project faces should be handled in a more practical manner and the site professional are to be trained to handle those change. During the planning stage all the challenges that are liable to occur is to be identified and are to be resolved at the earliest. The project duration is to be realistic and achievable by considering all the probable risks and challenges that can occur at the project. Incorporating intermediate milestones in the tender document and adding bonus clause and liquidity damage clause for intermediate milestones will have a sense of fear and awareness in completion of project on time. Even addition of rate escalation clause in the projects which last for many years provides a full independence in managing the cost of projects. Rate escalation clauses can be omitted in short duration projects and a bonus clause can be incorporated for timely completion.

Many complex projects can be carried out by using heavy machineries in order to complete it on time and to achieve a better-quality product. To add up machinery instead for labour workforce a proper rate analysis and comparative study to be carried out to minimize the cost and for decision making. During the tender phase a competent contractor who can manage all the challenges and tackle all the risk at project is to be decided and awarded the contract. Competent and experienced individuals are to be hired for execution of jobs in the engineer's team be in it contracting firm, consulting firm or client's organisation. Full optimization of labour manpower must be achieved by close monitoring. These can be achieved through close monitoring or by using special IOT tools that monitor labour productivity at workplace. A good supply chain management is to be achieved on site for material management be it material selection, identification, sourcing and timely delivery. Having a good management would lead to no delays or cost loss at the workplace and even a desired and specified material would be achieved. Keeping all this in mind one can achieve a triad harmony at workplace and in projects.

8.0 Conclusion

The study based on the information presented and analyzed in the assessment of TRIAD HARMONY (time, cost, and quality management) during retrofitting projects concludes that, to achieve impressive results in construction, all parameters governing the project success

be it time, cost and quality should work together. Some factors which are to be kept in mind during management of time are, better supply chain management, better understanding of scope, recruitment of trained professionals, employees, workers for execution of work, continuous monitoring of schedule that is “tracking” is a crucial factor. In case of cost, since it is one of the governing factors at most care is to be taken during budget allocation, cost management plans, and strategy to develop best model to minimize expense and increase output. Value engineering is one of the most suggested concepts to achieve cost to expense benefit. Finally, when it comes to quality, since material quality and workmanship comes first, one should take care of the material quality by having trained professionals to look after it. Utmost care should be taken in briefing the workers about the scope of work. As per our study, to achieve a Triad harmony it’s essential to have strong communication between all the divisions and a proper system in an organization is to be practiced. Even looking into the fast-moving competitive world with lots of digital tools, incorporating such IT tools would help in better management of projects.

9.0 Recommendations

Through the study carried out in this paper, to achieve integrated management between all parameters for a successful project completion we recommend doing the following:

- Streamlines supply chain management
- Recruit trained and skilled professionals
- Continuous Schedule monitoring
- Allocate budget meticulously to cover all project expenses
- Develop cost management plans
- Adopt value engineering

References

Aghbolaghi, A. H. G. (2023). A quantitative analysis of integrated quality and material management strategies in construction. *International Journal of Engineering Research & Technology (IJERT)*, 12(10), 5.

Alawag, A. M., Alaloul, W. S., Liew, M. S., Al-Aidrous, A. H., Saad, S., & Ammad, S. (2020). Total quality management practices and adoption in construction industry organizations: A review. *Second International Sustainability and Resilience Conference: Technology and Innovation in Building Designs*, 1(1), 6.

Albtoush, A. M. F., Doh, S. I., Abdul Rahman, A. R. B., & Albtoush, J. A. (2020). Factors affecting the cost management in construction projects. *International Journal of Civil Engineering and Technology (IJCIET)*, 11(1), 7.

Asfoor, H. M. A., Al-Jandeel, A. A. T., Igorevich, K. K., & Ivanovna, L. A. (2022). Control of time, cost and quality of construction project management. *E3S Web of Conferences*, 336, 00072. <https://doi.org/10.1051/e3sconf/202233600072>

Comparing time and cost performance of DBB and DB public construction projects in Kuwait. (2023). *Journal of Engineering Research*, 1(1), 11.

Gupta, C., & Kumar, C. (2020). Study of factors causing cost and time overrun in construction projects. *International Journal of Engineering Research & Technology (IJERT)*, 9(10).

Ibironke, O. T., & Akure, N. (2012). Impact of non-implementation of time, cost and quality management procedures in the Nigerian construction industry. *Journal of Building Performance*, 3(1), 7.

Irem, D., Talat, B. M., & Semiha, K. (2005). Strategic use of quality function deployment (QFD) in the construction industry. *Building and Environment*, 40(1), 245–255. <https://doi.org/10.1016/j.buildenv.2004.01.020>

Issa, A., Bdair, R., & Abu-Eisheh, S. (2022). Assessment of compliance to planned cost and time for implemented municipal roads projects in Palestine. *Ain Shams Engineering Journal*, 13(1), 11. <https://doi.org/10.1016/j.asej.2021.06.011>

Li, Y., & Li, M. (2022). PC project cost control analysis based on intelligent construction. *Procedia Computer Science*, 208, 211–215. <https://doi.org/10.1016/j.procs.2022.11.053>

Mansfield, N. R., Ugwu, O. O., & Doran, T. (1994). The causes of delay and cost overruns in Nigerian construction projects. *International Journal of Project Management*, 12(4), 254–260. [https://doi.org/10.1016/0263-7863\(94\)90050-7](https://doi.org/10.1016/0263-7863(94)90050-7)

Mustapha, Z., Akomah, B. B., & Ansah, S. K. (2023). Construction projects success: Time, cost, quality and safety. *International Journal of Research and Innovation in Social Science*, 7(9), 9.

Nguyen, D. T., Le-Haoi, L., Tarigan, P. B., & Tran, D. H. (2022). Trade-off time cost quality in repetitive construction project using fuzzy logic approach and symbiotic organism search algorithm. *Alexandria Engineering Journal*, 61(2), 1589–1608. <https://doi.org/10.1016/j.aej.2021.08.019>

Niazi, G. A., & Painting, N. (2017). Significant factors causing cost overruns in the construction industry in Afghanistan. *Procedia Engineering*, 182, 510–517. <https://doi.org/10.1016/j.proeng.2017.03.145>

Riggs, V. E. S., & Smith, L. S. (1991). *Managing retrofitting projects*. Construction Industry Institute, Department of Civil Engineering, University of Texas at Austin.

Senouci, A., Ismail, A., & Eldin, N. (2016). Time delay and cost overrun in Qatari public construction projects. *Procedia Engineering*, 164, 368–375. <https://doi.org/10.1016/j.proeng.2016.11.632>

Wani, V. R., & Wankhede, P. J. (2022). Time-cost-quality-risk of construction and development projects or investment. *International Journal of Research in Engineering, Science and Management*, 5(5), 5.

Zehro, K., & Jkhsi, S. (2020). Management, quality and economy in home building construction. *International Journal of Advanced Engineering, Sciences and Applications (IJAESA)*, 1(2), 6.

CHAPTER 146

Unravelling the Tapestry of Time Delays in Real Estate Development

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ABSTRACT

Time delays, invariably menace the integrity and prosperity of the project and interests of the stakeholders in the complex sphere of real estate development. This research paper seeks to address the multifaceted complexity of factors and consequences of time delays in real estate projects, with the goal of improving knowledge and creating effective mitigation strategies. This research mainly aims to identify key factors contributing to real-estate project delays, study their impacts on stakeholders and review current project management practices. Using a mixed-methods approach, this research incorporates qualitative and quantitative analyses via literature reviews, case studies, and surveys. Statistical programs and project management systems were used to evaluate the data and extract the information via software's such as NVivo. We assume that external governing risk, such as rules and regulations change or economic disruption, has a large impact on project schedule variables. This research paper is supported by a comprehensive literature study comprising 60 relevant research paper, allowing the analysis and conclusions to stand on a solid ground. As the research progresses, we plan to spend more time investigating solutions to managing risk and conducting negotiations in such a context. This research focuses on providing valuable recommendations that can be applied to real estate projects to mitigate delays and enhance project efficiency. Ultimately, the study aspires to promote sustainable practices in the real estate development sector and add to the corpus of knowledge in this industry.

Keywords: Time delays; Real estate development; Risk management; Project management; Stakeholder impact.

1.0 Introduction

In the competitive world of real estate development, timely completion is not just a matter of ticking off days on a calendar. Time plays a crucial role in determining success or failure of a project. Managing time in real estate projects, whether it be residential, commercial, or infrastructural developments, requires careful attention to detail.

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Delays in these projects not only disrupt schedules but also lead to increased costs, compromised quality, and hindered economic progress. It is essential for stakeholders to grasp the complexities of time delays in real estate projects to overcome challenges and achieve optimal project outcomes. The research delves into the numerous factors that contribute to delays in real estate projects, drawing on insights from a range of studies conducted in various geographical contexts including across India. By synthesizing and analyzing these findings, the paper aims to uncover the underlying causes of time delays in real estate development. It provides a comprehensive viewpoint that covers the challenges, reasons, impacts, and mitigation strategies associated with project delays.

The importance of timely completion in real estate development cannot be emphasized enough. Delays have far-reaching consequences for all stakeholders involved, including investors, developers, contractors, suppliers, and end-users. Therefore, it is crucial to understand the root causes of time delays and implement effective strategies to minimize their impact. This not only enhances project efficiency, sustainability, and profitability but also ensures the smooth functioning of the real estate ecosystem. Various methodologies have been employed to study time delays in real estate development, including questionnaire surveys, interviews, statistical analyses, and Nvivo graphical analysis.

By critically evaluating the strengths and limitations of these methodologies, the paper aims to provide insights into best practices for investigating and mitigating delays in real estate projects. Risk management plays a vital role in addressing delays in real estate projects. By emphasizing the link between risk mitigation and timely project completion, the research underscores the need for proactive risk assessment, allocation, and mitigation strategies. Through a synthesis of studies focusing on risk management practices in real estate projects, the research showcases the importance of effective risk management in preventing delays and enhancing project resilience. This research paper offers a comprehensive understanding of delay analysis in real estate projects, drawing on a diverse range of studies and methodologies. By shedding light on the causes, impacts, and mitigation strategies related to project delays, the paper equips stakeholders in the real estate industry with the knowledge and tools needed to navigate challenges and optimize project outcomes in a constantly evolving environment.

2.0 Research Objectives

This research aims to bridge the gaps by conducting an in-depth on the causes, effects, and mitigation strategies of delay, with much insight into making real estate development efficient and sustainable. The objectives of this research therefore come directly in response to the identified gaps in the literature review and incorporating the research questions; thus, ensuring that a comprehensive understanding as well as an appropriate strategy for minimizing project delays is obtained.

- Examine the effects that delay may cause upon stakeholders, developers, contractors, investors, government agencies, and, lastly, end-users.

- Assess how effective the existing project management, regulatory framework, and risk mitigation measures are in minimizing delays.
- Provide data-derived recommendations and best practices for delay reduction and project efficiency improvement.
- Identify and classify major contributors to delay in real estate projects through the analysis of inner and outer influences.

The problem addressed in the research stems from the persistent and multifaceted issues of project delays in real estate development, particularly within the Indian construction sector. Time overruns are seen as causative factors for increase in costs, contractual disputes, and decline in investor confidence, thus directly threatening the efficiency and sustainability of the entire real estate market. Though delay factors have been studied extensively, the literature lacks a comprehensive predictive framework in real-time, which constitutes an integration of qualitative stakeholder inputs with quantitative analytical models to counteract these ills. Delay in any project is traceable through various interrelated causes from some inefficiencies in project management, bottlenecking of approvals internally, budgetary constraints, and externalities such as economic and environmental disruptions. However, the hierarchical character of the industry, which abounds in fragmented communication and accountability amongst stakeholders, adds insult to that injury. This study intends to provide an answer to these gaps by delving into prominent delay causes, their impact on different stakeholders, and the effectiveness of some current mitigation strategies. The solution it proposes is much informed through an advanced mixed-methodological approach; it combines statistical correlation testing with thematic qualitative assessments, in order to formulate evidence-based recommendations to support project delivery, streamlining regulations, and overall risk management in the real estate sector.

3.0 Methodology

A mixed-methods research paradigm has been established which considers both qualitative and quantitative techniques to research and understand the causal factors and impact associated with delays in real estate development. Using a non-probability sampling method, respondents were conveniently selected from the industry, with a sample size of 86 professionals such as developers, project managers, contractors, and regulatory officials, with the expectation of having a rich and insightful dataset. Furthermore, 29 senior real estate professionals are interviewed to supply firsthand information on experience in declaratory system inefficiencies and regulatory constraints on project timelines.

Collection of data focuses on detailed surveys and expert interviews. In statistics, Pearson correlational coefficients would be used to provide the basis for descriptive definitions and regression analyzes to study the relationships of various delay factors to their impact. In qualitative part, Nvivo software solution would engage in thematic analysis to systematically code textual data to find patterns and repetitive aspects within data. This advanced analytical

framework allows for a deeper exploration of stakeholder viewpoints, facilitating the identification of inefficiencies within project execution and regulatory processes. This process, however, guarantees holistic integrated data-driven evaluation of delays in real estate projects while filling the existing knowledge gaps and offering practical interventions to reduce the inefficiency levels of project regulation as well as advanced project management practices.

4.0 Literature Review

The project management and planning has been one of the major factors that contribute to delays in construction projects especially in developing countries that suffer from indecision, labor shortages, and financial constraints. The results of (Placeholder2)various research studies confirm the fact that there is need for structured project planning methodology and proactive execution strategies to mitigate these problems. More so, it also necessitates a shift to modern statistical methodologies; the broader reliance on the traditional ones, ANOVA, regression analysis, and that of the Relative Importance Index (RII), constrain the predictions into a relatively limited accuracy. Future studies should consider simulating methods, including Monte Carlo analysis and Bayesian networks, for better results in forecasting delays.

Another central theme emerging in the agenda for research on construction delays remained risk management and financial constraints. Research often brings to light how all these factors adversely affect a construction project through delayed payments, budget overruns, or poor financial planning. These should be addressed through dynamic financial planning models that open up possibilities for better control of expenditures, risk assessment, and financial sustainability throughout the life cycle of a project. Similarly, the more advanced the construction becomes in the overall agenda of sustainability, the more relevant it becomes to have further mitigation tailored specifically against delays that are compounded by additional regulatory requirements and a poorer pool of qualified consultants experienced in navigating through the specifics of methodology in sustainable construction developments.

By far, external disruptions like that caused by a pandemic or the external event of an economic fluctuation do not cease to exist as challenges to the construction industry. The impact of COVID-19 pandemic brought about massive extinction in world supply chains and supply of labor, and indeed views the need for adaptive project management frames for real-time risk assessment and contingency planning. There is a strong need for future research to be focused on proactive risk management models that can counter the effects of external shocks for unforeseen incidents on construction timelines. Legal or contractual inefficiencies continue to block construction projects and completion; often, the regulatory bottlenecks and mechanisms for dispute resolution contribute to significant delays. There is increased need for rigorous research to come up with standardized contract clauses, improved arbitration and facilitative legal frameworks for project execution. Standardizing contract terms would result in predictability, efficiency and reduction in time and cost overruns at the conception stage.

