NICMAR
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CONVERGING HORIZONS

IN CONSTRUCTION AND THE BUILT ENVIRONMENT

DIGITAL, SUSTAINABLE AND STRATEGIC PERSPECTIVES

Volume 2

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

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VOLUME 2

About the Book

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

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

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

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

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

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

About the Editors

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

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

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

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

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

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

About the Editors

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

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

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

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

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

Preface

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

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

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

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

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

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

Editors

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

Acknowledgements

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

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

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

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

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

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

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

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

CHAPTER 41

Contractual Risk Allocation in EPC Mega Projects

Jebin George Roy[1], Sanchit Gupta[2], Rahul Dewangan[2] and Kurisuveettil Thomas Paul[2]*

ABSTRACT

This study investigates the complexities of contractual risk allocation in EPC megaprojects, combining insights from a literature review and primary data collected through a structured questionnaire. Data was gathered from industry professionals across the construction, energy, and infrastructure sectors through purposive sampling. Megaprojects, characterized by their scale and complexity, face risks ranging from technical and economic to political and social, requiring effective risk management for successful outcomes. Preliminary results highlight that inadequate risk-sharing mechanisms and ambiguities in contract terms often lead to disputes and delays. Participants emphasized the effectiveness of proactive strategies, including clear contract clauses and fair risk-sharing frameworks. The findings also reveal sectoral variations in risk allocation practices, highlighting the need for customized approaches based on project characteristics and regional contexts. Challenges such as power imbalances in negotiations and resistance to innovation due to risk aversion were noted. The study provides actionable recommendations for policymakers and practitioners to improve risk management frameworks, contributing to the broader success of large-scale construction projects.

Keywords: EPC megaprojects; Risk allocation; Contract management; Risk mitigation; Stakeholder collaboration.

1.0 Introduction

Effective project management focuses on the ability to identify, assess, and mitigate potential risks. In any project, but particularly in large, complex projects termed as megaprojects, an important aspect of risk management is risk allocation. This refers to the process of assigning responsibility for bearing the consequences of specific risks to different project stakeholders through contracts. Contractual risk allocation defines which party (owner, contractor, etc.) will be financially responsible for cost overruns, schedule delays, or other negative outcomes that may arise due to unforeseen circumstances. Megaprojects are inherently risky. Their large scale, extended timelines, and often cutting-edge technologies expose them to a wider range of uncertainties compared to smaller projects.

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These uncertainties can be technical (e.g., unforeseen ground conditions), economic (e.g., fluctuating material costs), political (e.g., regulatory changes), or social (e.g., public opposition). Traditional risk allocation approaches in project contracts may not be sufficient for the complexities of megaprojects. Inadequate risk allocation can lead to several problems: Disputes and claims**;** Disincentivization for innovation; and Project failure**.** This research project delves into the challenges and opportunities associated with contractual risk allocation in megaprojects. It aims to explore: Effective risk identification and assessment methods tailored to the specific characteristics of megaprojects; Contractual clauses and risk-sharing mechanisms that promote fair and efficient risk allocation between project stakeholders. By providing insights into effective risk allocation strategies, the research can help to: Reduce project risks and uncertainties; Improve project planning, budgeting, and scheduling; Facilitate better decision-making throughout the project lifecycle; Minimize disputes and claims; Enhance collaboration and communication among project participants; Increase the likelihood of project success. The prime research objective will be focused on below mentioned areas:

- To investigate the current practices and challenges of contractual risk allocation in megaprojects across different industries and regions.
- To assess the role of proactive risk management strategies in enhancing project success and mitigating conflicts in contractual risk allocation within megaprojects.

2.0 Review of Literature

Effective risk management begins with identifying potential risks that can affect the results of the project. Mubin *et al.* (2008) emphasized the importance of a structured approach as a risk assessment structure (RBS) to classify risks such as organizational challenges, natural destruction and investment uncertainty in gas pipeline projects. Similarly, Ferrada *et al.* (2014) emphasized the need to identify major risk factors in politically unstable areas by taking advantage of insights from experienced professionals. These studies emphasize that risk identification is necessary to reduce active risk management and project disorder.

The Quantitative models had been broadly hired to assess risks systematically. Lam *et al.* (2007) advanced a fuzzy logic-based decision version to transform professional expertise into measurable standards for chance allocation choices. Wang *et al.* (2012) brought the Analytic Hierarchy Process (AHP) mixed with intuitionistic fuzzy sets to evaluate dangers in electricity control contracts. These techniques provide frameworks for assessing risks, permitting stakeholders to prioritize them effectively, primarily based on probability and effect. However, their applicability is frequently contingent on data accuracy and adaptableness to diverse assignment contexts. Mitigating risks entails strategies to minimize their effect on venture performance. Mannan *et al.* (2013) confused the want for tailored mitigation procedures in EPC tasks inside challenging environments like Pakistan's oil and fuel sector. Tang *et al.* (2019) confirmed that collaborative partnering enhances interface management and mitigates risks in

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global EPC initiatives, mainly for Chinese creation agencies. These findings suggest that each technical techniques and collaborative methods are vital for powerful risk mitigation, specially in complex mega-initiatives. Equitable risk allocation is vital for minimizing disputes and ensuring undertaking success. Bali *et al.* (2014) tested the financial implications of risk allocation in EPC contracts, emphasizing its position in growing bankable agreements that steady lender assist. However, Loosemore *et al.* (2008) and Zain *et al.* (2018) discovered dissatisfaction amongst contractors regarding unequal bargaining strength in oilfield contracts, highlighting the need for fairer contractual terms to cope with power imbalances. Effective communication is crucial for aligning stakeholder perceptions of hazard obligations inside agreement frameworks. Zulhaiz *et al.* (2017) in addition emphasized that obvious conversation mechanisms are cruciato minimizing conflicts in international oil and gas projects.

3.0 Research Methodology

The research employs a quantitative approach, utilizing a structured questionnaire to gather data from industry professionals involved in megaprojects. This approach allows for the collection of measurable insights regarding the risks these professionals encounter, the strategies they use to allocate and mitigate such risks, and the effectiveness of these strategies. The primary data collection method is a questionnaire survey, administered to a target group of professionals working in fields such as construction, energy, infrastructure, and other sectors where megaprojects are prevalent.

The questionnaire is designed to capture a wide range of information, including both demographic data (e.g., years of experience, sector) and detailed responses about various risk types and contractual risk allocation practices. The survey is targeted at professionals with experience in managing or executing megaprojects, including project managers, engineers, consultants, and executives. A purposive sampling method was chosen to focus on individuals with direct knowledge and expertise in contractual risk allocation within their respective projects. Upon completion of data collection, responses will be analyzed by utilizing descriptive statistics to summarize the findings, highlighting key insights into common risks, preferred risk allocation methods, and common challenges.

4.0 Data Analysis and Findings

This section presents the analysis of data collected on contractual risk allocation in EPC megaprojects. The findings highlight key trends in how risks are distributed among project stakeholders, the criteria influencing these decisions, and the effectiveness of various risk mitigation strategies. The analysis provides insights into risk identification, allocation mechanisms, and the challenges associated with achieving balanced risk-sharing agreements.

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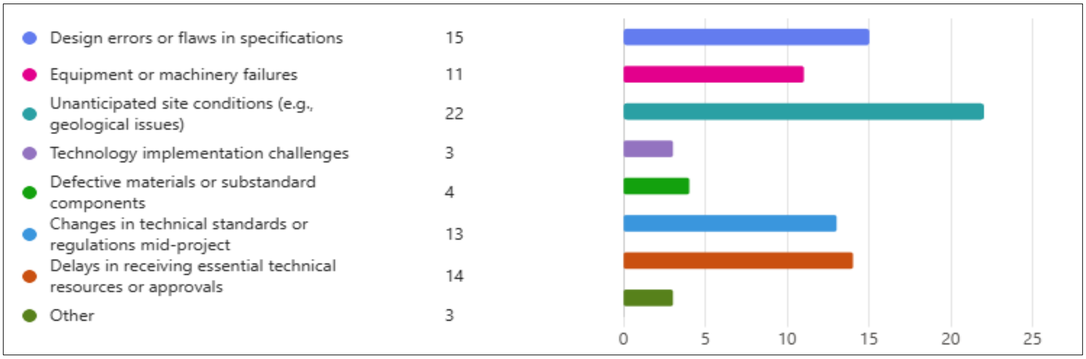
Figure 1: Technical Risks



From Figure 1, the various identified technical risks include design errors or flaws in specifications, equipment or machinery failures, and unanticipated site conditions such as geological issues. Additionally, challenges related to technology implementation, defective materials, and mid-project changes in technical standards or regulations were examined. Furthermore, delays in receiving essential technical resources or approvals were also highlighted as a critical risk factor. Out of these, it can be observed that unanticipated site conditions are the most frequently encountered technical risk in megaprojects. These conditions, such as unexpected geological issues, can cause significant disruptions to project timelines and budgets. Design errors or flaws in specifications are also a commonly reported challenge, indicating that inaccuracies in initial planning can lead to major project delays. Delays in receiving essential technical resources or approvals are another notable concern, highlighting the bureaucratic and logistical challenges that hinder smooth project execution.

Additionally, changes in technical standards or regulations mid-project pose a risk, emphasizing the need for adaptability in contract terms. While equipment or machinery failures are a concern for many, technology implementation challenges and defective materials appear to be less frequently encountered risks. This suggests that while technological advancements have improved reliability, regulatory and environmental uncertainties remain key obstacles in megaproject execution. From Figure 2, the various identified economic risks include fluctuating material costs, inflation, and rising labor costs, which significantly influence project budgets. Additionally, currency exchange rate volatility, delays in payments from clients or stakeholders, and shortages of funds or financing challenges were examined. Other economic risks assessed include the financial instability of subcontractors or suppliers, reduced access to credit or unfavorable lending conditions, and bankruptcy or insolvency risks of key partners. Out of these risks, it is evident that fluctuating material costs are the most significant economic risk impacting megaprojects. The volatility in raw material prices can lead to budget overruns, making cost estimation and financial planning challenging. Inflation and rising labor costs are also major concerns, reflecting the increasing expenses associated with workforce management.

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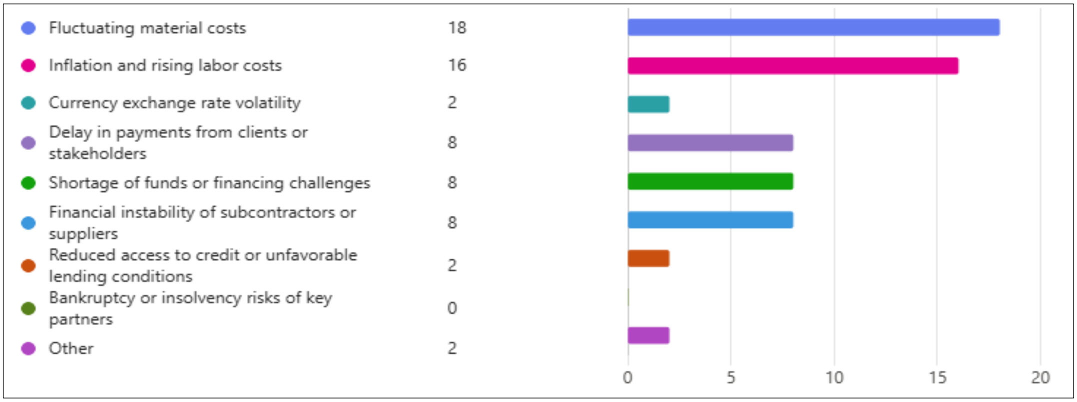
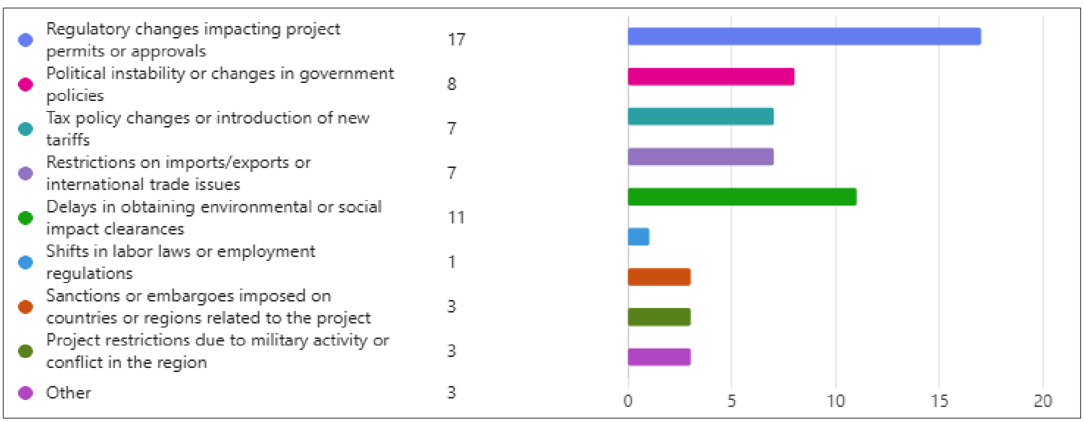
Figure 2: Economic Risks



Additionally, delays in payments from clients or stakeholders, along with shortages of funds or financing challenges, are common issues that can disrupt cash flow and hinder project progress. The financial instability of subcontractors or suppliers is another noteworthy risk, emphasizing the need for due diligence in selecting reliable partners. On the other hand, risks related to currency exchange rate volatility, reduced access to credit, or bankruptcy of key partners appear to be less frequently encountered, suggesting that while economic fluctuations are a challenge, they are often mitigated through strategic financial planning and contractual safeguards.

Figure 3: Political Risks



From Figure 3, the political risks identified include regulatory changes affecting project permits or approvals, political instability, and changes in government policies, which can create uncertainty in project execution. Additionally, tax policy changes, new tariffs, and restrictions

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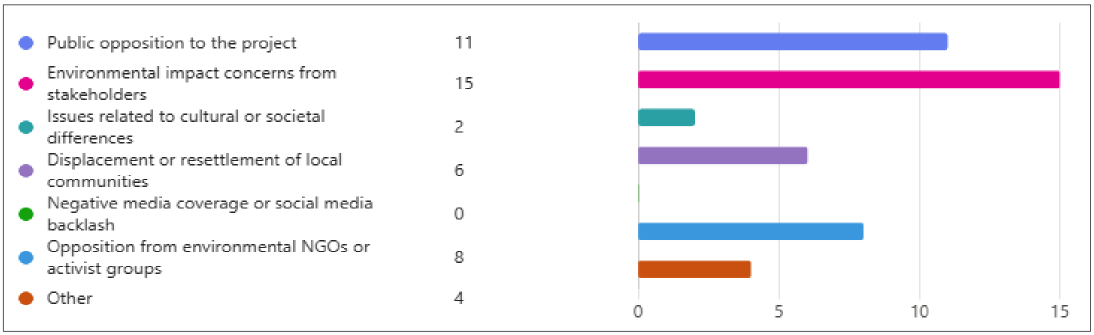
on imports/exports or international trade issues were examined due to their influence on project costs and supply chains. Delays in obtaining environmental or social impact clearances, shifts in labor laws or employment regulations, and sanctions or embargoes imposed on specific regions were also identified as key risks. Furthermore, project restrictions due to military activity or conflict in the region were also considered. Out of these risks, it can be observed that regulatory changes impacting project permits or approvals are the most significant political risk affecting megaprojects. Frequent amendments in regulations can create uncertainty, leading to project delays and increased compliance costs. Delays in obtaining environmental or social impact clearances are another major concern, reflecting the challenges associated with fulfilling sustainability requirements and stakeholder expectations. Political instability or changes in government policies also pose a substantial risk, potentially affecting project continuity and investment confidence. Additionally, tax policy changes and restrictions on imports/exports are noteworthy risks, as fluctuating trade regulations can disrupt supply chains and increase procurement costs. Less commonly reported risks include shifts in labor laws, sanctions on specific regions, and project restrictions due to military activity or conflict, suggesting that while political instability is a concern, its impact varies depending on the project's location and scope.

Figure 4: Social Risks



From Figure 4, the social risks identified include public opposition to the project, environmental impact concerns from stakeholders, issues related to cultural or societal differences, displacement or resettlement of local communities, opposition from environmental NGOs or activist groups and negative media coverage or social media backlash Out of these risks, it is evident that environmental impact concerns from stakeholders are the most prominent social risk in megaprojects. These concerns often arise due to potential ecological damage, resource depletion, and long-term environmental consequences, leading to resistance from both local communities and regulatory bodies. Public opposition to the project is another significant factor, reflecting community apprehensions about the project's impact on their livelihood, surroundings, or cultural heritage.

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Additionally, opposition from environmental NGOs or activist groups is a notable challenge, indicating the growing influence of social movements in project approval processes. Negative media coverage or social media backlash also plays a role, potentially shaping public perception and affecting project viability. Other social risks include displacement or resettlement of local communities, which can lead to conflicts if not managed with adequate compensation and rehabilitation measures. Less frequently encountered risks include issues related to cultural or societal differences, which, while not as widespread, can still create challenges in specific regions.

From Figure 5, it can be observed that liquidated damages clauses are the most commonly used contractual provisions for risk allocation. These clauses ensure that financial penalties are in place to compensate for delays or non-performance, making them a widely adopted risk mitigation tool. Force majeure clauses are the next most prevalent, highlighting the significance of protecting parties from unforeseen circumstances such as natural disasters, political unrest, or pandemics. Indemnity clauses also play a crucial role, offering protection against losses arising due to third-party claims or project-related liabilities. A small fraction of respondents indicated the use of other clauses, suggesting that while standard provisions dominate risk allocation strategies, some projects may require customized contractual terms based on unique risk factors.