Digital transformation clearly needs to come into project management nowadays, and so many studies are beginning to emphasize this need with digital tools such as AI-driven project analytics, BIM, and real-time monitoring facilities. Unfortunately, only a handful of such academic works present empirical evidence of such technologies operating in the real world. In future research, more emphasis must be laid on documenting case studies whereby innovations have proved more efficient in conducting a project, and reduction in time delays since such will hence forward provide a sound basis for evidence in terms of technology application for construction management.

5.0 Data Analysis

The 3 parameters as per the data analysis (Operational and site-specific attributes, External and regulatory environment, Technological integration and innovation) together explain approximately 78% of the variances among the nine original variables. Such an insight therefore provides a solid base for tackling the time lag's antagonistic nature in real estate development. The analysis here gives clarity to a consideration of the underlying relationships existing among critical project dimensions, thus translating into a matrix of actionable intelligence for mitigating delays. A high correlation (≥ 0.50) typically indicates that the two categories measure closely related constructs or that respondents' perceptions on one category strongly co-vary with the other. However, the moderate correlation (~ 0.30 - 0.50) signifies some relationship but not that strong, while low or near-zero correlation (< 0.30) would denote the categories are relatively independent in minds of respondents. If two categories (e.g., Contributors and stakeholders) are strongly correlated, it implies that interventions addressing the root causes of delays may also lessen the negative impacts on the project stakeholders.

6.0 Conclusion

The importance of actual digital integration thanks to BIM and AI-based analysis for real-time tracking, dynamic scheduling, and anticipatory risk management is highlighted in the study. Specific layouts of the data into integrated dashboards will provide the developers and managers with leverage to make important decisions to reduce uncertainties and avoid delays. Collaboration among stakeholders needs to be improved since misalignment of interests and poor communication among developers, contractors, investors, regulators, and end-users are major causes of delays. Setting up standard protocols for communication, collaborative platforms, and cross-sector forums will help bring about transparency and alignment across the project lifecycle. To discourage bureaucratic bottlenecks, regulatory reforms should be put forward in digitizing approvals and creating an efficient framework for project execution. The study underlines a radical change in outdated permitting procedures to promote the timely completion of a project. Capacity building is also of great importance, which will involve full-

scale training programs and academia-industry partnerships to empower project managers, technical staff, and relevant personnel in contemporary tools, project management methodologies, and proactive risk mitigation strategies.

Continuous improvement, by its nature, requires the institutionalization of benchmarking, iterative feedback loops, and performance assessments to inform the fine-tuning of predictive models and enhance management practices. Based on a comprehensive desk review, surveys, and interviews with 115 real estate professionals, the findings of the study establish delays in projects as being attributable to internal inefficiencies (poor planning, frequent design changes, resource shortages) and external factors (regulatory delays, supply chain disruptions). Statistical analyses in the form of multiple regression models lead to the identification of important predictors such as regulatory approvals and material procurement for project delays and show their combined impact in extending project timelines. Exploratory and confirmatory factor analysis further validate that the internal inefficiencies and external challenges interact and reinforce the requirement of an integrated, data-driven framework to effectively mitigate delays.

References

- Arya, A., & Kansal, R. (2016). Analysing delays of construction projects in India: Causes and effects. *International Journal of Science Technology & Engineering*, 3(6).
- Chen, L., Wang, B., & Cao, N. (2013). Study of real estate financing risk and prevention under macro-control policies. In *ICCREM 2013: Construction and Operation in the Context of Sustainability* (pp. 670–679). American Society of Civil Engineers. <https://doi.org/10.1061/9780784413029.067>
- Choudhary, P., & Sahu, V. (2018). Analysis of delays in real estate projects in Delhi/NCR. *International Journal of Management, Technology, and Engineering*, 8(12), 1430–1431.
- Deep, S., Asim, M., Kesarwani, N., & Kandpal, S. (2018). Identification of delay causing actor in the Indian real estate project: An AHP-based approach. *Baltic Journal of Real Estate Economics and Construction Management*. <https://doi.org/10.2478/bjreecm-2018-0009>
- Del Caño, A., & De la Cruz, M. P. (2002). Integrated methodology for project risk management. *Journal of Construction Engineering and Management*, 128(6), 473–485. <https://doi.org/10.1061/~ASCE!0733-9364~2002!128:6~473>
- Desai, M., & Bhatt, R. (2013). A methodology for ranking of causes of delay for residential construction projects in Indian context. *International Journal of Emerging Technology and Advanced Engineering*.

Doloi, H., Sawhney, A., Iyer, K. C., & Rentala, S. (2012). Analysing factors affecting delays in Indian construction projects. *International Journal of Project Management*, 30(4), 479–489. <https://doi.org/10.1016/j.ijproman.2011.10.004>

Durdyev, S., Omarov, M., & Ismail, S. (n.d.).

Huffman, F. E. (2003). Corporate real estate risk management and assessment. *Journal of Corporate Real Estate*, 5(1), 31–41. <https://doi.org/10.1108/14630010310812064>

Jian, S., Jing, Y., & Sun, Y. (2014). Risk management of real estate's development and construction projects. In *International Conference on Mechatronics, Electronic, Industrial and Control Engineering (MEIC 2014)* (pp. 1443–1444). Atlantis Press.

Koirala, M. P. (2014). Risks in housing and real estate construction projects. *Journal of the Institute of Engineering*, 10(1), 34–44. <https://doi.org/10.3126/jie.v10i1.10876>

Malek, M. S., Mohibali, S. F., & Bachwani, D. (2021). Identification, evaluation, and allotment of critical risk factors (CRFs) in real estate projects: India as a case study. *Journal of Project Management*, 6(1), 83–92. <https://doi.org/10.5267/j.jpm.2021.1.002>

Martinez-Pastor, B., Nogal, M., O'Connor, A., & Teixeira, R. (2022). Identifying critical and vulnerable links: A new approach using the Fisher information matrix. *International Journal of Critical Infrastructure Protection*, 39, Article 100570. <https://doi.org/10.1016/j.ijcip.2022.100570>

Prasad, K. V., Vasugi, V., Venkatesan, R., & Bhat, N. (2019). Analysis of causes of delay in Indian construction projects and mitigation measures. *Journal of Financial Management of Property and Construction*. <https://doi.org/10.1108/JFMPC-04-2018-0020>

Senouci, A., Ismail, A., & Eldin, N. (2016). Time delay and cost overrun in Qatari public construction projects. *Procedia Engineering*, 164, 368–375. <https://doi.org/10.1016/j.proeng.2016.11.632>

Shubham, J. V., & Kshirsagar, S. B. (2020). Review paper of factors affecting cost overrun in real estate industry in India. *International Research Journal of Modernization in Engineering Technology and Science*, 2(4), 1238–1240.

Uchegara, I., Hamma-Adama, M., Obiri, K. A., Jafarifar, N., & Moore, D. (2020). Construction industry response to COVID-19 pandemic: Impact assessment and mitigation strategies. *Malaysian Journal of Sustainable Environment Studies*, 14(S1), 41–53.

Voetsch, R. J., Cioffi, D. F., & Anbari, F. T. (n.d.). Project risk management practices and their association with reported project success. Retrieved from <https://www.researchgate.net/publication/257423494>

Wilfred, A., & Sharafudeen, M. (2015). A methodology to identify the delays and rank its causative factors in Indian construction industry. *International Research Journal of Engineering and Technology (IRJET)*, 2(3).

Zarei, B., Sharifi, H., & Chaghooee, Y. (n.d.). Delay causes analysis in complex construction projects: A semantic network analysis approach. *University of Tehran*.

CHAPTER 147

Use of Silica Fume in Pervious Concrete for Pavement Construction

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ABSTRACT

The growing urbanization and population of India have resulted in major water management issues, such as stormwater runoff and groundwater depletion. Pervious concrete with silica fume provides a sustainable option by enhancing permeability, minimizing waterlogging, and facilitating groundwater recharge. The current research investigates the influence of silica fume on the strength, durability, and permeability of pervious concrete for pavement purposes. Experimental investigation involves changing the cement-to-aggregate ratio, aggregate gradations, and silica fume replacement percentages to identify an optimal mix for improved mechanical performance. The results show that addition of silica fume improves compressive strength and minimizes clogging tendency without sacrificing high permeability. Findings support sustainable urban infrastructure by promoting pervious concrete as an environmentally friendly alternative to traditional pavements in conjunction with environmental conservation initiatives.

Keywords: Silica fume; Permeability; Sustainable pavements; Stormwater management; Pervious concrete.

1.0 Introduction

The high rate of urbanization and population growth in Indian cities has worsen water scarcity and flooding due to impermeable surfaces like roads and rooftops. Pervious concrete emerges as a viable solution, allowing water infiltration to recharge groundwater and mitigate stormwater runoff. Its cost-effectiveness in India, owing to lower labor costs, makes it a practical alternative for sustainable urban development. However, challenges such as clogging from dust accumulation must be addressed through routine maintenance. By integrating pervious concrete in pavements, parking lots, and green infrastructure, cities can enhance environmental resilience, reduce urban heat island effects, and improve overall water management. This research aims to investigate the impact of silica fume on pervious concrete, particularly its strength, durability, and permeability for sustainable pavements. Experiments will evaluate different cement-to-aggregate ratios and aggregate sizes to determine the optimal mix for maximum efficiency.

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A comparative analysis with conventional concrete will assess its environmental and structural benefits. By focusing on density, porosity, and drainage properties, this study contributes to eco-friendly urban infrastructure, aligning with India's sustainability goals. The research investigated the contribution of silica fume to the improvement of pervious concrete properties, especially for pavements, through its effect on strength, durability, and longevity using compressive strength tests. It tested water absorption and drainage capacity to determine its efficiency in groundwater recharge and stormwater management. Moreover, the study determined the best mix of cement, aggregate, and silica fume in order to ensure a strong and effective pavement system. Lastly, the research contrasted pervious concrete with common concrete in regards to durability, strength, and environmental sustainability to emphasize its merits and demerits.

2.0 Literature Reviews

Durability is a key concern for pervious concrete, particularly in harsh environmental conditions. Freeze-thaw resistance is improved by silica fume, polypropylene fibers, and latex-modified cementitious materials, which reduce micro-cracking and water absorption (Ho *et al.*, 2015; Schaefer *et al.*, 2006). Air-entrained pervious concrete exhibits up to 50% less surface scaling and higher freeze-thaw cycle resistance (Kevern *et al.*, 2010). Abrasion resistance is enhanced by using angular aggregates, surface treatments, and polymer coatings, while chemical resistance is improved by silica fume, fly ash, and sealers (Tabet Kheira *et al.*, 2022; Siddique & Iqbal Khan, 2011; Tang *et al.*, 2022). Skid resistance is another important property of pervious concrete, particularly for road safety. Its porous structure reduces surface water accumulation and hydroplaning risk, providing better skid resistance than traditional concrete and asphalt (Chopra *et al.*, 2010; Tabet Kheira *et al.*, 2022).

Angular aggregates like crushed granite or basalt offer superior friction, while smoother aggregates like river gravel deteriorate over time (Ajamu *et al.*, 2012). Maintenance strategies such as vacuum sweeping and pressure washing are essential to prevent clogging and maintain skid resistance, especially in cold climates where freeze-thaw cycles can degrade surface texture (Obla, 2010; Ho *et al.*, 2015). Hydraulic properties, including permeability, porosity, and void interconnectivity, are central to pervious concrete's effectiveness in stormwater management. Permeability values range from 36 to 864 inches per hour, depending on mix design and compaction methods (ACI Committee 522, 2006). Higher porosity improves water infiltration but may reduce mechanical strength, a trade-off addressed by incorporating silica fume and fibers (Vinoth *et al.*, 2021; Liu *et al.*, 2022). Well-graded aggregates and proper void distribution enhance hydraulic efficiency and durability, while clogging resistance is maintained through periodic maintenance (Marzulli *et al.*, 2018; Ho *et al.*, 2015).

Pervious concrete's drainage properties make it an eco-friendly solution for stormwater management, reducing waterlogging and peak runoff volumes. Its porosity (15%–35%) allows

rapid water infiltration, with drainage rates ranging from 36 to 864 inches per hour (ACI Committee 522, 2006; Marzulli *et al.*, 2018). Well-graded aggregates and optimized mix designs balance permeability and structural integrity, supporting sustainable urban drainage solutions (SUDS) and groundwater recharge (Chopra *et al.*, 2010; Ghosh, 2015). Cost-effectiveness is another advantage of pervious concrete. Although initial installation costs may be higher, long-term savings from reduced stormwater infrastructure, lower maintenance, and energy savings from urban heat island mitigation make it a viable investment (Obla, 2010; Ghosh, 2015). In regions with lower labor costs, such as India, pervious concrete is particularly economical due to its reliance on manual labor rather than heavy machinery.

Environmental benefits of pervious concrete include improved water quality, reduced carbon emissions, and support for sustainable urban development. Its permeable structure filters pollutants, reduces surface runoff, and recharges groundwater, addressing water scarcity in urban areas (Chopra *et al.*, 2010; Obla, 2010). The use of recycled aggregates, fly ash, slag, and silica fume further enhances its sustainability by reducing cement consumption and carbon emissions (Ajamu *et al.*, 2012; Aoki, 2009).

Additionally, pervious concrete mitigates urban heat island effects by lowering surface temperatures, contributing to cooler urban environments (Ganpule & Pataskar, 2011). Pervious concrete offers a sustainable, cost-effective, and environmentally friendly alternative to conventional concrete, with applications in stormwater management, urban infrastructure, and climate change mitigation. However, its performance depends on careful mix design, material selection, and maintenance to balance mechanical strength, permeability, and durability.

3.0 Methodology

The study adopts an experimental design to evaluate the effect of silica fume and coarse aggregate ratio on the compressive strength and permeability of pervious concrete. It follows a systematic approach, starting with a literature review to understand the fundamental properties of pervious concrete and the role of supplementary materials like silica fume. The research progresses through material selection, mix design, and sample preparation, ensuring consistency and reliability. Different cement-to-aggregate ratios, aggregate sizes, and silica fume replacement levels (ranging from 0% to 20%) are considered to determine their impact on concrete performance.

The experimental phase involves testing the prepared samples for compressive strength at 7 and 28 days, along with porosity and permeability assessments to evaluate water infiltration capacity. Data analysis identifies the optimal mix balancing strength and permeability for practical pavement applications. Findings highlight the significance of material proportions, with conclusions addressing real-world applicability and recommendations for further research to enhance pervious concrete efficiency.

4.0 Test Results and Analysis

After referring to various literature, the mix proportions for pervious concrete is normally taken in 1:4, 1:5, 1:6, cement: Aggregate ratio. Hence, the best compressive strength from these mixes is to be obtained.

4.1 Result of compressive strength test

This table gives the results of compressive strength of pervious concrete in terms of 1:4 cement-to-aggregate ratio for curing of 7 and 28 days. The mean compressive strength at 7 days is 8.12 N/mm², while at 28 days it is 16.35 N/mm². This shows that the concrete gets stronger with the passage of time and its maximum at 28 days.

**Table 1 Compressive Strength Test Results for Cement:
Aggregate Proportion 1:4 with aggregate Size of 4.75- 20mm**

Sr. No	c/s Area (mm ²)	Failure Load of 7 days (KN)	CS of 7 days (N/mm ²)	Avg. CS of 7 days (N/mm ²)	Failure Load of 28 days (KN)	CS 28 of days (N/mm ²)	Avg. CS of 28 days (N/mm ²)
1.	150x150	186	8.26	8.12	363	16.13	16.35
2.	150x150	228	10.12		372	16.53	
3.	150x150	161	7.15		369	16.40	

With the 1:5 cement-aggregate mix, the strength is much weaker than the mix with a 1:4 ratio. Average strength at 7 days is 5.763 N/mm², while at 28 days it is 9.83 N/mm². This is an assurance that decreasing the amount of cement in the mixture makes the concrete weaker, yielding lower overall strength.

**Table 2 Compressive Strength test Result for Cement:
Aggregate Proportion 1:5 with Aggregate size of 4.75- 20mm**

Sr. No	c/s Area (mm ²)	Failure Load of 7 days (KN)	CS of 7 days (N/mm ²)	Avg. CS of 7 days (N/mm ²)	Failure Load of 28 days (KN)	CS of 28 days (N/mm ²)	Avg. CS of 28 days (N/mm ²)
1.	150x150	121	5.378	5.763	197	8.75	9.83
2.	150x150	124	5.511		218	9.68	
3.	150x150	144	6.400		249	11.06	

For a 1:6 ratio of cement to aggregate, the concrete is weakest in terms of compressive strength. At 7 days, the average strength is 4.788 N/mm², and at 28 days, it is just 7.52 N/mm². This is the weakest of the three ratios tested, further verifying that the greater proportion of aggregate weakens the mix

**Table 3 Compressive Strength Test Results for Cement:
Aggregate Proportion 1:6 with Aggregate Size of 4.75- 20mm**

Sr. No	c/s Area (mm ²)	Failure Load of 7 days (KN)	CS of 7 days (N/mm ²)	Avg. CS of 7 days (N/mm ²)	Failure Load of 28 days (KN)	CS of 28 days (N/mm ²)	Avg. CS of 28 days (N/mm ²)
1.	150x150	114	5.067	4.788	171	7.60	7.52
2.	150x150	89	3.954		139	6.17	
3.	150x150	120	5.333		198	8.80	

This table gives the compressive strength results of all three mix ratios. The 1:4 ratio gives the maximum strength (16.35 N/mm² at 28 days), then 1:5 (9.83 N/mm²) and 1:6 (7.52 N/mm²). Also, the density is quite similar for all three mixes, meaning that the variation in strength is mostly due to cement content and not due to density variations.

Table 4 Overall Compressive Strength & Density Test Results for Varying Proportion of Cement: Aggregate 1:4, 1:5, 1:6 with Aggregate Size of 4.75 – 20 mm

Sr. No	Proportion Cement: Aggregate	Avg. Density (Kg/m ³)	Avg. CS of 7 days (N/mm ²)	Avg. CS of 28 days (N/mm ²)
1.	1:4	2100	8.120	16.35
2.	1:5	2106	5.763	9.83
3.	1:6	2027	4.788	7.52

5.0 Conclusion

This research illustrates the performance effectiveness of pervious concrete reinforced with silica fume in enhancing the performance of pavement, especially its strength, durability, and permeability. From the experimental analysis, it is evident that silica fume inclusion increases compressive strength without losing high permeability, making the material a best choice for groundwater recharge and stormwater management. The research shows that an even cement-to-aggregate ratio and optimized use of silica fume replacement make a major contribution to the pervious concrete's mechanical performance and long-term sustainability.

Furthermore, its capacity to minimize urban flooding, reduce the urban heat island effect, and decrease carbon emissions is in accordance with sustainable building practices. Despite its advantages, limitations such as clogging and maintenance implications must be addressed to promote extended efficiency. Large-scale field implementation, long-term durability testing, and creative maintenance practices should be emphasized in future research to leverage the full capability of pervious concrete in urban infrastructure.

References

ACI Committee 522. (2006). *Report on pervious concrete (ACI 522R-06)*. American Concrete Institute.

Ajamu, S. O. (2012). A study of unit weight and compressive strength relationships in pervious concrete. *International Journal of Civil Engineering*, 9(2), 112–118.

Ajamu, S. O., Jimoh, A. A., & Oluremi, J. R. (2012, May). Evaluation of structural performance of pervious concrete in construction. *International Journal of Engineering and Technology*, 2(5), 1–5.

Alaica, A. L., & Dolatabadi, M. H. (2010). Importance of material selection and mix design in pervious concrete applications. *Construction Science and Technology*, 24(2), 67–79.

Alaica, A., Dolatabadi, M. H., Sucic, A., & Shehata, M. (2010). Optimizing the strength and permeability of pervious concrete. In *Permeable Pavement Design and Technology Session, 2010 Annual Conference of the Transportation Association of Canada*, Halifax, NS, Canada.

Aoki, Y. (2009). *Development of pervious concrete* (Master's thesis). University of Technology Sydney, Faculty of Engineering and Information Technology.

Chopra, M., & Wanielista, M. M. (2010). Drainage characteristics of pervious concrete pavements. *Journal of Hydrology*, 392(3–4), 148–156.

Chopra, M., Kakuturu, S., Ballock, C., Spence, S., & Wanielista, M. M. (2010). Effect of rejuvenation methods on the infiltration rates of pervious concrete pavements. *Journal of ASCE*, 15(6), 426–433.

Delatte, N., & Schwartz, S. (2010). Sustainability benefits of pervious concrete pavement. In *Proceedings of the 2nd International Conference on Sustainable Construction Materials and Technologies*, University of Wisconsin Milwaukee, 1–9.

Deo, O., Sumanasooriya, M., & Neithalath, N. (2010). Permeability reduction in pervious concrete due to clogging. *Journal of ASCE*, 22(7), 741–751.

Gafoori, N., & Dutta, S. (1995). Laboratory investigation of compacted no-fine concrete for paving materials. *Journal of Materials in Civil Engineering*, 7(3), 183–191.

Ganpule, S. S., & Pataskar, S. V. (2011, October). Use of porous concrete as a green construction material for pavement. *International Journal of Earth Sciences and Engineering*, 4(6), 764–767.

Ghosh, K. (2015). Environmental impact of pervious concrete: Stormwater management benefits. *Environmental Engineering and Management Journal*, 14(3), 523–534.

Hamdy, M. (n.d.). Study on mechanical and durability properties of pervious concrete. *Construction and Building Materials Journal*.

Harber, P. J. (2005). *Application of no-fines concrete as a road pavement* (Report). University of Southern Queensland.

Ho, A., Liu, Y., & Zhang, C. (2015). Improving freeze-thaw resistance of pervious concrete with silica fume and fibers. *Cold Regions Science and Technology*, 120, 73–81.

Holland, T. C. (2005, April). *User manual of silica fume*. U.S. Department of Transportation and Federal Highway Administration, 7–10.

Joung, Y., & Grasley, Z. C. (2008). *Evaluation and optimization of durable pervious concrete for use in urban areas* (Research Report SWUTC), 1–117.

Kevern, J. T., Wang, K., & Schaefer, V. R. (2010). Effect of coarse aggregate on the freeze-thaw durability of pervious concrete. *Journal of ASCE*, 22(5), 469–475.

Kheira, T., & Vinoth, S. (2022). Effect of partial cement replacement on abrasion resistance in pervious concrete. *Construction and Building Materials*, 287, 123094.

Liu, Y., Tang, C., & Zhang, J. (2022). Enhancement of pervious concrete strength using silica fume and fibers. *Cement and Concrete Research*, 98, 234–245.

Liu, Y., Wang, H., & Tang, C. (2018). Analysis of drying shrinkage in pervious concrete. *Journal of Advanced Concrete Technology*, 16(4), 243–251.

Marzulli, F., & Zhang, J. (2018). Influence of void size distribution on permeability in pervious concrete. *Journal of Building Engineering*, 21, 215–223.

Obla, K. (2010, August). Pervious concrete – An overview. *Indian Concrete Journal*, 84(8), 17–18.

Panjehpour, M. (2011). A review for characterization of silica fumes and its effect on concrete properties. *International Journal of Sustainable Construction Engineering and Technology*, 2(6), 2–6.

Prakash, R., & Suresh, P. (2018). Aggregate selection and sealant application for improving abrasion resistance in pervious concrete. *Cement and Concrete Composites*, 85, 113–121.

Punmia, B. C. (2005). *Soil Mechanics & Foundations* (16th ed.), 186–200.

Schaefer, V. R., Wang, K., Suleiman, M. T., & Kevern, J. T. (2006, February). *Mix design development for pervious concrete in cold weather climates*. Transportation Research and Education, Iowa State University, 40–41.

CHAPTER 148

Using IoT for Health & Safety Management in Construction Site

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ABSTRACT

The use of IoT technology for construction site health and safety management is examined in this paper. The study highlights the main issues with traditional safety monitoring, including the inability to manage manual safety records, the absence of real-time monitoring, and the restricted ability to track worker compliance. The efficiency of current safety training was evaluated by a survey that identified workers' knowledge gaps as well as their strengths. These observations led to the proposal of an Internet of Things (IoT)-based safety monitoring system that uses sensors, RFID readers, and a central data gateway to improve real-time safety compliance tracking. The suggested system has several benefits such as Real-Time Monitoring; Data-Driven Decision-Making; Cost-Effectiveness; and Smooth Integration. Even though the system is still in the design stage, preliminary cost comparisons show considerable savings, and work is being done to find funds for deployment. This research aims to provide evidence to justify that Adoption of IoT in construction safety improves emergency response, real-time monitoring, and hazard detection, guaranteeing a safer working environment. Productivity, sustainability, and industry transformation are further enhanced by efficient human resource management and digital integration.

Keywords: IoT in construction safety; Real-time data monitoring; Hazard detection; Safety compliance; RFID sensors; Data-driven decision-making; Human resource management.

1.0 Introduction

1.1 Background

Despite being a major driver of economic growth, the construction industry confronts several obstacles, including low efficiency, a slow adoption of digital technology, and a reliance on reactive safety measures, which frequently results in accidents. With real-time monitoring, hazard detection, and enhanced compliance tracking, IoT integration provides a proactive solution. An IoT-enabled flexible safety solution improves risk reduction, certification verification, and employee training.

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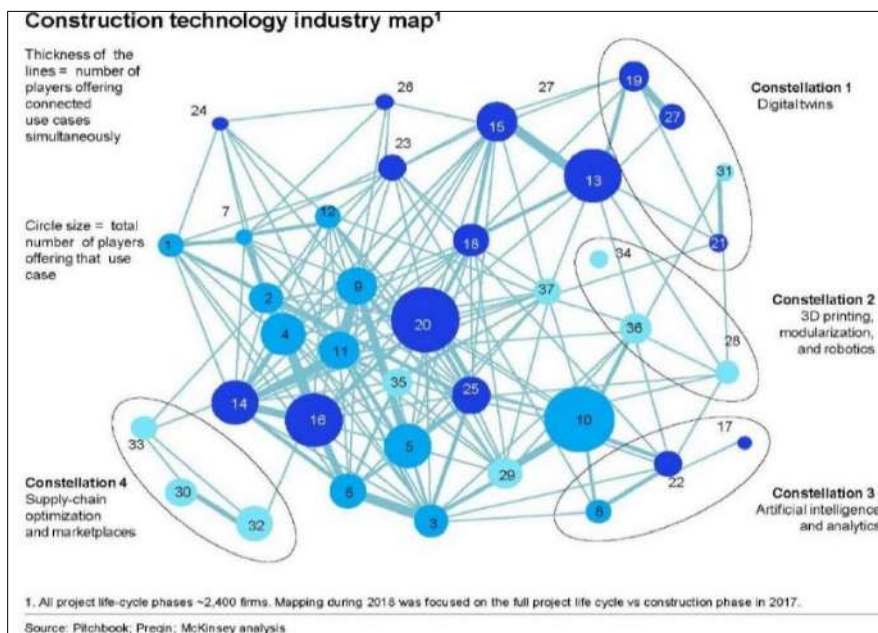
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Post-transition, efficient HR administration guarantees improved scheduling, communication, and employee retention. Adoption of IoT promotes sustainability, cost-effectiveness, and data-driven decision-making in addition to safety, which helps to revolutionise the sector over the long run.

1.2 Scope

This study examines how IoT affects construction health and safety, focussing on antiquated manual processes that raise the risk of accidents. Real-time monitoring, hazard detection, and proactive risk management are made possible by IoT technologies. IoT's promise to lower accidents, boost productivity, and fortify safety culture is analysed alongside obstacles like infrastructure, data privacy, and budgetary limitations. The study creates an interface that combines computer vision, automated safety training, real-time monitoring, and predictive analytics. Proactive, data-driven safety management may revolutionise construction by utilising AI, machine learning, and cloud computing, which will meet the digitalisation requirements of Industry 4.0.

Figure 1: Construction Industry Map



1.3 Research objectives

- To identify ways to improve health and safety management on the construction site using IoT.

- To explore the comparative advantage of IoT over the traditional method in improving health and safety management.
- To recommend best strategies for implementing IoT in health and safety management in construction projects.

2.0 Research Methodology

This research probes into the feasibility study on implementation of IOT application in construction site for health and safety management of workers through a survey-based approach and analyse the response using statistical tools.

2.1 Identification of IoT practices in construction

A literature review analysed academic research on IoT applications for safety and health management in construction. Relevant digitalization practices were extracted and documented.

2.2 Questionnaire survey

The survey was conducted among 84 construction professionals and students, ensuring diverse perspectives. Responses were collected and analysed.

2.3 Pilot interview

Five Interviews were conducted at different construction sites for better understanding in digital safety management.

2.4 IBM SPSS analysis

Data was statistically analysed using IBM SPSS, applying:

- Relative Importance Index
- Reliability analysis (Cronbach's alpha)
- Descriptive statistics (Mean, Standard Deviation, Range)
- One sample T Test

Table 1: Respondent Details

Sr. No.	Description Experience (in years)	Number of Respondents
1	1-5	60
2	6-10	14
3	Above 10	10

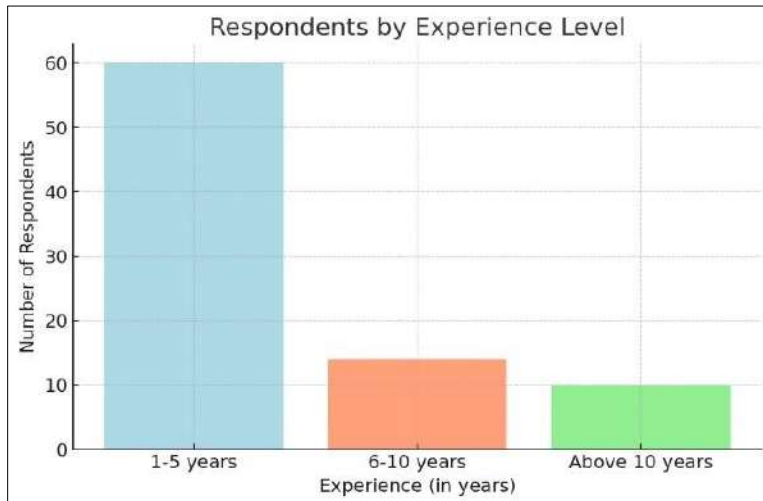
2.5 Descriptive statistical analysis

Responses were screened for completeness. Frequency distributions, factor averages, and graphical representations of agreement percentages were generated.