Figure 5: Contract Clauses to Address Risk Allocation

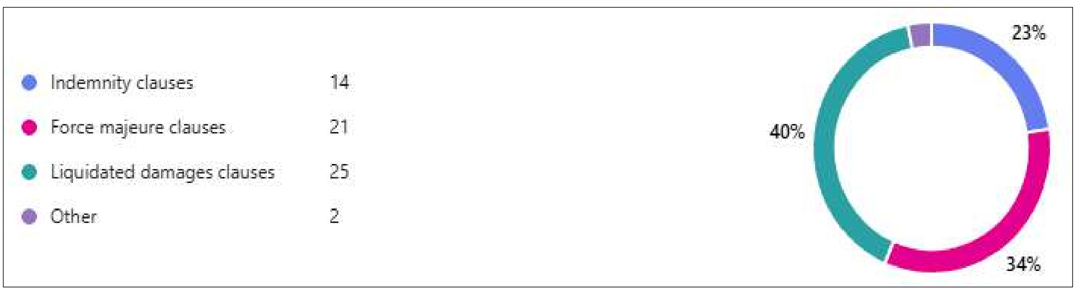
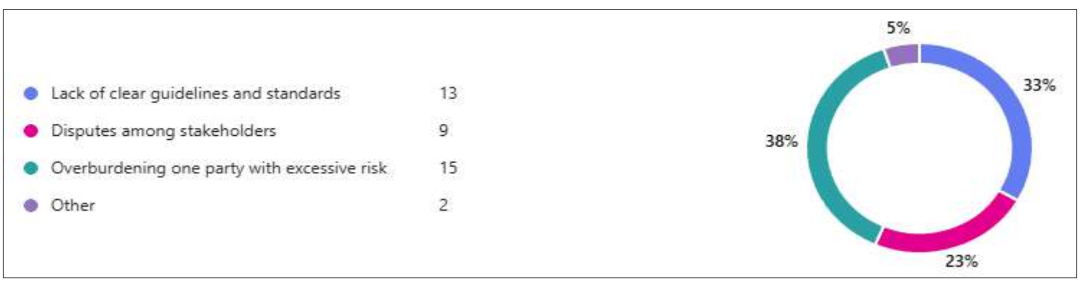


Figure 6: Challenges Faced in Effective Risk Allocation



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From Figure 6, it can be observed that overburdening one party with excessive risk is the most significant challenge in implementing effective risk allocation in megaprojects. This suggests that risk distribution is often imbalanced, leading to disputes or financial strain on certain stakeholders. The lack of clear guidelines and standards is another major issue, indicating that the absence of well-defined frameworks creates uncertainty and inconsistencies in risk allocation practices. Disputes among stakeholders also pose a considerable challenge, reflecting the complexities involved in negotiating and agreeing on risk-sharing terms. A small percentage of respondents cited other challenges, implying that while the primary concerns are well-documented, there may be additional project-specific difficulties in achieving fair and effective risk distribution.

Figure 7: Lessons Learnt from Past Risk Allocation Practices

From Figure 7, the most significant lesson learned from past risk allocation practices is the importance of clear contract terms (43%). This highlights that well-defined contractual agreements play a crucial role in minimizing ambiguities and ensuring fair risk distribution in megaprojects. Another key takeaway is the value of regular risk reviews (31%), suggesting that continuous monitoring and reassessment of risks are essential for effective risk management. Additionally, the need for continuous stakeholder collaboration (26%) emphasizes that open communication and cooperation among all parties can help in addressing potential disputes and ensuring smoother project execution. These findings indicate that improving contractual clarity, fostering collaboration, and implementing regular risk reviews can enhance risk allocation strategies in future megaprojects.

From Figure 8, it can be observed that improving contractual clarity is the most recommended approach to enhance risk allocation practices in future projects. This emphasizes the need for well-defined and transparent contract terms to ensure fair risk distribution and minimize conflicts. The use of advanced risk assessment tools is also a significant recommendation, highlighting the importance of leveraging technology and analytical methods to identify, evaluate, and mitigate risks effectively. Enhancing stakeholder communication is another key suggestion, indicating that better collaboration and dialogue among project participants can lead to more effective risk-sharing strategies. A small percentage of respondents

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suggested other recommendations, implying that while contractual clarity, risk assessment tools, and communication are the primary areas for improvement, additional strategies may also be beneficial in specific project contexts.

Figure 8: Recommendations to Improve Risk Allocation Practices

5.0 Conclusion

The study has given the following inferences:

- Contractual risk allocation plays a pivotal role in the management of megaprojects. Organizations face substantial challenges due to unanticipated site conditions and cost fluctuations, which disrupt project timelines and budgets. This underscores the necessity for robust contractual frameworks that clearly define risk responsibilities to mitigate potential disruptions effectively.
- Cost volatility in materials and labor is a predominant financial challenge, necessitating comprehensive budgeting and effective contract mechanisms. The reliance on sophisticated cost management strategies, such as fixed-price contracts or cost-reimbursable contracts with cap limits, can help stabilize project economics, while proper risk allocation can enhance profitability and project feasibility.
- Regulatory changes and environmental compliance delays emerge as significant political risks that can derail megaprojects. To navigate these challenges, contracts should include provisions for risk-sharing related to regulatory approvals and compliance processes. Such contractual terms can facilitate smoother interactions with stakeholders and reduce the likelihood of cost overruns and schedule delays associated with bureaucratic hurdles.
- The emphasis on environmental concerns in project execution highlights the importance of integrating sustainability-focused planning into contractual agreements. Engaging with stakeholders proactively through formalized communication channels can be embedded in contracts to address community impacts, thus enhancing project acceptance and reducing opposition related to environmental risks.

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- Organizations predominantly utilize collaborative discussions and historical knowledge for anticipating risks, implying that contracts should encourage knowledge-sharing among stakeholders. This could include clauses that promote the use of historical data and expert opinions in decision-making processes, fostering a culture of experiential learning within the project environment.
- The diversity in risk allocation indicates a trend towards more flexible and balanced approaches in contract negotiations. While some contracts disproportionately allocate risks to the owner or contractor, there is a significant movement towards shared risk agreements. Crafting balanced contracts can minimize disputes and promote cooperation among parties, leading to more successful project outcomes.
- The presence of clauses related to liquidated damages and force majeure in contracts reflects the importance of financial protection against unforeseen events. These clauses act as safety nets, ensuring that the parties involved have predefined mechanisms for managing unforeseen circumstances, thereby enhancing the resiliency of contractual risk allocation frameworks.
- The preference for negotiation and mutual agreement in ensuring fair risk distribution suggests that effective communication is crucial in contract implementation. Contracts should include mechanisms for dispute resolution and negotiation processes that prioritize collaboration, fostering an environment where parties can navigate conflicts without resorting to litigation.
- Many organizations prioritize contingency planning and risk reserves as a proactive strategy against unforeseen challenges. This approach underscores the need for contracts to include clear guidelines on the management of contingencies and the allocation of reserves, thus ensuring financial stability and operational resilience throughout the project lifecycle.
- Continuous stakeholder collaboration is identified as a critical lesson learned from past projects, affirming that relationship management is as vital as the contractual terms. Contracts should emphasize the importance of regular stakeholder engagement and communication protocols to maintain transparency and trust, ultimately leading to enhanced risk management and project success in megaprojects.

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CHAPTER 42

Cost and Benefit Analysis of Green Buildings Versus Conventional Buildings

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ABSTRACT

The growing demands of environmental sustainability and urbanization make the use of green building principles imperative. This study compares the costs and benefits of green versus conventional structures in India based on lifecycle costs, greenhouse gas emissions, and energy use. The study assesses the financial and ecological effects of green building using methods like Cost-Benefit Analysis (CBA) and Life Cycle Cost Analysis (LCCA). The results show that operational cost reductions from water, energy, and sustainable materials offset the higher investment required for green buildings, which range from 16% to 43.3%. Payback periods typically range from two to six years. Office and residential building case studies indicate substantial decreases in electrical energy consumption per year (38.7%–73.9%) and improved occupant health, due to better indoor air quality and daylighting. According to research, the short-term costs of implementing green buildings are higher, with estimates of According to a systematic participant study of designers, architects, and users, the main obstacles to the adoption of green buildings are market reluctance, technical limitations, and budgetary constraints. However, long-term economic savings and environmental concerns continue to be very strong motivators. According to the report, policy measures like tax breaks and building codes are essential for green building. This study supports the move toward sustainable urban development by highlighting the financial and environmental advantages of green buildings. To accelerate the adoption of green buildings and ensure a resilient and green urban future, it encourages collaboration amongst environmental authorities, developers, and policymakers.

Keywords: Green buildings; Sustainable construction; Environmental sustainability; Cost-benefit analysis (CBA); Life Cycle Cost Analysis (LCCA); Carbon footprint; Lifecycle costs; Operational savings; Energy efficiency; Sustainable materials; Economic feasibility.

1.0 Introduction

With roughly 40% of global energy consumption including 30% of emission of greenhouse gases, the construction industry has been one of the main causes of environmental issues after the growing urbanization of the world.

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Despite ostensibly providing a short-term cost benefit, reliance on conventional forms has resulted in increased resource depletion, efficiency losses, and long-term maintenance expenses. These structures, which are often built with traditional materials and techniques, consume a lot of water and energy and release massive amounts of carbon dioxide over the course of their lives. However, the ecologically responsible approach is to design green buildings in accordance with internationally recognized standards like those set forth by IGBC. Green buildings lessen their environmental impact by using environmentally friendly materials, water conservation regulations, and energy-efficient designs. Green buildings are an effective method of decreasing the negative environmental effects of urban expansion because they prioritize energy efficiency, better interior air quality, and improved occupant health. Nevertheless, the widespread adoption of green buildings has fallen short of expectations in spite of all these well-established facts.

The primary obstacle that deters developers and investors is the alleged high initial investment cost. Additionally, the shift to sustainable development is hampered by unclear financial incentives, fragmentary norms, and a lack of stakeholder awareness. With reference to a model IGBC Gold-rated office structure in India, this study compares the costs and benefits of green and conventional buildings in great detail to solve these issues. The study estimates the long-term economic and ecological benefits of sustainable development by combining environmental impact analysis, energy modeling, and financial modeling. By calculating the potential cost savings, energy efficiency gains, and greenhouse gas reduction, the study seeks to produce evidence-based conclusions that inform policy changes, spur green infrastructure investment, and quicken the transition to sustainable urban development.

2.0 Research Objectives

- Compare the initial and ongoing expenses of conventional vs green structures.
- Calculate how much fewer resources such as water, energy, and carbon are used in projects that have earned IGBC certification.
- Analyse how policy incentives, such as solar subsidies and GST rebates, affect financial viability.
- Provide methods to reduce adoption obstacles by educating stakeholders and enlisting regulatory assistance.