3.0 Data Analysis

Following figures show the respondents as per their current designations and years of experience in their respective fields. The respondents chosen are with different portfolios and responsibility in the construction sector.

Figure 2: Respondent Details: Distribution of Respondents by Experience Level



Section 1: Safety Management - Traditional method

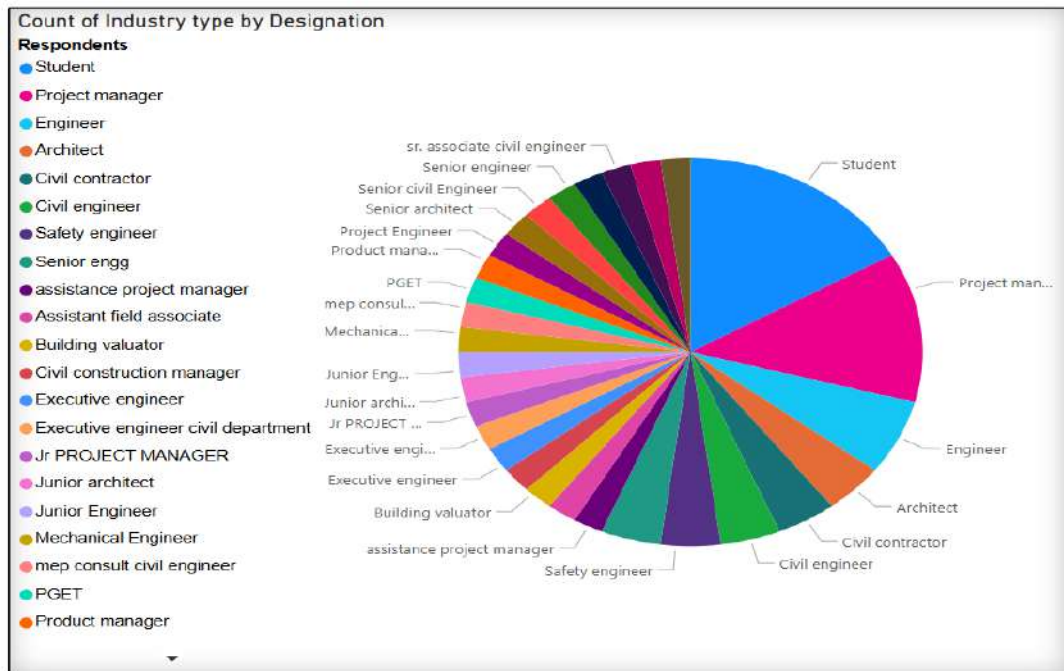
Very less frequency of safety training sessions is conducted on site leading to an increase in risk of accidents. Poor safety audits are conducted on sites. Reporting safety incidents is quite often ignored by the organization management. Manual records are hard to handle and maintain on site. This shows that there needs to be an improvement on safety monitoring on site by technology implemented solution.

Section 2: Using IoT in Safety Management

Majority of respondents agreed safety monitoring and management is efficient when it is digitalized compared to manual work of safety engineers or supervisors on site. Wearable safety IoT devices have good agreeableness to monitor workers safety, health and movement on site. IoT based warning systems can reduce the rate of accidents on site. IoT based decision making has a faster way of making decisions compared to manual making. The results show there is strong support towards implication of IoT on construction site.

Section 3: Challenges & Recommendations of using IoT in Construction Safety

High initial costs. Required government funding and subsidiary schemes. Resistance from workers to adapt. Require efficient training. Technological knowledge drawback with regards to labourers

Figure 3: Respondent Details: Count of Industry Type by Designation**Table 2: Construction Project Details**

	Location	Type of project	Scale of project	Designation of the personnel	Experience
Site 1	Thane, Mumbai	Residential	Large	Senior Engineer	5 years
Site 2	Baner, Pune	Residential	Medium	Senior Engineer	7 years
Site 3	Baner, Pune	Residential & Commercial	Medium	Safety Engineer	5 Years
Site 4	Mahalunge Phase 2, Pune	Residential & Commercial	Large	Safety engineer	7 years
Site 5	Moshi, Pune	Residential	Medium	General Manager	12 years

3.1 Details of pilot interview participants

Summary of responses from construction site:

- Due to high initial cost with respect to project cost.
- In small and medium-sized private projects, there is no special personnel regarding safety, i.e. a Safety engineer.
- Lack of technical knowledge about usage of IoT devices.
- The Traditional practices itself are not being taken seriously i.e. there is no SOP regarding Safety.

- The shoes, helmets and other safety utilities are being misplaced every day, using expensive IoT devices will be a headache for the client and contractor.
- The safety engineer itself is not trained in using the IoT devices, which makes it difficult to handle and maintain the IoT devices on site.
- Labors are hesitant to use the devices because there is no direct Benefit to them.

Table 3: RII Table

No.	Questions	Mean
1	Using IOT tools like Wearable Safety Devices, Smart Barrier Systems, etc. can help to track each labourer's activity on site	4.62
2	A safety induction program is mandated for labourers.	4.60
3	Cameras and IOT sensors can be placed around construction sites to detect unsafe conditions.	4.57
4	Warning and alarm systems for any hazardous and unsafe conditions can be implemented on-site using IoT.	4.57
5	More training programs should be conducted to educate management employees and workers about IoT integrated safety systems.	4.54
6	IoT safety devices could be designed more user-friendly for construction workers.	4.52
7	Government and industry stakeholders support is required for IoT implementation.	4.49
8	Lack of technical knowledge among workers is a major barrier to implementing IoT.	4.45
9	IOT can become a modern construction safety strategy 4.40	4.40
10	The work of a safety assistant or safety manager on site will become easier by using IOT applications to automate the manual tasks.	4.39
11	Decision-making on any unsafe/ hazardous conditions will become easier using IOT.	4.37
12	IOT can be used in optimizing labour efficiency.	4.25
13	High initial costs make IoT adoption in construction safety difficult.	4.25
14	Small and medium-sized construction firms find IoT implementation financially unfeasible.	4.21
15	Manual safety audit records are not easy to handle and store on site.	4.19
16	Tracking all the labourers will make it easier to ensure the safety of each labourer on site.	4.18
17	Training sessions on safety procedures are infrequent on the construction site.	3.87
18	Integrating IoT with existing construction safety processes is complex	3.70
19	There is resistance from workers and management in adopting IoT-based safety solutions.	3.69
20	. Safety training does not reflect current best practices and regulations.	3.65
21	Management often ignores reported safety incidents.	3.36
22	Safety Audits do not happen regularly on the construction site.	3.30
23	The death of labourers can be reduced using traditional safety management methods.	2.54
24	. Traditional methods of safety management are the best ways to decrease unsafe conditions on construction sites.	2.37

3.3 Relative importance index

A statistical tool called the Relative Importance Index Table is used to rank various elements according to their significance. It is frequently used in research projects, particularly in project prioritizing, safety evaluation, and construction management.

- *High Important factors*: RII close to 5.0: According to the responders, structured safety programs and Internet of Things solutions are essential for improving building site safety.
- *Moderate Important factors*: RII between 3.5 – 4.5: Despite its perceived benefits, IoT adoption is slowed by obstacles like cost, complexity, and stakeholder reluctance.
- *Less important factors*: RII below 3.5: According to the respondents, IoT-based solutions are more effective than conventional safety management techniques.
- Uses of RII:
 - Setting priorities aids in determining the most crucial elements influencing a particular field (e.g., safety, project hazards).
 - Decision-making by prioritizing factors.
 - Assists in identifying areas that require immediate attention.
 - The RII chart emphasizes how important IoT technology is for enhancing construction safety.
 - Cost, reluctance to adapt, and complexity are major obstacles.
 - Relying solely on conventional safety management techniques is the last strategy.

3.4 Reliability analysis

From the software of IBM – SPSS, a reliability analysis test was conducted for the questionnaire survey done and the alpha value found is 0.76 which is considered good.

Table 4: Case Processing Summary

		N	%
Cases	Valid	84	100.0
	Excluded	0	.0
	Total	84	100.0

Table 5: Reliability Statistics

Cronbach's Alpha	N of Items
.760	19

From the software of IBM – SPSS, a reliability analysis test was conducted for the questionnaire survey done and the alpha value found is 0.76 which is considered good. The supposed alpha value range should be between 0.7-1 to be considered. As the test conducted and the result obtained is consistent as the range of 0.7-0.8 is minimum acceptable value.

The formula to calculate Cronbach's Alpha:

where, N = number of items

$\bar{c}$ = mean covariance between items.

$\bar{v}$ = mean item variance.

Table 6: Reliability Analysis

Case Processing	Values
Total cases	84
Valid cases	84
Excluded cases	0
Alpha Value	0.760
Number of items in case	19

- Due to inadequate training, auditing, and record-keeping, traditional safety techniques are regarded as ineffectual.
- IoT is viewed as a useful substitute for decision-making, hazard detection, and safety tracking.
- Two of the biggest obstacles to IoT adoption are high costs and a lack of technical expertise.
- For implementation to be successful, additional training and government backing are required.

Table 7: One-sample t Test

	Test Value = 84						
	T	df	Significance		Mean Difference	95% Confidence Interval of the Difference	
			One-Sided p	Two-Sided p		Lower	Upper
Training sessions on safety procedures are infrequent on the construction site.	-715.035	83	<.001	<.001	-80.131	-80.35	-79.91
Safety Audits do not happen regularly on the construction site.	-796.584	83	<.001	<.001	-80.702	-80.90	-80.50
Traditional methods of safety management are the best ways to decrease unsafe conditions on construction sites.	-553.658	83	<.001	<.001	-81.631	-81.92	-81.34
Safety training does not reflect current best practices and regulations.	-648.591	83	<.001	<.001	-80.345	-80.59	-80.10
Management often ignores reported safety incidents.	-765.940	83	<.001	<.001	-80.643	-80.85	-80.43
The death of labourers can be reduced using traditional safety management methods.	-505.749	83	<.001	<.001	-81.464	-81.78	-81.14
A safety induction program is mandated for labourers.	-1101.394	83	<.001	<.001	-79.405	-79.55	-79.26
Manual safety audit records are not easy to handle and store on site.	-714.649	83	<.001	<.001	-79.810	-80.03	-79.59
IOT can become a modern construction safety strategy	-1170.526	83	<.001	<.001	-79.595	-79.73	-79.46

Using IOT tools like Wearable Safety Devices, Smart Barrier Systems, etc. can help to track each labourer's activity on site	-1256.893	83	<.001	<.001	-79.381	-79.51	-79.26
Tracking all the labourers will make it easier to ensure the safety of each labourer on site.	-888.099	83	<.001	<.001	-79.821	-80.00	-79.64
Warning and alarm systems for any hazardous and unsafe conditions can be implemented on-site using IoT.	-1096.692	83	<.001	<.001	-79.429	-79.57	-79.28
The work of a safety assistant or safety manager on site will become easier by using IOT applications to automate the manual tasks.	-1077.792	83	<.001	<.001	-79.607	-79.75	-79.46
IOT can be used in optimizing labour efficiency.	-908.281	83	<.001	<.001	-79.750	-79.92	-79.58
Decision-making on any unsafe/ hazardous conditions will become easier using IOT.	-1057.146	83	<.001	<.001	-79.631	-79.78	-79.48
Cameras and IOT sensors can be placed around construction sites to detect unsafe conditions.	-1162.083	83	<.001	<.001	-79.429	-79.56	-79.29
There is resistance from workers and management in adopting IoT-based safety solutions.	-880.867	83	<.001	<.001	-80.310	-80.49	-80.13
High initial costs make IoT adoption in construction safety difficult.	-1056.187	83	<.001	<.001	-79.750	-79.90	-79.60
Integrating IoT with existing construction safety processes is complex.	-815.714	83	<.001	<.001	-80.298	-80.49	-80.10
Small and medium-sized construction firms find IoT implementation financially unfeasible.	-922.585	83	<.001	<.001	-79.786	-79.96	-79.61
Government and industry stakeholders support is required for IoT implementation.	-1122.408	83	<.001	<.001	-79.512	-79.65	-79.37
More training programs should be conducted to educate management employees and workers about IoT integrated safety systems.	-1234.399	83	<.001	<.001	-79.464	-79.59	-79.34
IoT safety devices could be designed more user-friendly for construction workers.	-1233.314	83	<.001	<.001	-79.476	-79.60	-79.35
Lack of technical knowledge among workers is a major barrier to implementing IoT.	-1094.777	83	<.001	<.001	-79.548	-79.69	-79.40

3.5 Descriptive statistical analysis of data

The survey results assessing traditional safety methods in construction are included in this sheet. A Likert scale (1–5) is used in the responses to gauge respondents' agreement with various claims including safety measures, audits, and training. Each question received ratings

from 85 respondents. Areas where respondents agree or strongly agree with statements are shown by higher mean ratings. Areas where conventional approaches can be viewed as ineffectual are highlighted by lower mean scores.

Most Agreed Statement:

- “Safety induction program is mandated for laborers.”
- According to this, safety induction programs are a tried-and-true method in conventional safety management.
- Most Disagreed Statement (Mean = 2.36, Mode = 1):
- “Traditional methods of safety management are the best ways to decrease unsafe conditions on construction sites.”
- This implies that many respondents do not entirely trust conventional approaches to enhancing safety. According to the research, standard safety measures are not thought to be very successful in averting dangerous situations or fatalities, although having certain advantages (such as induction programs). Improvements are required in the areas of management accountability, training updates, and improved record-keeping

Section 2: Using IoT application for safety and health monitoring

Survey results on IoT-based safety techniques in construction are included in this sheet. A Likert scale (1–5) is used in the responses to gauge respondents’ agreement with various claims on the efficacy of IoT.

- High mean scores → Show a high level of agreement with the advantages of IoT.
- Low Mean Scores → Indicate scepticism or reluctance to IoT adoption.
- Standard Deviation → Indicates the consistency or division of ideas.
- Most Agreed Statement (Highest Mean & Mode = 5):
 - “IoT can improve construction safety.”
 - It shows a strong belief in the potential of IoT to improve safety protocols.
- Most Disagreed Statement (Lowest Mean & Mode = 2-3):
 - “IoT can optimize labor efficiency.”
 - Raises doubts about the direct effect of IoT on employee productivity.

Consistently high ratings for the use of cameras and wearable safety devices for monitoring showed broad acceptance. Ratings for safety assistant job assistance and labour efficiency optimisation with IoT were more inconsistent, indicating ambiguity in practical implementation.

4.0 Conclusion

This study examines how IoT technology can enhance health and safety management on construction sites. Findings indicate that IoT-based solutions enable automatic safety compliance tracking, real-time monitoring, and data-driven decision-making. By integrating sensors, RFID, and IoT gateways, construction firms can improve worker safety, reduce

accidents, and streamline safety procedures. Cost analysis reveals that IoT deployment offers significant long-term savings compared to manual safety management. Despite these benefits, widespread adoption faces challenges such as high initial costs, integration difficulties, and worker resistance. Cybersecurity risks and data privacy concerns must be addressed to prevent unauthorized access. The study highlights the need for industry-wide standards and regulations for seamless IoT implementation.

While IoT can transform construction safety, further research is required to address scalability, enhance security, and develop user-friendly systems. Future studies should focus on pilot testing and real-world applications to evaluate long-term effectiveness. Overcoming these challenges will enable IoT to reduce fatalities, improve safety, and enhance industry productivity. IoT-based safety management in construction offers many benefits, but several challenges hinder its adoption. High upfront costs for sensors, RFID tags, and cloud infrastructure pose financial barriers. Resistance from workers and management, limited internet access at remote sites, and the need for ongoing technical expertise further slow implementation. Concerns over surveillance and lack of familiarity also impact worker acceptance. Effective training programs are essential to ensure proper use. Additionally, IoT solutions must be user-friendly to encourage adoption. Overcoming these organizational, financial, technical, and regulatory challenges is crucial to maximizing IoT's potential in construction safety.

4.1 Recommendation

The investigation suggests that the following steps could enhance conventional safety procedures:

- A rise in Frequent Safety Audits: The modest level of agreement (Mean = 3.30) with the audits indicates that their frequency or enforcement needs to be improved.
- Revise Programs for Safety Training:
 - According to respondents (Mean = 3.65), safety training is out of date.
 - Effectiveness can be increased by utilizing IoT-based training, digital learning resources, and real-time case studies.
 - 3. Enhance Management Accountability & Incident Reporting:
 - There is room for improvement in the way management handles reported events (Mean = 3.36).
 - Putting in place automated reporting methods could improve openness and stop safety issues from being ignored.
 - 4. Improve Safety Audit Data Management.
 - It is believed that keeping audit records by hand is inefficient (Mean = 4.19).
 - Safety record digitization may improve usefulness and accessibility.
 - To boost IoT-based safety solutions' uptake and acceptance.
- Increase Awareness & Training: Since tracking and monitoring are generally accepted, training employees more about AI-based decision-making helps increase acceptance.

References

Abioye, S. O., Oyedele, L. O., Akanbi, L., Ajayi, A., Davila Delgado, M. J., Bilal, M., Akinade, O., & Ahmed, A. (n.d.). *Artificial intelligence in the construction industry: A review of present status, opportunities and future challenges*. ScienceDirect.

Alotaibi, B. S., Shema, A. I., Ibrahim, A. U., Abuhussain, M. A., Abdulmalik, H., Dodo, Y. A., & Atakara, C. (2024). Assimilation of 3D printing, artificial intelligence (AI) and Internet of Things (IoT) for the construction of eco-friendly intelligent homes: An explorative review. *Heliyon*, 10(17).

Althoey, F., Waqar, A., Alsulamy, S. H., Khan, A., Alshehri, A., Falqi, I. I., Abuhussain, M., & Abuhussain, M. A. (2024). Influence of IoT implementation on resource management in construction. *Heliyon*, 10(15), e32193. <https://doi.org/10.1016/j.heliyon.2024.e32193>

Arshad, S., Akinade, O., Bello, S., & Bilal, M. (2023). Computer vision and IoT research landscape for health and safety management on construction sites. *Journal of Building Engineering*, 76, 107049. <https://doi.org/10.1016/j.jobbe.2023.107049>

Bureau of Labor Statistics. (2024). *Construction industry and accidents*. <https://www.bls.gov/opub/ted/injuries-illnesses-and-fatalities.htm>

Business Standard. (2024, July 25). Indian statistics on accidents. https://www.business-standard.com/industry/news/workplace-injuries-rise-8-5-and-fatalities-fall-21-says-iias-study-124072500868_1.html

Cheng, M.-Y., Khitam, A. F. K., & Tanto, H. H. (n.d.). *Automation in construction*.

Eber, W. (2020). Potentials of artificial intelligence in construction management. *Organization, Technology and Management in Construction*, 12(1), 2053–2063. <https://doi.org/10.2478/otmcj-2020-0002>

Elrifaae, M., Zayed, T., Ali, E., & Ali, A. H. (2024). IoT contributions to the safety of construction sites: A comprehensive review of recent advances, limitations, and suggestions for future directions. *Internet of Things*, 101387. <https://doi.org/10.1016/j.iot.2024.101387>

Fang, Q., Castro-Lacouture, D., & Li, C. (2024). Smart safety: Big data-enabled system for analysis and management of unsafe behavior by construction workers. *Journal of Management in Engineering*, 40(1). <https://doi.org/10.1061/jmenea.meeng-5498>

- Johare, K., Wagh, V., & Shaligram, A. (2022). Scope and impact of Internet of Things (IoT) and artificial intelligence (AI) in the global construction industry. *International Journal of Innovative Research in Management, Pharmacy and Sciences*, 10(4).
- Khahro, H., Zainun, N. Y., Shaikh, H. H., & Khahro, S. H. (2023). Critical success factors affecting labour productivity in building sector projects. In *E3S Web of Conferences* (Vol. 437). EDP Sciences.
- Khan, S. I., Ray, B. R., & Karmakar, N. C. (2024). RFID localization in construction with IoT and security integration. *Automation in Construction*, 159. <https://doi.org/10.1016/j.autcon.2024.104504>
- Ling, F. Y. Y., Heng, G. T. H., Chang-Richards, A., Chen, X., & Yiu, T. W. (2023). Impact of digital technology adoption on the comparative advantage of architectural, engineering, and construction firms in Singapore. *Journal of Construction Engineering and Management*, 149(12). <https://doi.org/10.1061/jcemd4.coeng-13743>
- Nagaraju, S. K., Reddy, B. S., & Chaudhuri, A. R. (2012). Resource management in construction projects: A case study. *International Journal of Engineering Research and Applications*, 2(3).
- Nawaz, N. (2013). Human resource information systems: A review.
- Okonkwo, C., Okpala, I., Awolusi, I., & Nnaji, C. (2023). Overcoming barriers to smart safety management system implementation in the construction industry. *Results in Engineering*, 20, 101503. <https://doi.org/10.1016/j.rineng.2023.101503>
- Taher, G. (2021). Industrial Revolution 4.0 in the construction industry: Challenges and opportunities. *Management Studies and Economic Systems (MSES)*, 6(3/4), 109–127.
- Zhang, M., Ghodrati, N., Poshdar, M., Seet, B. C., & Yongchareon, S. (2023). A construction accident prevention system based on the Internet of Things (IoT). *Safety Science*, 159, 106012. <https://doi.org/10.1016/j.ssci.2022.106012>
- Zhong, X. (2022). Construction of power IoT platform under digital transformation. *Energy Reports*, 8, 718–727. <https://doi.org/10.1016/j.egyr.2022.02.242>
- Zhu, M., Liang, C., Yeung, A. C. L., & Zhou, H. (2024). The impact of intelligent manufacturing on labor productivity: An empirical analysis of Chinese listed manufacturing companies. *International Journal of Production Economics*, 267, 109070.
- Zhu, M., Liang, C., Yeung, A. C. L., & Zhou, H. (n.d.). The impact of intelligent manufacturing on labor: An empirical analysis of Chinese listed companies.

CHAPTER 149

Utilization of Biomedical Incineration Ash by It's Application in Concrete Pavement

Rajat Balasaheb Kshirsagar¹ and Sunil S. Pimplikar²

ABSTRACT

Scientific and technological advancements are intimately related to advances in the medical field. The generation of medical waste has sharply increased in tandem with the growth of the global population and the rising use of medical facilities. Because of their hazardous nature, these wastes pose serious environmental and public health risks. Although incineration is a frequently used technique for handling this kind of waste, it produces ash, usually disposed of in landfills. This practice can lead to groundwater pollution due to the leaching of contaminants from the ash, which also consumes large amounts of land. This research aims to explore alternatives to burning incinerator ash in landfills. This study further investigates the potential of utilizing medical incineration ash in concrete road construction to reduce sunlight reflection by repurposing the ash. The research attempts to minimize environmental impacts and contribute to the reduction of urban heat island effects.

Keywords: Concrete pavement; Ash; Environmental impacts.

1.0 Introduction

India has long been a leader in the medical field, and it has also been prominent in infrastructure development. As the population grew, there was a corresponding expansion in the medical sector, and the need for road construction increased to extend the infrastructure network. With the diminishing availability of natural asphalt sources over time, a shortage of asphalt arose, leading to the emergence of concrete roads. These roads are solid, durable, and last significantly longer, which has led to their widespread adoption in a short period. Currently, majority of the highways in India are being constructed with concrete. However, a downside is emerging: the reflection of sunlight from cement roads is causing discomfort to drivers' eyes and increasing the rate of accidents. In addressing this issue, a solution is found in another problem which is growing medical waste in the country and the ash produced from it's controlled incineration. The ash has properties similar to cement and is black, so roads made from it are black and have reduced sunlight reflection.

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This lowers the amount of cement used and, by adding medical waste ash, also contributes to a reduction in soil pollution and costs because of the lower cement content percentage.

2.0 Literature Review

Baghotia (2017) emphasizes the importance of a systems approach to manage biomedical waste effectively, particularly in India, where smaller healthcare facilities often lack adequate waste management practices. The review of regulatory frameworks, such as the Bio-medical Waste Management Rules of 2016, highlights the need for enhanced protocols and infrastructure to mitigate health risks and ensure compliance with environmental laws. The categorization of biomedical waste into healthcare general waste (HCGW) and healthcare risk waste (HCRW) is crucial for effective management. The principles of reduction, reuse, and recycling (the “3Rs”) are advocated to minimize waste generation, while proper segregation, storage, transport, and disposal methods are essential to prevent environmental damage and health hazards. Research by Kumar *et al.* (2016) explores the potential of using biomedical waste ash as a partial replacement for cement in concrete, indicating that it can improve compressive strength while reducing landfill demand. However, the study also notes that higher ash content may decrease workability and strength, suggesting a balanced approach to its application in construction.

3.0 Specific Objectives

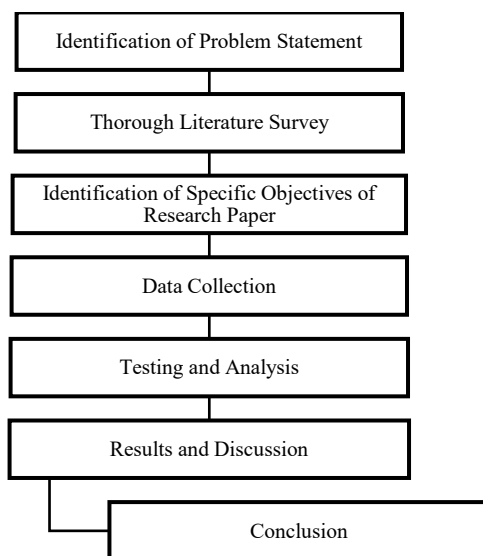
- To evaluate possibility of using medical incineration ash in roads by replacing conventional cement.
- Determine the optimal mix proportions of incineration bottom ash, cement, aggregate, and other additives to achieve desired concrete proportions while minimizing cement content to lessen the sunlight light reflection on roads.
- Conduct road reflection study by field trials to evaluate the actual performance of concrete pavement with incineration bottom ash under real-world traffic and environmental conditions

4.0 Methodology

Problem identification: With the continuous increase in population and increase in the use of medical facilities there is a sharp rise in the generation of medical waste. These wastes are hazardous and have the greatest potential to have an impact on living beings and the environment. One of the important methods of treatment of such waste is incineration but this method also produces ash which is a subject of landfilling. This causes the wastage of large

areas of land also leaching contaminants in ashes causes contamination of ground water. The purpose of this project is to find some alternative for landfilling incineration ashes.

Figure 1: Methodology



Collecting the sample of incineration bottom ash: To investigate the use of bottom ash from biomedical incineration in concrete, we took a sample from the Bio Clean Plant, which is situated on Barshi Road in Solapur. Additionally, the process of collecting the sample biomedical incineration ash has been successfully finished. To determine this sample's qualities and appropriateness for usage in concrete applications, analysis will be performed.

Composition of the biomedical incineration bottom ash: To use the biomedical incineration bottom ash in concrete, it was necessary to analyze the composition of the bottom ash so that its suitability could be determined. The following are the major components of the biomedical incineration bottom ash:

- SiO_2 - (11.93%)
- CaO - (22.8 %)
- Na_2O - (9.13%)
- Al_2O_3 - (5.16%)
- Fe_2O_3 - (2.93%)

Replacement of cement by biomedical incineration bottom ash: In this method, cement content is reduced by a certain percentage and is replaced by incineration bottom ash in concrete. The other components of concrete are taken as per the mix design. Three cubes are Casted and their average compressive strength is considered as a result.

Preparation of mix design of M30: Because of its high calcium oxide (CaO) content (22.8%), which aids in binding and strength characteristics, and its silica (SiO₂) content (11.3%), which promotes pozzolanic activity and increases long-term strength and durability, biomedical incineration ash can be utilized in M30-grade concrete. By recycling waste materials, using this ash in place of some of the cement improves the sustainability of the concrete and lowers production costs and carbon emissions, making it an eco-friendly way to achieve the necessary strength and performance of M30-grade concrete. Optimizing the ratios of cement, fine aggregates, coarse aggregates, and water is part of the mix design for M30 grade concrete that incorporates biomedical incineration ash. The ash is used to partially replace cement or fine aggregates. The physical and chemical characteristics of biomedical incineration ash are described, and replacement percentages usually vary from 5 to 15% based on the ash's reactivity and effect on concrete performance. The mix design has a water-to-cement ratio of 0.4 to 0.45 and complies with IS 10262:2019.

Cube casting of 0.015 cum: In order to cast 0.015 m³ of biomedical incineration ash (BIA) cubes into concrete, BIA is mixed with aggregates and water, partially substituted for cement, and then poured into a mold. To assess the effect of (BIA) biomedical incineration ash on concrete performance, the cube is cured in water after setting and then tested for compressive strength.

Testing of cubes: When testing cubes that contain bottom ash from biomedical incineration in concrete pavement, the material's mechanical qualities, longevity, and performance under load-bearing circumstances are assessed. By substituting different percentages of bottom ash for conventional aggregates, this method tests the compressive strength of the concrete cubes. The results are examined to ascertain whether using bottom ash in pavement construction is feasible, taking into account elements like long-term performance, resistance to environmental conditions, and structural integrity. Through the reuse of biomedical waste by-products in concrete applications, the study seeks to advance Environmental sustainable construction practices.

Result Analysis: The investigation of biomedical incinerator ash (BIA) and its possible usage in concrete pavement are the main topics of the study. In order to determine whether biomedical incinerator ash BIA can be used as a partial substitute for traditional materials in concrete, the process entails obtaining it from incineration plants and then thoroughly characterizing it both physically and chemically. Different mix patterns were created by substituting biomedical incinerator ash BIA in varying percentages for some of the cement or fine aggregate. Standard tests for workability, durability, and compressive strength were then performed on these mixes. The findings showed that biomedical incinerator ash BIA might improve concrete's strength and environmental sustainability at the right replacement levels, making it a feasible material for environmentally friendly concrete pavements. However, more research is needed to determine the long-term performance and possible leaking of hazardous materials.

5.0 Materials and Procedures

5.1 Bio-medical Incineration bottom ash collection

To study and use the biomedical incineration bottom ash in concrete, a sample was collected from the Bio clean Plant Barshi Road, Solapur.