3.0 Methodology

A combination of methods was used:

- Hypothetical Case Study: IGBC Gold requirements (AAC blocks of information, VRF HVAC, solar panelling) and traditional standards (RCC, split ACs) were used to create a 2,300-square-meter office building.

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- Financial study includes payback period, sensitivity analysis, and the net present value (NPV), or (6–10% discount rates, along with 3–7% inflation).
- Environmental Metrics: Operating carbon (CEA grid factors) and embodied carbon (ICE database).
- Stakeholder surveys: 37 experts participated in structured interviews to gauge their opinions on the viability of green buildings.

4.0 Literature Review

Research comparing green and conventional buildings emphasizes the long-term advantages of sustainable construction as well as its cost-effectiveness and environmental impact. Numerous studies have examined the economic and environmental elements of green buildings, with particular attention on life cycle costs, carbon footprint, energy usage, and occupant well-being. In Bangalore, India, Srikar *et al.* (2022) was contrasting an environmentally friendly office building with a traditional one, highlighting the fact that 39% of carbon emissions worldwide are caused by the building sector. According to their research, which used Cad 2021, SketchUp over illustration, the ICE library for embodied carbon evaluation, and STACK technology for cost estimation, sustainable buildings use a lot less power (100 kWh/m²/year compared to 180 kWh/m²/year). Double-glazed windows, rooftop solar panels, effective air conditioning and heating, and water conservation solutions are some of the key features. In a similar vein, Warang *et al.* (2023) compare conventional and sustainable structures in Thane, India, and find that the initial cost of green buildings is 21.23% more because of features like solar power and rainwater collecting. But thanks to operational savings, these investments are recouped in ten years. Green buildings encourage urban sustainability and raise property values.

Focusing on cost-benefit analysis, Saurav & Abrol (2018) discover that green buildings are cost-effective despite their higher initial costs because they use 38.7% fewer kWh than conventional ones. Boyajian & Zirakian (2019) examine a sustainable house in Los Angeles, pointing out the advantages of energy conservation and rainwater harvesting while projecting a 30% rise in building costs because of LEED certification. Life cycle cost analysis is emphasized by Appa Saheb Shantappa Ingale, who concludes that green buildings are 16% more expensive initially but pay for themselves in two to three years due to lower energy and water costs. Water expenses are greatly reduced by the study’s rainwater gathering system, which gathers 64,010 litters a year. According to Rehm & Ade (2013), sustainable office buildings have reduced running costs to make up for their 2%–8% higher construction costs. According to Jadhav *et al.* (2021), the integration of Building Information Modelling, or BIM, results in better hydraulic and electrical system design, which lowers costs in energy-efficient buildings.

In their discussion of the benefits of green buildings for occupant health, Johnson *et al.* (2016) make the connection between increased productivity and decreased absenteeism and

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natural lighting, cleaner air, and thermal comfort. According to Ms. Jyoti Paramappa Kalikeri as well as Vanakudari (2023), sustainable buildings use a lot less energy and cost less to make than conventional ones. To reduce the financial hurdles to adoption, Garcia & Thompson (2018) look at monetary incentives for environmentally friendly construction, such as tax credits, discounts, and LEED certifications. The life cycle cost analysis (LCCA) approaches are examined by Luay N. Dwaikata as well as Ali (2018), who show that investments in green buildings eventually pay off financially. Stronger regulatory support is advised by Gauri Balkrishna Tarde as well as Binayake (2022), who emphasize the value of IGBC accreditation in waste management, conserving water, and energy efficiency. To promote the adoption of green buildings, Yashwanth Pamu along with Mahesh (2019) analyse the IGBC as well as GRIHA certification systems in India and call for a single rating system. All things considered; these studies show that green buildings have long-term economic plus environmental advantages despite their higher starting costs. Stakeholder awareness, financial incentives, and policy changes are essential for hastening the adoption of green construction.

5.0 Data Analysis

5.1 Building specifications

- Plot Area: 55m × 35m (1,925 sqm)
- Built-Up Area: 55m × 30m (1,650 sqm per floor, 3,300 sqm total)
- Foundation: RCC strip footing (1.5m depth, M20 grade concrete)
- Structure: RCC columns (450mm×450mm), beams, flat slab roof (150mm thick)
- Walls: 230mm clay bricks (external), 115mm AAC blocks (internal)
- HVAC: 33 split AC units (1 ton per 100 sqm)

Figure 1: Side Elevation (Left)

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Figure 2: Side Elevation (Right)

The study's data analysis compares the cost-benefit from green buildings with those of conventional buildings using a methodical technique. A two-story workplace case study was used as an example, encompassing operational, financial, and environmental issues to allow for a comprehensive evaluation. There are one-time capital charges and ongoing operating costs associated with the financial evaluation. Conventional construction methods, such as RCC constructions, clay brick barriers, single-glazed openings, and split air conditioners, were used to rate the conventional structures. Air conditioning (AAC) blocks with insulating material, windows with double glazing, VRF air conditioning systems, roof solar power panels (50 kW), and rainwater collection systems were all used in the green building, which met IGBC Gold certification requirements. CREDAI records and benchmark rates from CPWD (2023) were used to estimate the costs of both buildings. Financial modeling used 6%–10% discount rates for life-cycle cost evaluation and 3%–7% inflation rates to account for labor, material, HVAC, plumbing systems, and electrical costs.

Energy, water, and maintenance costs were used to estimate the annual operational cost. While the environmentally friendly building's energy-efficient appliances and renewable power significantly reduced utility bills, traditional buildings had higher long-term costs because they were entirely dependent on grid electricity. According to the study, compared to conventional structures, green buildings saved 40% of their water use and 37% of the energy they consumed.

By estimating the carbon impact from energy use and building material construction, the environmental advantages were quantified. Operational carbon was computed using power usage and renewable contributions, whereas embodied carbon materials including steel, bricks, and concrete were assessed using industry-standard emission factors. Over a 20-year period, green buildings reduced their operational carbon footprint by 40% and their embodied carbon

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emissions by 30%. A 40% decrease in water dependence was also attributable to rainwater collection and greywater reuse. An analysis of long-term cost savings was conducted using the net present value (NPV) technique. The results showed that, despite their initial 17.3% higher cost, green buildings conserved ₹32.7 crore in net present value (NPV) over a 20-year period, with a 7.2-year payback period. This suggests that even though they are more expensive at first, green buildings end up being more affordable in the long run because of their energy efficiency, reduced maintenance requirements, and the availability of legislative incentives like solar subsidies and GST rebates.

The data analysis demonstrates that green structures are more environmentally friendly, economically sustainable, and operationally cost-effective than conventional buildings. The organized cost-benefit analysis emphasizes how regulatory initiatives, financial rewards, and training promote green building methods in India. The study offers a solid basis for promoting environmentally friendly and cost-effective sustainable real estate development.

6.0 Conclusion

According to the study, green buildings provide significant for a long time economic and environmental advantages over conventional buildings, while requiring more capital. Green buildings save a significant amount of money on energy (37%), water (40%), and maintenance (30%), according to a thorough cost-benefit study. This results in an estimated net present value (NPV) gain of ₹32.7 crore over 20 years, with a period of payback of 7.2 years. Lower operating costs and greater environmental sustainability are the outcomes of integrating renewable energy sources, energy-efficient technologies, and sustainable building materials.

Furthermore, the 40% reduced operating carbon footprint and 30% decrease in embedded carbon emissions highlight the overall importance of green buildings in limiting climate change and lessening the negative environmental effects of urbanization. The financial attractiveness of green construction is further enhanced by policymaking incentives like GST rebates, solar subsidies, and the advantages of IGBC certification. Incentives like greater upfront costs, a lack of knowledge among customers, and policy inequalities, however, continue to be obstacles to general acceptance.

The paper highlights the need for more regulatory instruments, financial incentives, and stakeholder knowledge to accelerate the transition to sustainable real estate. Green buildings have the potential to be the next big thing in urban development thanks to the integration of life-cycle costing, environmental analysis, and cutting-edge construction technology. Overall, this study lays the groundwork for advancing green building techniques that will eventually lead to a better, cleaner built environment by offering efficiency, responsibility to the environment, and economic feasibility.

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CHAPTER 43

Cost Escalation in Construction Projects

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ABSTRACT

Cost increases for construction projects affect economic progress, viability, and financial planning. This study, which uses the Relative Importance Index (RII) technique to analyse the primary causes, polled 111 industry experts. The findings indicate that budgetary constraints, labour shortages, worker productivity, and changes in material prices are significant factors. Stakeholders have a variety of concerns; experts highlight material costs, contractors highlight labour issues, and customers highlight financial constraints. The study highlights the importance of proactive cost projection, efficient scheduling, and stakeholder involvement. The efficiency, sustainability, and financial stability of construction may be improved by lowering risks using BIM, AI-based cost forecasting, and improved contract management.

Keywords: Construction; Construction projects; Project management; Cost; Escalation.

1.0 Introduction

The construction industry is crucial to economic growth due to its contributions to GDP, employment, and infrastructure. Nevertheless, cost escalation—when actual spending exceeds budgets—remains a serious issue. Numerous factors that impact profitability, such as design modifications, poor planning, variations in material prices, budgetary constraints, and execution delays, can cause project delays or abandonment. This problem needs to be fixed if the project is to be efficient and financially sustainable. Stakeholder disputes, poor financial management, and poor planning are the main causes of cost inflation, which affects 60% of construction projects in India. For this study, which employed the Relative Importance Index (RII) to determine significant causes of cost escalation, 111 industry experts were surveyed. The findings assist companies, project managers, and legislators in developing data-driven strategies to improve cost control and reduce financial risks. The cost escalation in the construction industry across various organisational structures is examined in this study. Financial issues like cash flow issues and late payments, as well as site management inefficiencies like subcontractor performance, are significant causes for concern.

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It also examines non-human factors like design modifications, stakeholder cooperation, and shifts in material costs and availability. The study's primary focus on development projects in India may limit its applicability to other places. The reliability of the data is also a disadvantage because survey responses are subject to bias due to participant experiences and opinions. Furthermore, shifting market conditions, such as shifts in labour availability and material prices, are not considered in real time.

2.0 Literature Review

Rising construction costs continue to be a significant issue that affects project budgets, long-term financial viability, and economic growth. Prior research has identified the primary causes of cost overruns and provided remedies. According to (Memon *et al.*,2020) found several important factors, such as poor planning, changes to the design, delayed payments, and variations in material costs. In a similar (Touran *et al.*,2006) emphasised inadequate cost projections and financial mishandling in significant infrastructure projects. (Kanchana *et al.*, 2018) discovered that a lack of manpower, poor site management, and contractor inefficiency were the primary drivers of cost inflation in the Indian context.

Additionally, (Lende *et al.*,2023) linked misaligned stakeholders and inefficient resource allocation to monetary losses. Stakeholders have differing opinions about the causes of cost increases. Contractors usually blame labour shortages and fluctuating material prices, while consultants emphasise poor documentation and frequent design revisions. (Mulla *et al.*, 2015) Study Conducted by (Welde *et al.*,2020) conducted a study in Nigeria and found that while customers focus on budgetary constraints and productivity losses, advisors prioritise procurement and clearance delays. Although prior research has examined the causes of cost escalation, few studies have examined the distinctions between project types (residential vs. infrastructure). Additionally, there is no information on how data analytics and artificial intelligence could aid in cost containment. According to the literature review, misaligned stakeholders, inadequate planning, a shortage of employees, and financial mismanagement are the main causes of cost increases. Even though earlier research provides useful information, more sophisticated cost modelling, AI-based prediction, and improved collaboration frameworks are needed to improve cost predictability and project efficiency.

3.0 Research Methodology

This study investigates the causes of the increase in building costs using a methodical approach. To share their thoughts, 111 professionals from the industry including consultants, contractors, and project owners completed a questionnaire survey. To ensure the accuracy of the data, the study, which focusses on the Indian building sector, selects specialists with a minimum of five years of experience.

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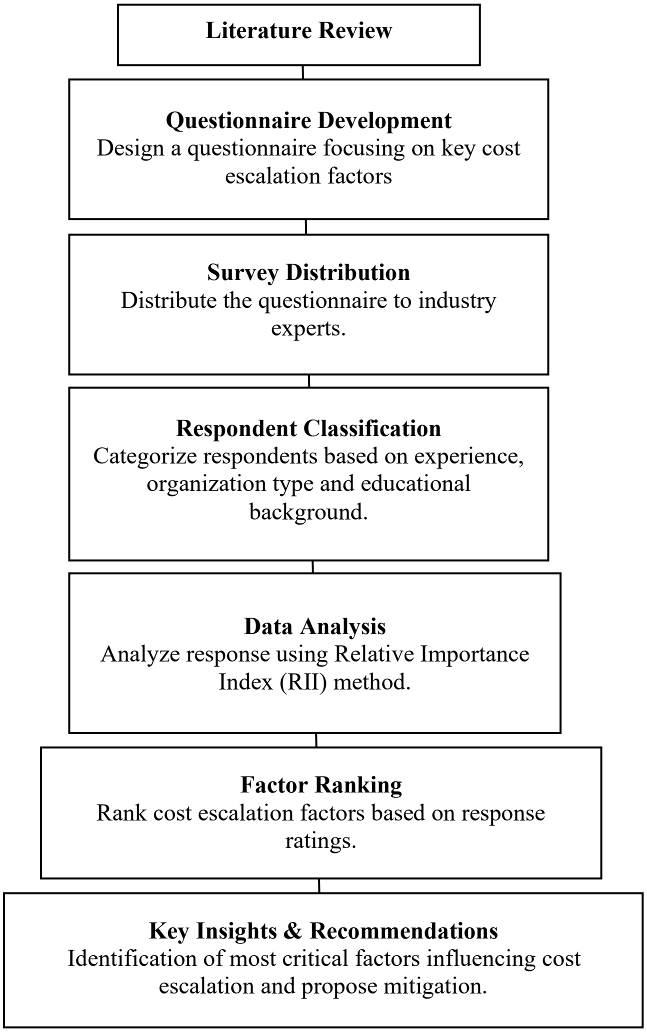

The present study will employ the ordinal scale as proposed by Enshassi *et al.*, (2022) which consists of follow mentioned categories: Extremely Significant (E.S), Very Significant (V.S), Slightly Significant (S.S), and Not Significant (N.S).

Likert Scale: The questionnaire utilized a 5-point Likert scale ranging from 1 to 5. Respondents were asked to rate a list of 13 factors causing cost escalation. To rank the factors influencing cost escalation, the Relative Importance Index (RII) was computed using the following formula $RII = \sum W/A*N$.

W = Weight assigned to each factor (1 to 5)

A = Highest possible weight (i.e., 5)

N = Total number of respondents

The higher the RII value, the greater the impact of that factor on cost escalation.

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4.0 Data Analysis

The respondents were categorized based on their years of experience, educational background, and kind of company to ensure diverse representation from a range of industrial sectors

4.1 Demographics of respondents

4.1.1 Educational background

The respondents had varying levels of education, ensuring a mix of academic and practical industry knowledge: The members' diverse educational backgrounds ensured a balance between practical and intellectual skills. The study's reliability was enhanced by the addition of specialised and field expertise from those with diplomas (7.21%) and PGDs (1.80%), which contrasted with the majority's master's (30.63%) and bachelor's (60.36%) degrees.

4.1.2 Experience level

To assess industry expertise, respondents were grouped based on their experience. Early-career professionals (1–5 years, 53.15%) offered fresh viewpoints, while mid-level specialists (6–10 years, 31.53%) balanced theory and practice. Senior professionals (11–15 years, 8.11%) and veterans (15+ years, 7.21%) contributed significant industry knowledge.

Figure 1: Education Level of Respondents

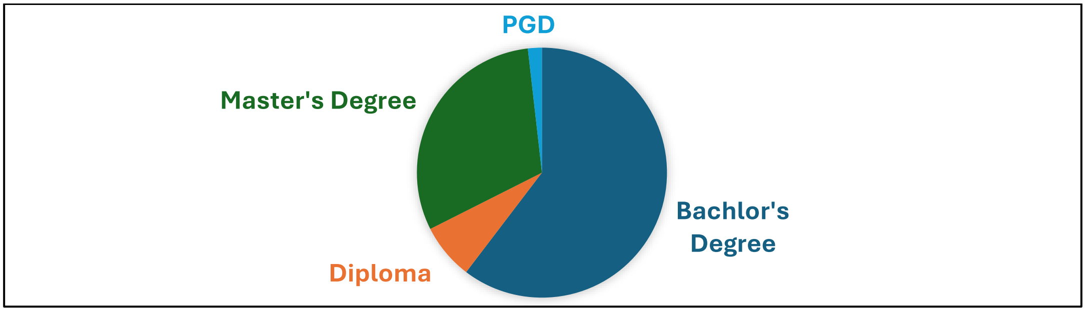
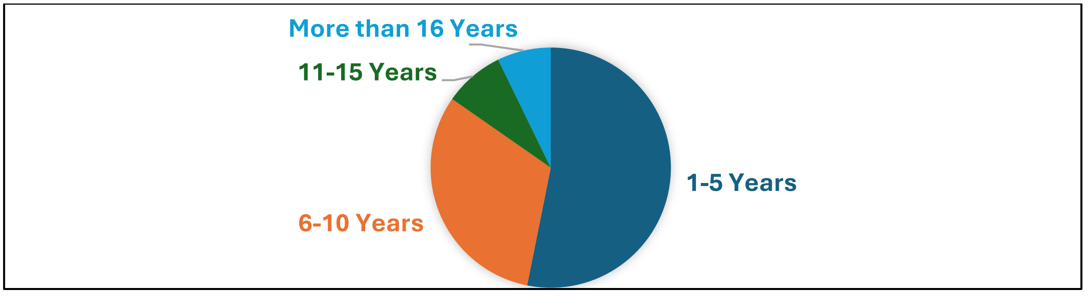


Figure 2: Experience of Respondents



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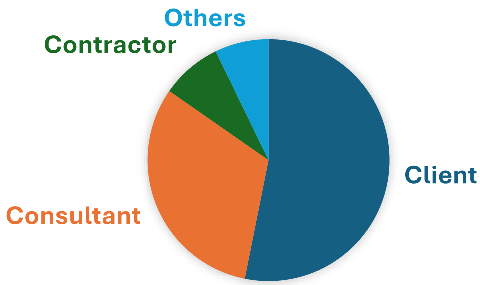
4.1.3 Organization type

Many people in the industry responded to the survey. Contractors (50.45%) focused on execution issues, consultants (18.91%) on design and planning, and clients/owners (18.02%) on budgetary constraints. The inclusion of fresh, business-focused perspectives from students and entrepreneurs (11.71%) guaranteed a comprehensive industrial outlook.