Objectives	Biomedical ash 10% used					
CONCRETE GRADE	M30					
MATERIAL AND THEIR SOURCE				SPECIFIC GRAVITY		
CEMENT: OPC/PSC/PCC	OPC : ULTRATECH				3.15	
CRUSH SAND	WAGHOLI : GANRAJ STONE CRUSHER				2.85	
COARSE 1 (10 MM)	WAGHOLI : GANRAJ STONE CRUSHER				2.87	
COARSE 2 (20 MM)	WAGHOLI : GANRAJ STONE CRUSHER				2.9	
W/C RATIO	0.38				1.11	
MOISTURE CONTENT ABSORPTION VALUES						
MATERIAL	10MM	20MM	RIVER SAND	CRUSH SAND		
SURFACE MOISTURE	0.00%	0.00%	0.00%	0.50%		
ABSORPTION	1.30%	1.30%	0.00%	3.50%		
CORRECTED	1.30%	1.30%	0.00%	3.00%		
			BATCH VOLUME :- 0.0136 M3			
MIX PROP/UNIT BATCH WEIGHTS/M3			WEIGHT PER M3	CORRECTION	CORRECTED BATCH	TRIAL BATCH WT
CEMENT, KG	371		371	0.000	371	5.05
BIOMEDICAL ASH, KG	42		42	0.000	42	0.57
CRUSH SAND, KG	638		638	19.140	618.86	8.42
COARSE : 1 (10MM), KG	347		347	4.511	342.49	4.66
COARSE : 2 (20MM), KG	810		810	10.530	799.47	10.87
WATER IN KGS	155		155	34.181	189.18	2.37
THEROTICAL B.D	2363.00		2363.00	68.36	2363.00	95.82
HARDENED PROPERTIES						
COMPRESSIVE STRENGTH	AGE	STRENGTH IN MPA	AVERAGE STRENGTH IN MPAS			
	7	28.85	28.4			
	7	28.4				
	7	27.95				
	28	38.82	38.99			
	28	39.17				
	28	38.99				

5.2 Culture and antibiotic sensitivity test on biomedical incineration ash

To better understand microbial contamination and assess the sample's potential health and environmental risks, the bottom ash sample was sent to a pathology lab in Pune for a thorough Culture and Antibiotic Sensitivity Test. The lab carries out microbial culturing, which involves putting the sample in a controlled environment with particular growth media to promote the growth of any bacteria or fungi that are present. This stage is crucial for separating and identifying pathogens potentially dangerous microorganisms that could infect people, animals, or the environment. Furthermore, the observed microbial activity might point to the possibility of toxic leachate formation, which could contaminate groundwater and soil.

In order to precisely identify the species of microorganisms present, the identification procedure usually takes two to three days and uses sophisticated techniques like Gram staining, biochemical assays, and molecular methods like PCR. Following identification, the pathogens undergo antibiotic sensitivity testing, in which they are exposed to a variety of antibiotics in order to assess their resistance or susceptibility. Finding multidrug-resistant organisms that present serious public health risks, like MRSA or strains that produce ESBL, requires this step.

Figure 2: Sample of Ash for Lab Test



This sample of ash was given for culture and antibiotic sensitivity tests to identify the presence of bacteria or fungi as well as leachate sensitivity. The report states that no organism is isolated in biomedical incineration ash hence it is sterile and leachate-free.

5.3 Composition of the biomedical incineration bottom ash

It is essential to examine the composition and characteristics of bottom ash from biomedical incineration in order to assess its possible application in concrete. An effective method used in this investigation to evaluate the ash's mineralogical and structural properties is X-ray diffraction (XRD). This technique examines the diffraction patterns created when X-rays interact with the material's crystalline phases. The patterns offer important information about the kinds and amounts of crystalline compounds that are present, which has a direct impact on the reactivity and functionality of the ash in concrete applications. XRD analysis is crucial for identifying substances like quartz, calcite, or other silicates and oxides that may affect the structural compatibility of biomedical incineration ash with cement because it frequently contains a mixture of crystalline and amorphous phases. The XRD data is essential for assessing

whether the ash is suitable for use in construction. Amorphous silica and aluminosilicates are examples of crystalline phases with pozzolanic activity that can improve the strength and durability of concrete, whereas inert or hazardous substances can lessen its efficacy or safety. Through the identification of these phases, XRD analysis aids in the evaluation of the ash's chemical and physical characteristics and directs the improvement of its application and processing. The successful and long-lasting integration of biomedical incineration ash into building materials is made possible by this understanding, which serves as the foundation for additional testing, such as chemical, mechanical, and environmental assessments.

The chemical composition of biomedical incineration ash is highlighted in the provided XRD report, with calcium oxide (CaO) accounting for 22.8%, silica (SiO₂) for 11.3%, and iron oxide (FeO₃) for 2.93%. These elements are important markers of the material's possible application in concrete. The silica content indicates the possibility of pozzolanic reactions, which improve strength and durability, while the high calcium content is consistent with the fundamental binding qualities needed for cementitious materials.

Although small, the iron oxide content is within permissible bounds for concrete applications and does not present a serious problem. The ash's calcium and silica content makes it appropriate for partial cement substitution in concrete. While silica combines with calcium hydroxide to create more calcium silicate hydrates, which gradually increase strength, calcium oxide aids in the setting and hardening process. By recycling waste materials and lowering dependency on natural resources, using incineration ash in concrete also benefits the environment and is consistent with sustainable building methods. Additional tests are advised to assess durability, pozzolanic activity, and compressive strength in order to verify its suitability. Fine grinding is one method of processing ash that can improve its reactivity and cement compatibility. In order to balance performance, cost, and environmental impact, it is also essential to optimize the blend ratio with cement. Ash from biomedical incineration has the potential to be a practical and sustainable ingredient in the manufacturing of concrete with these steps. According to the report, ash from biomedical incineration is rich in calcium, iron, and silicon dioxide, all essential cement ingredients. For strength, CaO and SiO₂ combine to create calcium silicate (CaO), and Fe₂O₃ works as a flux and fortifies the mixture.

6.0 Line of Work

6.1 Replacement of cement by biomedical incineration bottom ash in concrete (5%, 10%, 15%, 20%, 25%)

By using this method, the percentage of cement in the concrete is decreased by 5%, 10%, 15%, 20%, and 25% and is replaced with bottom ash from incineration. The other components of concrete are taken as per the mix design. Three cubes are cast of each percentage and their average compressive strength of 7 days and their average compressive strength of 28 days are considered as a result.

6.2 Preparation of mix design of M30 grade concrete

The concrete cubes were cast in M30 Grade concrete according to the following mix design.

Figure 3: Cube Casting



6.3 Cube casting process

The cube was cast by the mixed design adopted from IS 10262-2009. This sequence of steps can be undertaken.

6.4 Testing of cubes

The following two tests are carried out on cubes:

- Compression test
- Reflection test by lux meter apparatus

6.4.1 Compression test

The ability of a material or structure to resist or tolerate compression is known as its compressive strength. The capacity of a material to withstand failure in the form of fissures and cracks is what determines its compressive strength. The push forces applied to the concrete specimen's two faces during the test, as well as the highest compression the material can withstand without failing, are recorded.

- Compression test following a 7-day healing period
- Compression test following a 28-day healing period

Figure 4: Concrete Block (Using incineration ash)



6.4.2 Reflection test by lux meter apparatus

To gauge how much light is reflected off a specific work surface, use a lux meter. A sensor on the light meter gauges the amount of light shining on it and gives the user a quantifiable reading of the illuminance. The light sensor of the illuminometer satisfies the requirements for this kind of instrument by consisting of a photodiode that transforms light into an electrical signal, an optical filter that guarantees the same sensitivity as the human eye, and a diffusing globe that makes cosine correction easier.

6.4.3 Reflection of sunlight measured by lux meter after 28 days

Because biomedical incineration ash (BIA) significantly alters the material's surface characteristics, there is less reflection in the concrete block that contains BIA. The carbon residues, silica, and other oxides that are commonly found in BIA darken the concrete's surface and increase its propensity to absorb sunlight rather than reflect it. Given that darker surfaces typically reflect less light than lighter ones, this darker coloring is a major contributing factor to the lower reflectivity. Additionally, by adding microscopic roughness, the ash particles may change the concrete's surface texture. The amount of light that is reflected back to the luxmeter is decreased by this roughness, which disperses the sunlight in various directions. The luxmeter reading of 125 LUX, which is less than what would be predicted from conventional concrete 190 LUX, shows that these combined chemical and physical effects significantly reduce the surface's capacity to reflect sunlight. This illustrates how the addition of BIA affects the material's reflective qualities.

Figure 5: Concrete Block (Conventional)



6.4.4 Reflection of sunlight measured by LUX meter after 28 days

The interaction of the material composition and surface characteristics of a 28-day-old conventional concrete block containing incineration ash can account for a luxmeter reading of 190 LUX. Concrete's texture, color, and density all affect how much sunlight it reflects. The formation of a dense matrix by cement hydration affects surface texture, which in turn affects light reflectivity. A rougher surface scatters light, lowering the lux value, whereas a smoother surface reflects more light. Moderate reflectivity is indicated by the reading of 190 LUX, which is typical for regular concrete that has additional materials like incineration ash added.

The conventional concrete block's luxmeter reading of 190 LUX indicates a substantially higher sunlight reflectivity than the block with biomedical incineration ash, which recorded 125 LUX. This discrepancy can be explained by the fact that biomedical incineration ash has a finer particle size and a darker color, which tends to absorb more light and scatter less, decreasing its reflectivity. Conventional concrete that doesn't contain this kind of ash frequently has a lighter surface and a less absorbent texture, which makes it more capable of reflecting sunlight. The decreased lux reading in biomedical ash concrete emphasizes the material's changed surface characteristics, which include a denser, darker, and less reflective material due to the pozzolanic activity and ash composition. This illustrates how the kind of incineration ash greatly affects concrete's optical properties.

7.0 Result and Discussion

Various tests were carried out and the results of these are as follows:

Table 1: Compressive Strength of the Concrete Block

Percentage of Ash	Block No.	Compressive Strength after 7 days (N/mm ²)	Average (N/mm ²)	Compressive Strength after 28 days (N/mm ²)	Average (N/mm ²)
5%	1	42.63	42.3	49.97	49.9
	2	41.95		49.83	
	3	42.32		49.90	
10%	1	28.85	28.4	38.82	38.99
	2	28.40		39.17	
	3	27.95		38.99	
15%	1	27.40	27.4	38.44	37.83
	2	27.65		37.35	
	3	27.21		37.69	
20%	1	25.29	25.08	37.70	36.57
	2	24.81		36.03	
	3	25.14		35.98	
25%	1	23.29	2222.84	35.24	3434.96
	2	23.11		35.38	
	3	22.13		34.28	

- From the above results, it is observed that a 5% bio medical ash replacement block gives maximum compressive strength as compared to other percentages.
i.e. 7 days = 42.3 N/mm² and 28 days = 49.9 N/mm²
- Then the percentage of replacement of incineration ash is taken up to 20% as it gave strength 36.57 N/mm² (which is more than the ideal value i.e 30 N/mm² according to IS Code) Hence, as per IS code standard one is supposed to get 100% strength but in this study, 115% strength was obtained even after replacement of 20% cement content.

Table 2: Lux Meter Reading

Concrete Block (Normal)	Concrete Block (Incineration Ash)	Reduced Percentage
190 x 100 LUX	125 x 100 LUX	34%

- The above result shows the reflection of the concrete block (normal) is more than the concrete block (incineration ash).
- The reflection is reduced by 34% in concrete blocks (Incineration Ash).

8.0 Conclusion

- The biomedical incineration bottom ash was confirmed to be sterile, with no bacterial growth or toxic substances found in the culture test, making it a safe material for use in concrete

- The maximum compressive strength was achieved with a 5% replacement of cement by biomedical incineration ash, with concrete showing optimal performance at both 7 and 28 days of curing

Figure 6: Compressive Strength after 7 Days at Different Replacement Ash (%)

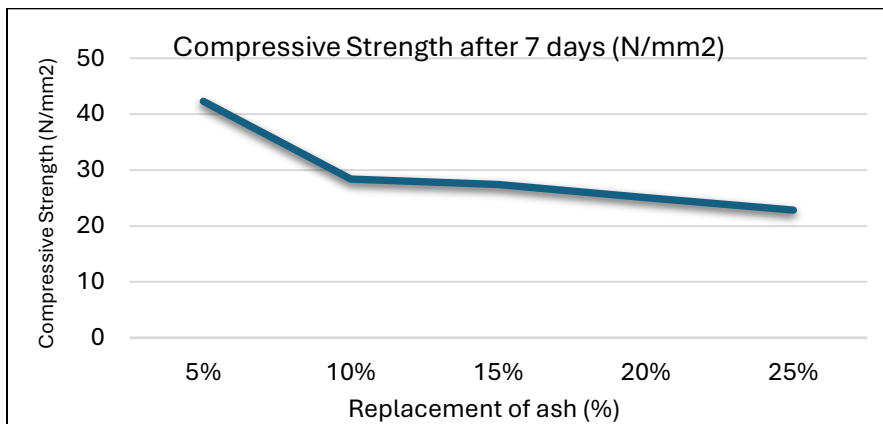
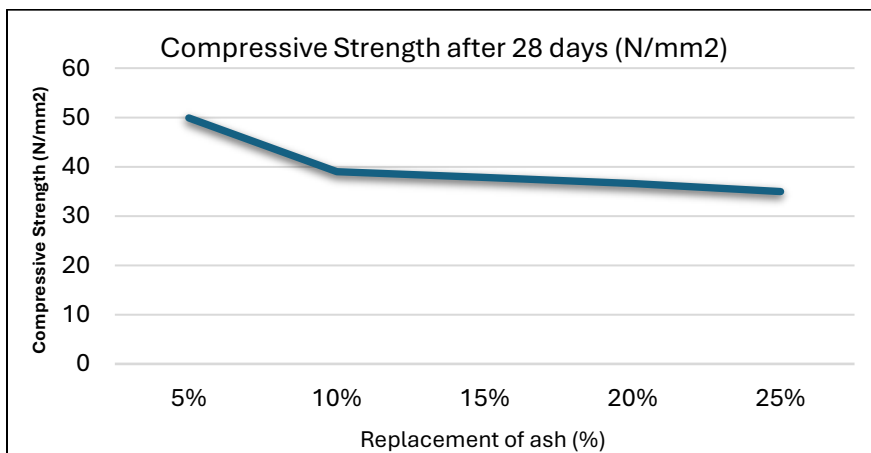


Figure 7: Compressive Strength after 28 Days at Different Replacement Ash (%)



- A 25% replacement of cement with biomedical incineration ash resulted in a compressive strength of 34.96 N/mm² after 28 days, exceeding the IS Code's ideal strength of 30 N/mm², indicating that the ash can significantly contribute to concrete strength.
- The addition of biomedical incineration ash created a darker, asphalt-like surface, reducing sunlight reflection and improving road safety by lowering the risk of accidents caused by glare.

- The study highlights the environmental benefits of using biomedical incineration ash in concrete, such as reducing landfilling, conserving land resources, and mitigating soil and groundwater pollution, while providing a cost-effective alternative for construction activities

References

Abebe, M. A. (2017). Study of hazardous biomedical waste management practices and development of hazardous biomedical waste management guidelines in Addis Ababa. *International Journal of Scientific Engineering and Science*, 1(8). <http://ijses.com/>

Akyıldız, A., *et al.* (2017). Compressive strength and heavy metal leaching of concrete containing medical waste incineration ash. *Construction and Building Materials*, 138, 326–332. <https://doi.org/10.1016/j.conbuildmat.2017.02.017>

Allawzi, M., *et al.* (2018). Characterization and leachability propensity of bottom ash from medical waste incineration. *Water, Air, and Soil Pollution*, 229(5). <https://doi.org/10.1007/s11270-018-3810-5>

Amthor, M., Hartmann, B., & Denzler, J. (2015). Road condition estimation based on spatio-temporal reflection models. In *European Conference on Computer Vision*. https://doi.org/10.1007/978-3-319-24947-6_1

Bamigboye, G. O., Bassey, D. E., Olukanni, D. O., Ngene, B. U., Adegoke, D., Odetoyan, A. O., Kareem, M. A., Enabulele, D. O., & Nworgu, A. T. (2020). Waste materials in highway applications: An overview on generation and utilization implications on sustainability. *Journal of Cleaner Production*. <https://doi.org/10.1016/j.jclepro.2020.124581>

Boulanouar, A., & Kettab, R. M. (2023). Effects of dune sand on reduction of reflection cracking in double-layered paving systems for roads: A laboratory investigation. *Journal of Applied Geophysics*. <https://doi.org/10.1016/j.jappgeo.2023.105166>

Chitrala, S., Jawahar, J. G., Sreenivasulu, C., Ramakrishnaiah, A., & Jawahar, J. G. (2015). Mechanical properties of geopolymer concrete using granite slurry as sand replacement. *International Journal of Advances in Engineering & Technology*, 8(2). <https://www.researchgate.net/publication/297738773>

Ebert, B. A. R., Steenari, B. M., Geiker, M. R., & Kirkelund, G. M. (2020). Screening of untreated municipal solid waste incineration fly ash for use in cement-based materials: Chemical and physical properties. *SN Applied Sciences*, 2(5). <https://doi.org/10.1007/s42452-020-2613-7>

Ghazali, E. (n.d.). Mechanical and leaching properties of solidified clinical waste incinerator fly ash mortar.

Girma, M., & Asteray, B. (2022). Fresh, mechanical, and microstructural properties investigation on the combined effect of biomedical waste incinerator ash and bagasse ash for high-strength concrete. *Advances in Materials Science and Engineering*, 2022. <https://doi.org/10.1155/2022/5685372>

Kheirabadi, S., & Sheikhi, A. (2022). Recent advances and challenges in recycling and reusing biomedical materials. *Current Opinion in Green and Sustainable Chemistry*, 38. <https://doi.org/10.1016/j.cogsc.2022.100695>

Mataalkah, F. (2023). Recycling of hazardous medical waste ash toward cleaner utilization in concrete mixtures. *Journal of Cleaner Production*. <https://doi.org/10.1016/j.jclepro.2023.136736>

Miao, J., Li, J., Wang, F., Xia, X., Deng, S., & Zhang, S. (2022). Characterization and evaluation of the leachability of bottom ash from a mobile emergency incinerator of COVID-19 medical waste: A case study in Huoshenshan Hospital, Wuhan, China. *Journal of Environmental Management*, 303. <https://doi.org/10.1016/j.jenvman.2021.114161>

Ni, P., et al. (2017). Relation between leaching characteristics of heavy metals and physical properties of fly ashes from typical municipal solid waste incinerators. *Environmental Technology*, 38(17), 2105–2118. <https://doi.org/10.1080/09593330.2016.1246612>

Pan, J., Shi, Z., Meng, X., Yue, Y., Lin, C., Chen, J., Liu, H., & Cui, J. (2023). Reflection characteristics of typical road defects in 3D GPR images for collapse mitigation. *Journal of Applied Geophysics*. <https://doi.org/10.1016/j.jappgeo.2023.105166>

Patel, K. M., & Devatha, C. P. (2019). Investigation on leaching behavior of toxic metals from biomedical ash and its controlling mechanism. *Environmental Science and Pollution Research*, 26(6), 6191–6198. <https://doi.org/10.1007/s11356-018-3953-3>

Rena, Y., Yadav, S., Patel, S., Killedar, D. J., Kumar, S., & Kumar, R. (2021). Eco-innovations in solid waste management (SWM) in India: Advancements in automation, recycling, and resource recovery. *Journal of Environmental Management*. <https://doi.org/10.1016/j.jenvman.2021.113953>

Suresh Kumar, A., Muthukannan, M., Kanniga Devi, R., Arunkumar, K., & Chithambar Ganesh, A. (2021). Reduction of hazardous incinerated bio-medical waste ash and its environmental strain by utilizing in green concrete. *Water Science and Technology*. <https://doi.org/10.2166/wst.2021.239>

Thareja, P., Singh, B., Singh, S., Agrawal, D., & Kaur, P. (n.d.). Biomedical waste management: Need for human civilization. *Indian Journal of Clinical Anatomy and Physiology*, 2(2).

Xie, R. *et al.* (2016). Assessment of municipal solid waste incineration bottom ash as a potential road material. *Road Materials and Pavement Design*, 18(4), 992–998. <https://doi.org/10.1080/14680629.2016.1206483>

CHAPTER 150

Vulnerability Assessment of Slums: A Case Study of Yavatmal City

Komal Handore¹ and Akshay Gajelwad²

ABSTRACT

This paper reviews methods to determine vulnerability in urban informal settlements and then applies one such method to Yavatmal City, Maharashtra. In the context of increasing urbanization pressures and challenges faced by slum environments, the review highlights the importance of adopting integrated methods for assessment. Using the PRISMA framework, more than 600 records were screened which resulted in 35 peer-reviewed studies being selected. The review examines methods, major findings, and policy implications, with a focus on spatial approaches such as GIS mapping. Yavatmal is a case in study which mirrors the unique vulnerability backdrop of tier-2 cities rooted in the complex interplay of environmental, infrastructural, socio-economic and social vulnerabilities. Finally, the paper ends with recommendations regarding integrated frameworks, secure tenure and participatory governance and identifies research gaps that can contribute to more resilient urban development.

Keywords: Slum, Vulnerability; Yavatmal; GIS mapping; Socio-economic; Environmental risks; SDG11.

1.0 Introduction

The rapid urbanization of the world has significantly influenced the growth of slums in urban areas, with a notable concentration of slum populations in small cities and intermediate towns. As of 2020, 55% of the global population resides in urban areas, and among them, 24.2% live in slums or slum-like conditions (UNSD). The World Bank highlights that 64% of slum dwellers are in Asia, with Central and Southern Asia reporting that 31.2% of their urban population lives in slums, and Eastern and South-Eastern Asia at 27.2% (KIKUCHI, 2017). In India, as of 2020, 49% of the urban population resides in slums, despite a decrease from 55% in 2002 (Census, 2011). Slums are not confined to major cities; they are also prevalent in medium and small towns due to rapid urbanization (Kumar, 2014). Residents of slums typically face inadequate housing, limited access to safe water and sanitation, insufficient living space, and insecure tenure. This demographic represents the most deprived segment of the urban poor and is particularly vulnerable to disasters (UN-Habitat, 2004).

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The lack of proper infrastructure exacerbates environmental degradation and poses significant risks to human health, as human waste accumulates in these areas (Porio, 2011). Furthermore, slums often lack the necessary protective infrastructure to mitigate the effects of environmental degradation and climate change (Satterthwaite & Moser, 2008; Wekesa *et al.*, 2011; Alcayna-Stevens, 2015). While much research has focused on slum vulnerabilities in tier 1 cities, there exists a critical gap in studies addressing these issues in tier 2 cities. This thesis aims to assess the vulnerabilities of slums in Yavatmal City, contributing to a deeper understanding of the challenges faced by these communities in smaller urban contexts. This research will explore the socio-economic factors that exacerbate these vulnerabilities, including access to basic services, housing quality, and community resilience strategies. The aim of this research is “to gain a comprehensive understanding and to calculate the vulnerabilities faced by slum communities in urban areas, in regard to environmental, social, economic and infrastructural factors.”

To achieve this aim, the study will address the following research objectives:

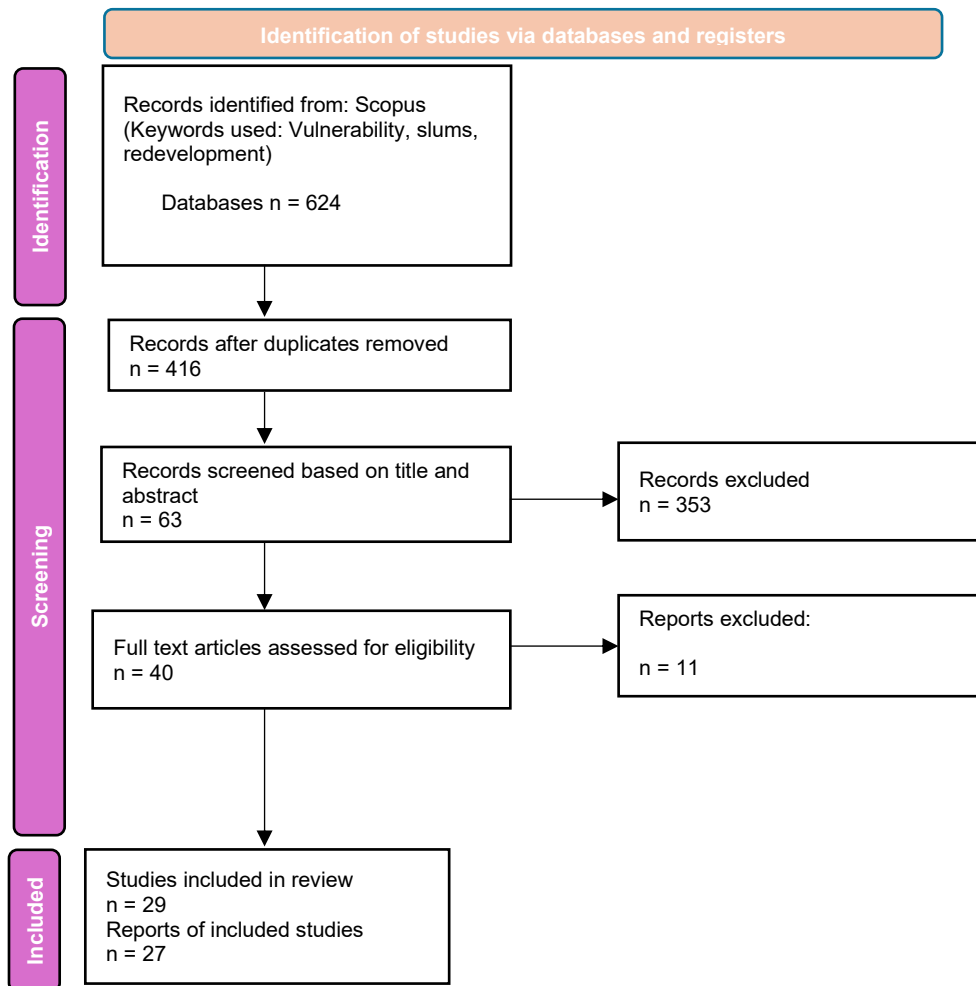
- To understand different vulnerabilities faced by slums in urban areas
- To identify and mark notified and unnotified slums using GIS.
- To compare vulnerability levels across different slum pockets.
- To identify National & International policies that are related to slums.
- To propose policies and interventions for vulnerable slums.

Considering the academic and practical importance of studying urban vulnerability, this review hopes to give urban planners, policymakers, and scholars a comprehensive and systematic summary of state-of-the-art practice and emerging gaps in the literature.

2.0 Literature Review

2.1 Literature search and selection

Literature follows the PRISMA method to gather various papers throughout Scopus. The process starts with searching keywords like “vulnerability, slum, redevelopment” on Scopus, and collected about 624 records found after this search, then after downloading all the documents the records are screened for duplicate documents and removed from the database, after removing all the duplicate documents. Records are screened based on their titles, and we remained with 63 papers to review. And for 2nd screening read all the abstracts of all 63 papers and excluded 11 papers that were irrelevant to the study for the final study read and included 27 papers. This systematic approach allowed the selection of relevant information that is not biased and ensured the analysis was holistic enough to ensure that all the available current information was understood thoroughly. Throughout the literature review 4 major areas of urban poor vulnerability have emerged which are Environmental risks, social, economic, and infrastructural vulnerability. The papers are divided into these themes accordingly for study. These major themes contain sub themes under them for developing questioners.

Figure 1: PRISMA Diagram for Literature Review

Theme	No. of papers
Environmental Vulnerability	8
Social Vulnerability	11
Economic Vulnerability	9
Infrastructural Vulnerability	7

2.2 Economic vulnerability

Economic vulnerability is a significant concern because slum dwellers often face job insecurity, unstable incomes, and limited savings to cope with crises or increased living costs (Khan *et al.*, n.d.). This economic instability contributes to overall vulnerability and can lead to

increased poverty and unemployment, if not addressed promptly. The lack of financial resources often results in a cycle of poverty, where residents struggle to invest in education, healthcare, or better housing, further perpetuating their vulnerability (Khan *et al.*, 2024; Pitoyo *et al.*, n.d.). Additionally, many slum dwellers work in the informal sector, which lacks job security and social protection, making it particularly susceptible to economic shocks and downturns (Owusu & Nursey-Bray, 2019).

2.3 Environmental vulnerability

Environmental risk plays a crucial role in slum vulnerability. Studies have shown that slum areas are often exposed to industrial waste, proximity to hazardous sites, and poor environmental conditions, which increases health risks for residents (Effat *et al.*, 2022). Environmental hazards can lead to various health issues, including respiratory problems, waterborne diseases, and chronic illnesses. Limited access to basic services such as clean water, sanitation, and healthcare further exacerbates these vulnerabilities (Corburn & Sverdluk, 2017; Thakore *et al.*, 2024). The lack of proper waste management systems and inadequate drainage often result in the accumulation of waste and stagnant water, creating breeding grounds for disease vectors and increasing the risk of epidemics.

2.4 Social vulnerability

Social factors also significantly contribute to vulnerability in slum areas. Factors such as social marginalization, lack of awareness of health and hygiene practices, and limited participation in decision-making processes increase the vulnerability of slum dwellers (Mukherjee *et al.*, 2020). The social stigma associated with living in slums can lead to discrimination in employment, education, and access to public services, further marginalizing these communities. Gender-based vulnerabilities are particularly noteworthy, as women often face additional challenges due to unequal access to resources and limited participation in community decision making (Owusu *et al.*, 2018). Women in slums may experience higher rates of domestic violence, limited access to education and healthcare, and a greater burden of unpaid care, all of which contribute to their increased vulnerability (Kher *et al.*, 2015).

2.5 Infrastructural vulnerability

Housing conditions in slums are critical aspects of vulnerability assessment. Studies have highlighted that a significant percentage of houses in slum areas are often kutcha structures prone to collapse, indicating the risks associated with natural calamities (Khan & Kraemer, 2014). These substandard housing structures provide inadequate protection against extreme weather events, such as heavy rains, floods, or heatwaves, putting residents at risk of displacement and property loss. Overcrowding and inadequate sanitation facilities further compounded these vulnerabilities and hindered the adoption of disease-prevention measures (Brown-Luthango *et al.*, 2016). The high population density in slums makes it

challenging to implement social distancing measures during disease outbreaks, thereby increasing the risk of rapid transmission of infectious diseases (Nguyen *et al.*, n.d.).