Figure 3: Organization Types of Respondents



4.2 Data analysis and results

The following table presents a comparative analysis of RII scores for the overall top-ranked cost escalation factors

Table 1: Overall Analysis of Cost Escalation Factors through RII & Ranking Method

Group	Factor	RII	Overall Rank
Contractor's site management related factors	Poor site management and supervision	0.62162	11
	Incompetent subcontractors & Lack of experience	0.68288	3
	Inadequate planning and scheduling or Schedule delay	0.65946	6
Design and documentation related factors	Mistakes and errors in design & Frequent design changes	0.66126	4
	Incomplete design at the time of tender	0.63423	9
Financial management related factors	Cash flow and financial difficulties faced by contractors	0.66126	4
	Financial difficulties & Delay in progress payment by the owner	0.62703	10
Information and Communication Related Factors	Lack of coordination between parties	0.65586	8
	Slow information flow between parties	0.60721	13
Human resource (workforce) related factors	Shortage of Site workers (Skilled, Unskilled) & technical personnel	0.68649	1
	Workers productivity & high cost	0.65766	7
Non-human resource related factors	Fluctuation of prices & Shortage of materials	0.68649	1
	Late delivery or Availability & Failure of Equipment and Materials	0.61982	12

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Table 2: Comparative Analysis of using Respondents' Organization Type – Client Perspective

Group	Factor	Client Perspective	
		RII	Rank
Contractor's site management related factors	Poor site management and supervision	0.69	9
	Incompetent subcontractors & Lack of experience	0.77	2
	Inadequate planning and scheduling or Schedule delay	0.72	7
Design and documentation related factors	Mistakes and errors in design & Frequent design changes	0.73	6
	Incomplete design at the time of tender	0.65	13
Financial management related factors	Cash flow and financial difficulties faced by contractors	0.7	8
	Financial difficulties & Delay in progress payment by the owner	0.66	10
Information and Communication Related Factors	Lack of coordination between parties	0.75	3
	Slow information flow between parties	0.66	10
Human resource (workforce) related factors	Shortage of Site workers (Skilled, Unskilled) & technical personnel	0.74	5
	Workers productivity & high cost	0.79	1
Non-human resource related factors	Fluctuation of prices & Shortage of materials	0.75	3
	Late delivery or Availability & Failure of Equipment and Materials	0.66	10

According to the results, the two primary drivers of rising building costs are labour shortages and shifts in material prices. Growing costs for steel, cement, and fuel put pressure on budgets, and a lack of workers leads to longer deadlines, more expensive labour, and delays, all of which lower project quality and emphasise the importance of workforce planning and stable prices. Customers identified the primary drivers of cost inflation as high expenses and employee productivity. Low productivity caused by inefficiencies, poor site management, and skill gaps leads to delays and higher labour costs. To lower labour-related costs and boost productivity, they strongly emphasise worker training, technology use, and efficient scheduling.

Experts acknowledge price fluctuations and material shortages as primary contributors to cost increases, often linked to inaccurate forecasts, inefficient designs, and contract modifications. Consultants place a strong emphasis on precise cost estimates, well-designed projects, and flexible contracts to lower these risks and improve budget stability.

Changes in material prices, incompetent subcontractors, and a lack of workers are the primary reasons given by contractors for cost increases. Lack of workers leads to poor performance, delays, and a greater need for expensive substitutes like overtime. They strongly emphasise better labour management, reliable subcontractor selection, and flexible procurement strategies to mitigate these challenges.

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Table 3: Analysis of Cost Escalation Factors through Consultants' Perspective

Group	Factor	Consultant's	
		RII	Rank
Contractor's site management related factors	Poor site management and supervision	0.59048	9
	Incompetent subcontractors & Lack of experience	0.73333	3
	Inadequate planning and scheduling or Schedule delay	0.64762	7
Design and documentation related factors	Mistakes and errors in design & Frequent design changes	0.68571	4
	Incomplete design at the time of tender	0.66667	5
Financial management related factors	Cash flow and financial difficulties faced by contractors	0.66667	5
	Financial difficulties & Delay in progress payment by the owner	0.5619	11
Information and Communication Related Factors	Lack of coordination between parties	0.62857	8
	Slow information flow between parties	0.52381	13
Human resource (workforce) related factors	Shortage of Site workers (Skilled, Unskilled) & technical personnel	0.74286	2
	Workers productivity & high cost	0.57143	10
Non-human resource related factors	Fluctuation of prices & Shortage of materials	0.77143	1
	Late delivery or Availability & Failure of Equipment and Materials	0.54286	12

Table 4: Cost Escalation Factors are Ranked based on Contractor's Perspective

Group	Factor	Contractor's Perspective	
		RII	Rank
Contractor's site management related factors	Poor site management and supervision	0.65	11
	Incompetent subcontractors & Lack of experience	0.65714	8
	Inadequate planning and scheduling or Schedule delay	0.66786	2
Design and documentation related factors	Mistakes and errors in design & Frequent design changes	0.65357	9
	Incomplete design at the time of tender	0.63929	13
Financial management related factors	Cash flow and financial difficulties faced by contractors	0.66786	2
	Financial difficulties & Delay in progress payment by the owner	0.66786	2
Information and Communication Related Factors	Lack of coordination between parties	0.66429	6
	Slow information flow between parties	0.65357	9
Human resource (workforce) related factors	Shortage of Site workers (Skilled, Unskilled) & technical personnel	0.675	1
	Workers productivity & high cost	0.66786	2
Non-human resource related factors	Fluctuation of prices & Shortage of materials	0.64643	12
	Late delivery or Availability & Failure of Equipment and Materials	0.66071	7

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Table 5: Others (Students and Entrepreneurs) Perspective towards Cost Escalation Factors

Group	Factor	Other's Perspective	
		RII	Rank
Contractor's site management related factors	Poor site management and supervision	0.47692	13
	Incompetent subcontractors & Lack of experience	0.6	2
	Inadequate planning and scheduling or Schedule delay	0.58462	3
Design and documentation related factors	Mistakes and errors in design & Frequent design changes	0.56923	6
	Incomplete design at the time of tender	0.56923	6
Financial management related factors	Cash flow and financial difficulties faced by contractors	0.58462	3
	Financial difficulties & Delay in progress payment by the owner	0.53846	10
Information and Communication Related Factors	Lack of coordination between parties	0.55385	8
	Slow information flow between parties	0.49231	12
Human resource (workforce) related factors	Shortage of Site workers (Skilled, Unskilled) & technical personnel	0.58462	3
	Workers productivity & high cost	0.55385	8
Non-human resource related factors	Fluctuation of prices & Shortage of materials	0.63077	1
	Late delivery or Availability & Failure of Equipment and Materials	0.53846	10

Other individuals (students and entrepreneurs): "Fluctuation of prices and shortage of materials" was e explanation that this group ranked highest because it combined academic and real-world knowledge about construction cost overruns.

5.0 Conclusion

According to the results, "Fluctuation of prices and shortage of materials" was shown to be the most important cause causing cost increases for all kinds of organizations. Furthermore, various stakeholders had differing opinions on which causes were most important:

- Clients identified "Worker productivity and high costs" as the primary concern.
- Consultants ranked "Fluctuation of prices and shortage of materials" as the top factor, often linked to cost prediction errors and contract inefficiencies.
- Contractors emphasized "Shortage of skilled and unskilled workers", affecting project execution.
- Others (students and business owners) also highlighted "Fluctuation of prices and shortage of materials" as a key concern.

In conclusion, addressing cost escalation requires collaboration between consultants, contractors, and clients through improved risk management and project governance. Future research should look at cost-control measures, technology adoption, and legislative frameworks

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to increase cost predictability in construction projects. If the study's findings are implemented, the construction industry will carry out projects more efficiently, fairly, and sustainably.

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CHAPTER 44

Cost Overrun Analysis in Indian Real Estate Projects: Challenges and BIM-Based Optimization

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ABSTRACT

Cost overruns are recurring challenge for the real estate scene in India, significantly affecting profit margins and the length of time projects take to finish. This review dives into the reasons behind these overruns and looks at some possible solutions, especially highlighting Building Information Modeling (BIM) as a highly effective approach to tackle the issue. A systematic approach was employed to select research papers for analysis and utilizing the Theory, Context, Characteristics, and Methodology (TCCM) framework for literature review. The work undertaken indicates that Building Information Modeling (BIM) and enhanced risk management strategies can improve cost efficiency. Additionally, insights were enriched through the use of questionnaire surveys and expert interviews, enabling a comprehensive understanding of industry practices and challenges. Building Information Modelling (BIM) enhances cost efficiency by providing accurate cost estimations, real-time tracking, and clash detection to minimize design errors and rework. Combined with robust risk management strategies, BIM enables proactive identification and mitigation of potential project risks, ensuring optimal resource utilization and adherence to budgets. However, the widespread adoption of BIM in India encounters substantial hurdles, primarily due to high implementation costs and a shortage of adequately skilled personnel. These challenges hinder the broader uptake of BIM.

Keywords: Cost overrun; Construction delays; Project management; Real estate; Building Information Modeling (BIM).

1.0 Introduction

Construction projects involve a lot of complicated processes, in addition to the natural variability across each project. Even if best efforts are made, cost and time overruns are still common occurrences: delays, high expenses, even legal disputes all rain down on tardy projects. To overcome these challenges, we need establish at an early stage the causes of overruns and then deal with them.