Geospatial techniques have emerged as valuable tools for assessing and mapping slum vulnerabilities. High-resolution satellite images and GIS techniques have been used to identify and map slum areas based on factors such as population density, tenement density, and location (Mundhe, 2019). This approach aids in sustainable urban planning and identification of vulnerable slums near environmentally sensitive areas. Geospatial analysis can help policymakers and urban planners prioritize interventions, allocate resources more effectively, and monitor changes in slum conditions over time. By integrating various data sources, including socioeconomic indicators, environmental factors, and infrastructure information, geospatial techniques provide a comprehensive understanding of slum vulnerabilities and their spatial distribution (Awasthi *et al.*, 2024). Furthermore, the interconnectedness of various vulnerability factors underscores the need for integrated and holistic approaches to slum improvement. Addressing economic vulnerabilities through livelihood support programs, for instance, can have positive spillover effects on health and educational outcomes. Similarly, improving environmental conditions through improved waste management and sanitation infrastructure can lead to improved health outcomes and increased economic productivity.

In conclusion, the vulnerability assessment of slums requires a comprehensive approach that considers the economic, environmental, social, and infrastructural factors. The case study of Yavatmal can benefit from these insights to develop targeted interventions and policies aimed at reducing vulnerability and improving the overall quality of life for slum residents. By addressing the root causes of vulnerability and leveraging community strength, it is possible to create more resilient and sustainable urban environments that promote the well-being of all residents, including those in slum areas.

3.0 Methodology: Review Approach

This study utilizes a systematic review approach that emphasizes the collection, evaluation, and synthesis of previous studies on urban slum vulnerability. As opposed to collecting original data, the emphasis is on a systematic reviewing procedure that synthesizes evidence across various types of research methods.

3.1 Search strategy and inclusion measures

The search was carried out by looking for appropriate studies in several trustworthy databases using a mixture of key words. Inclusion criteria were:

- Peer-reviewed articles published in reputable conference proceedings or in peer-reviewed journals.
- Research that targets one or more aspects of the vulnerability of the slum, particularly studies using GIS mapping and MCDM methods.
- Research in various geographic settings using concrete data on population trends in urban slums.

3.2 Quality evaluation and data extraction

The selected studies were screened for methodological quality and relevance to the urban slum environment. Data were extracted to note the indicators of vulnerability used, the methods applied, and the implications for policies that were considered. Narrative synthesis and quantitative aggregations were used where feasible in order to synthesize results across the included studies.

3.3 Contextual link with Yavatmal city

The distinctive Yavatmal City setting is integrated by aligning the international literature using specific prior field experience findings. The discussion considers how methods like the use of GIS and the Multi-Criteria Decision Making (MCDM) method applied in Yavatmal previously can be integrated with larger conclusions to provide actionable solutions for city planners in other similar tier-2 cities.

4.0 Results and Discussion

4.1 Synthesis of findings of the literature

The analysis yielded strong differences between studies in how vulnerability is defined and assessed. In spite of these differences, there is a clear agreement that vulnerability in urban slums is multidimensional and intertwined. For instance, studies conducted using spatial analysis uniformly indicate that environmental hazards are heightened by infrastructural conditions. Equally, social and economic vulnerabilities are revealed to reinforce one another, where low literacy levels and casual labor further constrain community resilience and adaptation capacity.

4.2 A comparison across studies shows that

- Research that utilizes GIS mapping offers a scientific basis for determining environmental risk assessment yet might lack socio-economic sophistication.
- MCDM methods provide a strong system to synthesize various vulnerability indicators, but their efficacy is reliant upon the quality of the input data.
- Qualitative studies give in-depth contextual information on social and economic issues, though rarely quantify the degree of vulnerabilities.

4.3 Contextual analysis: Yavatmal city insights

The analysis also gives a comprehensive overview of the Yavatmal City case, citing important vulnerabilities that reflect global trends as well as unique local issues. Field studies and prior analyses in Yavatmal have pointed towards critical issues like:

- The heavy concentration of slum settlements in environmentally risky or flood-prone areas, primarily a result of fast and unplanned urban expansion.

- Characterized by a socio-economic profile of high informal employment and financial insecurity that results in a persistent cycle of poverty.
- Infrastructural shortcomings, such as insufficient water supply, sanitation, and uncertain road networks, that directly raise the level of susceptibility of residents during emergencies

The precise GIS mapping in earlier studies in Yavatmal offers unambiguous spatial trends corresponding to the conclusions in the larger literature, and hence offers support to the usefulness of integrated assessment frameworks in various city contexts.

5.0 Policy Implications and Recommendations

Based on the synthesis of the literature and the contextual observations in Yavatmal, the following policy recommendations arise:

- *Integrated assessment tools:* Policymakers and urban planners ought to use integrated vulnerability assessment tools that integrate GIS mapping and MCDM methods. Integrating GIS mapping and MCDM methods would enable them to get a better understanding of how various vulnerabilities interact.
- *Infrastructure strengthening:* Investment in the upgrading of core infrastructure—water supply, sanitation facilities, roads, etc.—is the key to vulnerability reduction in the slum environment. Moreover, policies which support enhancing secure tenure can also build lasting resilience.
- *Economic empowerment and social inclusion:* Economic and social inclusion initiatives in the form of microfinance schemes and vocational skill development schemes are the key to eradicating the cycle of poverty. Additionally, improving social engagement and ensuring that marginalized communities, women in particular and minority groups, benefit by having a voice in urban planning can result in better and inclusive policies.
- *Regular monitoring and evaluation:* Having a system of regular monitoring of vulnerability indicators through the application of improved spatial and decision-support tools will allow for timely adjustments of policies and resource allocations.

6.0 Limitations and Areas for Future Research

While the literature contains many studies of slum vulnerability, in the review the authors find multiple gaps in the research:

- The majority of studies focus largely on environmental and infrastructural vulnerabilities but give less consideration to long-term socio-economic concerns.
- Much of the assessment is cross-sectional, and there is a need for longitudinal studies that track how vulnerabilities change over time.
- The diversity of methodologies reduces the comparability of findings across contexts. This may provide a basis for the development of standardized indicators and assessment procedures that would allow comparative analysis with implications for public policy.

These reflect promising avenues for future work, which could include more integrative, longitudinal studies that involve local stakeholders directly in the research process.

7.0 Conclusion

In this paper, we have conducted a systematic review of the existing literature on vulnerability assessment as understood in urban slums, synthesising a diverse body of work to draw attention to the multidimensionality of vulnerability. The synthesis demonstrates that integrated approaches with a specific focus on those incorporating GIS and MCDM tools can provide a promising platform for assessing and addressing risks in slum contexts. Yavatmal City, as a case study, highlights how tier-2 cities in India are plagued with these pressing challenges – Infrastructure deficits, socio-economic instability, and environmental hazards combine to make vulnerability worse.

The review ends with a number of key recommendations:

- Multidisciplinary assessment frameworks should be employed, embracing the environmental, infrastructural, social and economic dimensions of urban policies.
- Improvement in living conditions of slum dwellers depends crucially on investment in basic services and secure tenure, and economic empowerment and inclusive governance.
- Regular, standardised monitoring will enable the adjustment of policies over time to the changing nature of the threats posed, making sure that interventions remain responsive and effective.

In conclusion, the existing methods can provide insight into vulnerabilities present in urban slums, however there are considerable opportunities to improve and standardize these methods. Mitigating those gaps via integrative research and policy actions may lead to resilient urban settings, contributing to sustainable development for everyone.

References

Awasthi, S., Maroof, M., Singh, H., & Singh Martolia, K. (2024). Mapping and vulnerability assessment in urban slums of Nainital and Udham Singh Nagar districts of Uttarakhand: A cross-sectional survey. *Indian Journal of Community Health*, 36(2). <https://doi.org/10.47203/IJCH.2024.v36i02.007>

Corburn, J., & Sverdlik, A. (2017). Slum upgrading and health equity. *International Journal of Environmental Research and Public Health*, 14(4), 342. <https://doi.org/10.3390/ijerph14040342>

Damte, E., Manteaw, B. O., & Wrigley-Asante, C. (2023). Urbanization, climate change and health vulnerabilities in slum communities in Ghana. *The Journal of Climate Change and Health*, 10, 100189. <https://doi.org/10.1016/j.joclim.2022.100189>

Effat, H. A., Ramadan, M. S., & Ramadan, R. H. (2022a). A spatial model for assessment of urban vulnerability in the light of the UN New Urban Agenda guidelines: Case study of Assiut City, Egypt. *Modeling Earth Systems and Environment*, 8(3), 3687–3706. <https://doi.org/10.1007/s40808-021-01281-7>

Egum, H., & Moinuddin, G. (2018). Livelihood framework: Understanding poverty and vulnerability and coping strategies of the urban poor in Dhaka. *The Journal of Social Sciences Research*, (Special Issue), 101–108. Retrieved October 2, 2024, from <https://ideas.repec.org/a/arp/tjssrr/2018p101-108.html>

Elsey, H., Manandah, S., Sah, D., Khanal, S., MacGuire, F., King, R., Wallace, H., & Baral, S. C. (2016). Public health risks in urban slums: Findings of the qualitative “Healthy Kitchens Healthy Cities” study in Kathmandu, Nepal. *PLoS ONE*, 11(9), e0163798. <https://doi.org/10.1371/journal.pone.0163798>

Ernst, K. C., Phillips, B. S., & Duncan, B. D. (2013). Slums are not places for children to live: Vulnerabilities, health outcomes, and possible interventions. *Advances in Pediatrics*, 60(1), 53–87. <https://doi.org/10.1016/j.yapd.2013.04.005>

Furszyfer Del Rio, D. D., & Sovacool, B. K. (2023). Of cooks, crooks and slum-dwellers: Exploring the lived experience of energy and mobility poverty in Mexico’s informal settlements. *World Development*, 161, 106093. <https://doi.org/10.1016/j.worlddev.2022.106093>

Jankowska, M. M., Weeks, J. R., & Engstrom, R. (2011). Do the most vulnerable people live in the worst slums? A spatial analysis of Accra, Ghana. *Annals of GIS*, 17(4), 221–235. <https://doi.org/10.1080/19475683.2011.625976>

Joulaei, H., Keshani, P., Foroozanfar, Z., Afrashteh, S., Hosseinkhani, Z., Mohsenpour, M. A., Moghimi, G., & Homayouni Meymandi, A. (2023). Food insecurity status and its contributing factors in slums’ dwellers of southwest Iran, 2021: A cross-sectional study. *Archives of Public Health*, 81(1). <https://doi.org/10.1186/s13690-023-01049-8>

Kapoor, A., & Thakur, B. (2020). Slum upgradation, redevelopment and relocation through slum vulnerability assessment in Delhi. In *Urban and Regional Planning and Development: 20th Century Forms and 21st Century Transformations* (pp. 221–241). Springer. https://doi.org/10.1007/978-3-030-31776-8_14

Kher, J., Aggarwal, S., & Punhani, G. (2015). Vulnerability of poor urban women to climate-linked water insecurities at the household level: A case study of slums in Delhi. *Environment and Urbanization ASIA*, 22(1), 15–40. <https://doi.org/10.1177/0971521514556943>

Kumar, J. (2014). Slums in India: A focus on metropolitan cities. *International Journal of Development Research*. <http://www.journalijdr.com>

Marwasta, D., & Rahayu, T. D. K. (2020). Spatial distribution of slums and its association with disaster vulnerability in Yogyakarta City. *E3S Web of Conferences*, 200, 03011. <https://doi.org/10.1051/e3sconf/202020003011>

Mukherjee, S., Sundberg, T., & Schütt, B. (2020). Assessment of water security in socially excluded areas in Kolkata, India: An approach focusing on water, sanitation and hygiene. *Water*, 12(3), 746. <https://doi.org/10.3390/w12030746>

Mundhe, N. (2019). Identifying and mapping of slums in Pune city using geospatial techniques. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 42(5/W3), 57–63. <https://doi.org/10.5194/isprs-archives-XLII-5-W3-57-2019>

Nabirye, C., Denyer Willis, L., Nayiga, S., Kayendeke, M., Staedke, S. G., & Chandler, C. I. R. (2023). Antibiotic “entanglements”: Health, labour and everyday life in an urban informal settlement in Kampala, Uganda. *Critical Public Health*, 33(1), 95–104. <https://doi.org/10.1080/09581596.2021.1994526>

Nath, S., Schneider, S., Kabisch, S., & Karutz, R. (n.d.). Slum upgrading schemes for better liveability: Case of Pune, India. *Faculty of Architecture and Urbanism*.

Nguyen, T. P. L., & Pattanarsi, S. (2022). WASH, vulnerability, severity, and the response of urban slum dwellers to the COVID-19 pandemic. *Journal of Water, Sanitation and Hygiene for Development*, 12(8), 600–611. <https://doi.org/10.2166/washdev.2022.076>

Owusu, M., & Nurse-Bray, M. (2019). Socio-economic and institutional drivers of vulnerability to climate change in urban slums: The case of Accra, Ghana. *Climate and Development*, 11(8), 687–698. <https://doi.org/10.1080/17565529.2018.1532870>

Pitoyo, A. J., & Kurniawan, A. (2020). Vulnerability of economic resilience of slum settlements in the city of Palembang. *IOP Conference Series: Earth and Environmental Science*, 451(1), 012106. <https://doi.org/10.1088/1755-1315/451/1/012106>

Plaza del Pino, F. J., Chraibi, G., Molina-Gallego, B., Humanes-García, M., Sánchez-Ojeda, M. A., & Ugarte-Gurrutxaga, M. I. (2024). Access to the health care system of undocumented Moroccan migrant slum dwellers in southern Spain: A qualitative study. *Nursing Reports*, 14(1), 494–505. <https://doi.org/10.3390/nursrep14010038>

Quintana Vigiola, G. (2022). Informal housing and residents' well-being in Caracas and Sydney: A comparative study of residents' experiences. *Global Discourse*, 12(2), 289–308. <https://doi.org/10.1332/204378921X16309244430387>

Rao, B. T., & Thakur, J. S. (2007). Vulnerability assessment in slums of Union Territory, Chandigarh. *Indian Journal of Community Medicine*, 32(3), 189–191. <http://www.journalonweb.com>

Svensson, E., Hansson, M., & Nilsson, P. (2020). 'As far below as you can come'? Historical archaeology on vulnerability and marginalization of life at the bottom of the social ladder. *Post-Medieval Archaeology*, 54(2), 165–185. <https://doi.org/10.1080/00794236.2020.1812291>

Yulastuti, N., Sariffudin, & Syafrudin. (2023). Social vulnerability level appraisal at tidal flood areas: The case of a coastal settlement in Indonesia. *International Review for Spatial Planning and Sustainable Development*, 11(2), 99–113. https://doi.org/10.14246/irspsd.11.2_99

Zaman, H. (2018). Vulnerability and social exclusion in urban settings: A comparative analysis. *The Journal of Social Sciences Research*, (Special Issue), 184–193. <https://ideas.repec.org/a/arp/tjssrr/2018p184-193.html>

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