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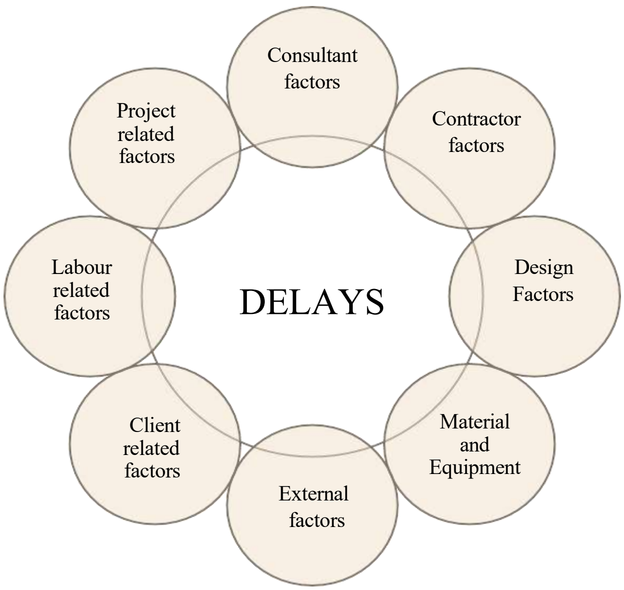
One of the major problems is cost overrun - a project whose actual costs are greater than what it was budgeted for. To handle this, prevention is crucial:

- *Precise budgeting:* Carry out thorough research and analysis before fixing the preliminary budget to secure practical cost estimates.
- *Scope changes:* Changes to the scale of your work may call for additional money on your part.
- *Price fluctuations:* Rapidly rising material costs and labor prices may result in increased expenditures.
- *Effective management:* Strong project management, coordination among stakeholders, and crucial decisions that are timely can be key factors to avoid horrible headaches later down the road.
- *Unforeseen conditions:* Future breakthroughs like adverse weather, geological problems and unexpected government changes could easily mean more money is taken out of your pocket.

With these aspects in mind, a project remains within budget and proceeds very close to completion.

Figure 1: Factors Lead to Delays in Construction Projects



In construction, all too often poor planning, unrealistic timetables, unforeseen obstacles within weeks from start to finish are frequent causes of delays. Project delays are caused by regulatory barriers, permit delays, legal problems, adverse weather, labour shortages and strikes, design changes. The important issue here is to ensure that design documents accord with construction needs, otherwise project implementation will be delayed. By looking ahead to

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potential obstacles and taking care of them in good time, projects could go ahead as scheduled within budget with great success.

1.1 Factors causing delays in construction projects

Several factors lead to delays in construction projects, as shown in Figure 1:

- Factors Related to Consultants: Delays which consultants bring about. Some examples include design mistakes or slow decision-making by advisors.
- Factors Related to the Project: Issues including the lack of resources poor logistics, necessary speed and so forth.
- Factors Related to the Contractors: Delays caused by contractors who are not working efficiently, whether through poor site management or because they are not coordinating things properly.
- Factors Related to the Workers: Strikes, shortages, or poor worker productivity.
- Design Factors: Changes or errors in the design that demand rework.
- Factors From the Client: Delays caused by clients, such as frequent changes in direction or late payments for work already done.
- Materials and Equipment: Delays in the delivery of material or breakdowns with machinery.
- External Factors: Regulatory hurdles, adverse weather, or other external disruptions.

1.2 Challenges in BIM adoption in India

While BIM offers significant benefits, its adoption in India faces several challenges:

- *Lack of awareness and education:* A lot of people involved in India's construction industry don't know how helpful BIM can be. This includes architects, engineers, contractors, and clients. To fix this, we need to teach professionals about BIM tech and methods through in-depth training programs.
- *High implementation costs:* Starting to use BIM needs a big investment. You have to spend money on software, hardware, training, and infrastructure. These costs can be too much for small and medium-sized companies to handle those in the informal sector.
- *Shortage of skilled professionals:* There is a lack of expert BIM professionals in India. The complications related to BIM tools as well as the need for a specialized training program in the industry's human resources equates to the fact that hiring well experienced personnel who can effectively apply BIM and who will make the selection, installation, and utilization of BIM practical is difficult.
- *Interoperability issues:* BIM software often lacks compatibility with systems used in the Indian construction industry. This incompatibility can complicate joint tasks and hinder the transfer of information among stakeholders.

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- *Regulatory and standardization challenges:* The absence of clear regulations and standards for BIM adoption in India makes it difficult to ensure consistency and interoperability across projects.
- *Resistance to change:* Many stakeholders are reluctant to adopt BIM due to entrenched traditional practices and workflows.
- *Infrastructure and connectivity issues:* Inadequate infrastructure and unreliable internet access in some regions of India hinder the effective implementation of cloud-based BIM solutions.
- *Data security and privacy concerns:* The digitization of construction data through BIM raises concerns about data security and privacy. Robust measures are needed to protect sensitive project information from unauthorized access and cyber threats.

1.3 Key success factors for minimizing cost overruns

Reducing cost overruns largely depends upon the following factors:

- *Meticulous planning:* Planning is key in the early stages of a project to avoid unexpected costs and delays.
- *Contractor and architect experience:* Experienced professionals can assist in ensuring projects are completed effectively and on budget.
- *Client-contractor relationship:* A good relationship between the client and contractor encourages better communication and cooperation, reducing the probability of disputes and delays.
- *Early contractor involvement:* Engaging contractors early on the project identifies any potential issues and ensures that the execution is seamless.

The adoption of these approaches will help the construction sector across India in minimizing cost overruns and ensure successful projects.

2.0 Research Methodology

We used a systematic approach to select research papers for analysis, applying the TCCM framework for our literature review. To gain deeper insights into cost overruns, BIM awareness, and the challenges faced by the construction industry, we conducted a structured survey targeting professionals in the field.

2.1 Data collection

Our survey was designed to gather insights from construction professionals who deal with these issues daily. The questionnaire included multiple-choice questions, rating scales, and open-ended questions, allowing respondents to share their experiences and opinions. We distributed the survey online via Google Forms, making it easy for participants to complete at their convenience.

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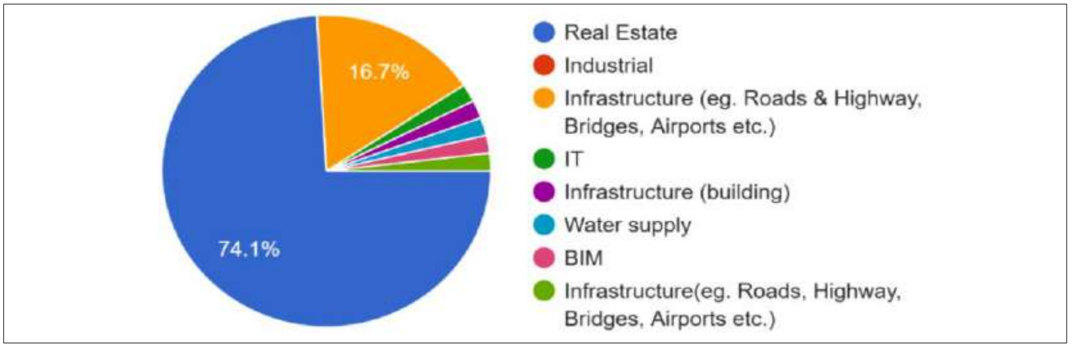
The survey focused on three key areas:

- *Cost overruns:* We aimed to understand how common cost overruns are and what causes them.
- *BIM awareness:* We explored how familiar professionals are with BIM and how widely it's used in their work.
- *Implementation challenges:* We sought to identify the difficulties professionals face when implementing BIM in their projects.

2.2 Target audience

We targeted a diverse group of professionals in the real estate sector, including engineers, project managers, consultants, architects, and contractors.

Figure 2: Target Audience



Source: Compiled by authors

While our primary focus was on the Indian real estate sector, we also included infrastructure and commercial construction professionals to provide a broader perspective. Quantitative methods, such as surveys, are commonly used to assess factors influencing cost overruns. Case-based studies have demonstrated BIM's potential for real-time cost tracking, but mixed-method approaches that combine quantitative and qualitative insights are still underrepresented in Indian research.

3.0 Literature Review

3.1 Theory

Risk management theory and agency theory form the theoretical foundation of this research. Risk Management Theory underscores how unexpected regulatory changes, material price fluctuations, and site conditions impact project costs. Agency Theory highlights conflicts between stakeholders, leading to budget escalations. BIM improves transparency and decision-making, mitigating cost risks.

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3.2 Context

Regulatory delays, land acquisition issues, and fluctuating labor costs significantly impact project costs in India. BIM's real-time project tracking capabilities can streamline approvals and improve financial control. Additionally, many construction projects face challenges due to inefficient project management and lack of stakeholder coordination, further escalating costs. The integration of BIM enables project managers to predict potential overruns, allocate resources efficiently, and facilitate better communication among all involved parties.

3.3 Characteristics

Project size, complexity, and stakeholder coordination influence cost overruns. Larger projects with multiple subcontractors experience more cost deviations. Effective stakeholder communication via BIM minimizes misunderstandings and budget escalations. Furthermore, projects that involve public-private partnerships (PPPs) often struggle with bureaucratic inefficiencies, making BIM a critical tool in improving decision-making and transparency in these ventures.

3.4 Methodology

Existing studies employ quantitative methods such as surveys and case studies to assess cost overruns. This research integrates qualitative insights through expert interviews to provide a holistic understanding. Furthermore, BIM case studies have demonstrated its potential to mitigate cost overruns through real-time tracking, predictive cost analysis, and streamlined workflows. The mixed-method approach adopted in this study ensures a comprehensive topic analysis.

4.0 Results and Analysis

4.1 Research paper analysis

Our analysis of selected research paper studies revealed that regulatory delays, inaccurate cost estimations, and stakeholder conflicts are major contributors to cost overruns in Indian real estate. BIM shows promise to address these issues by offering better cost tracking, real-time data, and enhanced collaboration. However, while large developers benefit from BIM, smaller firms struggle with high implementation costs and a lack of expertise.

4.2 Survey analysis

The survey results highlighted the widespread cost overruns in Indian construction projects. The most significant causes of cost overruns are Design Changes During Construction (68.5%) and Material Cost Fluctuations (59.3%). Delays in Approvals (57.4%) and Inadequate Project Planning (33.3%) are also notable contributors, highlighting the necessity for thorough planning and efficient approval processes. Shortage of Labour (37%) and Regulatory Delays (20.4%) further illustrate how resource availability and regulatory compliance impact project costs.

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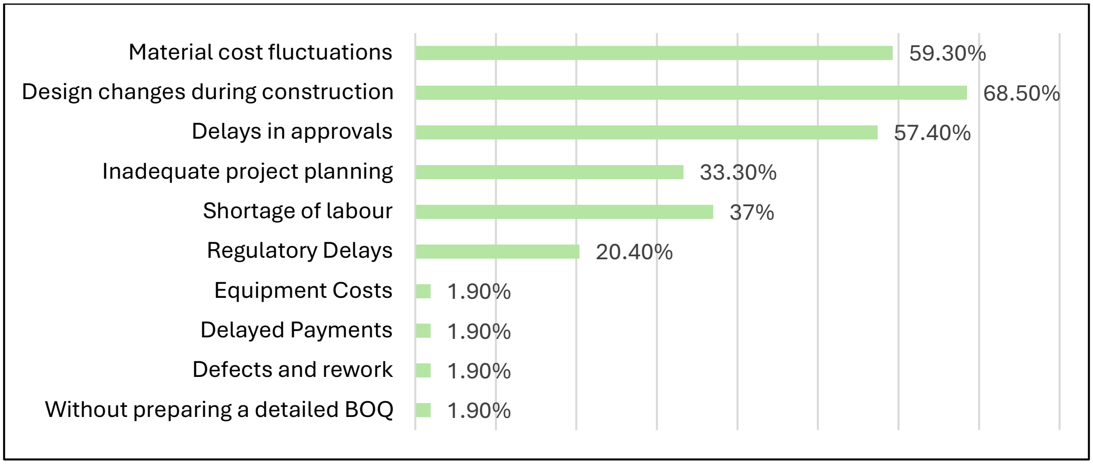
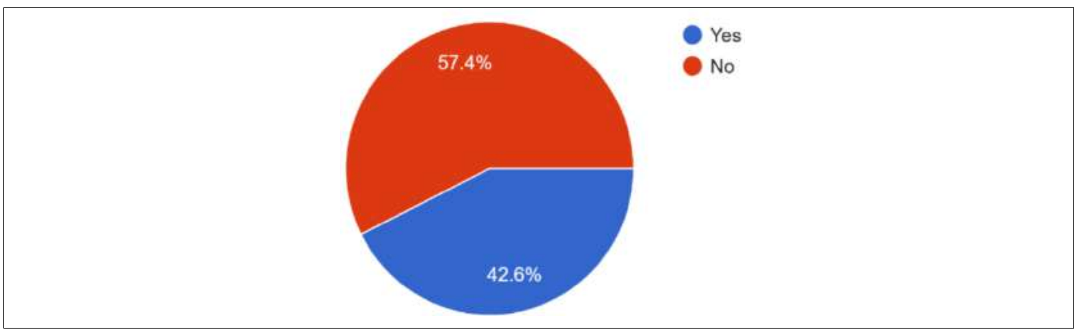
Figure 3: Reasons of Cost Overrun



BIM is seen as one of the solutions to these problems. Many professionals know BIM but face significant implementation challenges, including high costs and a shortage of skilled personnel. 68.5% of people surveyed know about Building Information Modelling (BIM), showing its importance in the industry. BIM helps at different project stages by improving visualization, coordination, and data integration. 31.5% of respondents do not know about BIM, meaning some professionals are not using this technology. This lack of knowledge might result from job roles, project types, or insufficient training. The awareness gap shows we need focused educational programs to improve our understanding of BIM, which could enhance project processes and teamwork.

Figure 4: BIM Implementation in Organisations



Despite these barriers, there is a growing recognition of BIM's potential to improve cost efficiency and project outcomes. Survey results also show that organizations are gradually

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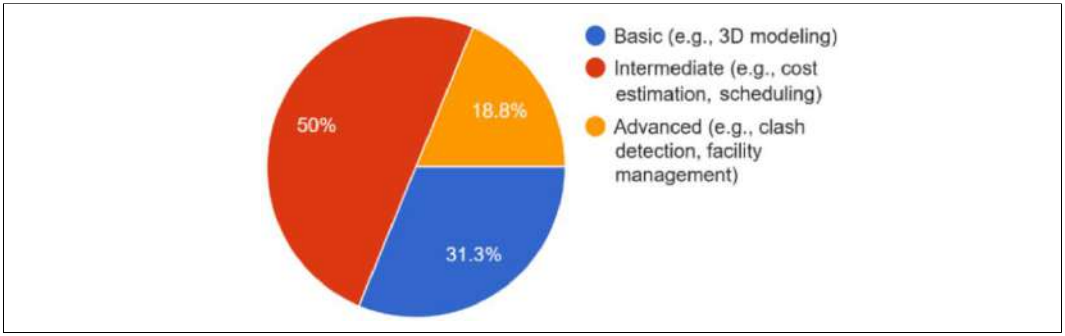
adopting BIM. Most organizations (57.4%) currently using BIM acknowledge its growing importance and benefits.

Figure 5: BIM Level Implemented in Organisations



However, 50% of the organizations are at a basic level, focusing on 3D modelling, indicating many have yet to leverage BIM's potential fully. 31.3% are at an advanced level, showing that a substantial portion is fully utilizing BIM. The distribution highlights the need for ongoing education, training, and support to encourage advancement through the levels of BIM usage.

5.0 Conclusion

Cost overruns in Indian real estate projects stem from regulatory challenges, scope changes, and market fluctuations. BIM offers a promising solution for cost control through improved planning, real-time tracking, and error reduction. However, successful adoption requires overcoming financial and technical barriers.

The findings of this study emphasize the importance of investment in BIM training programs and government-backed initiatives to facilitate its adoption. BIM can significantly improve cost management efficiency, but its success depends on industry-wide collaboration. Policymakers should consider implementing incentives such as tax benefits for companies integrating BIM into their workflows. Additionally, increased research and development efforts should be directed toward developing cost-effective BIM solutions tailored to the Indian construction sector.

Future research should explore case-based BIM implementations to validate their impact on cost efficiency. A longitudinal study on BIM adoption trends in India could provide further insights into how technological advancements shape cost optimization in real estate projects.

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CHAPTER 45

Cost Overrun Analysis of Irrigation Projects

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ABSTRACT

The number of irrigation projects is expected to grow rapidly in upcoming years due to the rise in population, industrialization, urbanization, and agriculture. The aim of this paper is to study irrigation projects in view of cost overruns of dam projects in Konkan region. Cost overruns and performance results of selected dam projects in the basin of west-flowing rivers in Maharashtra state. Based on available data, cost overruns and underperformance are exhibited. The completion of a project within stipulated budget, not causing a burden on the state exchequer has become the most crucial and challenging task for clients and contracting agencies. The overall objective is to identify reasons responsible for cost overruns in-water construction projects and recommend remedial solutions for land acquisition methods, execution of excess quantity and change in scope of work. The most important factors causing overruns in project cost are determined using Garrett's ranking technique, in order to rank the factors. A questionnaire was prepared and circulated to contracting agencies and irrigation departments. The most crucial factors of cost overrun were identified as: Paucity of funds; Excess due to higher tender rates; Delay in land acquisition; Increase in the cost of land acquisition; Claims for extra work of boulders. This study uses the Earned Value Method to assess an ongoing dam construction project's performance.

Keywords: Cost over run; Irrigation projects.

1.0 Introduction

There is a need for prioritising the backlog of ongoing irrigation projects in Maharashtra. The cost escalation of irrigation projects has been a major issue for the state government. Irrigation projects are essentially long-term projects involving huge investment of financial resources. For any major project involving public funds, keeping the expenditure within the stipulated budget amount is one of the major challenges before project management. Lack of financial autonomy, absence of long-term plan and prioritization of project execution, problems of land acquisition, rehabilitation of PAP's, resulting in delay and stoppage of work, clearances, resulting in abnormal delays and consequent increase in cost.

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In a complex irrigation project, inadequacies in planning or efficiency in execution can lead to manifold increase in project cost which in turn affects speed of completion. The gap between project creation and actual creation of Irrigation potential keeps increasing. The explanations for cost overruns and delays for water projects are largely on account of inflation being not considered in the initial cost estimates to get project pass through, geological difficulties, frequent design changes, increase in irrigation potential and construction of additional work. The achievement of intended outcomes of such important projects gets adversely affected by cost overruns. There is a significant shortfall in irrigation of the targeted areas. Cultivation in the command area of the projects is not up to its full potential as estimated in the DPRs.

1.1 Cost overrun in infrastructure projects

Cost overrun in infrastructure projects arises when the final cost of a project exceeds its initially estimated or budgeted cost. This is a common issue that has attracted a lot of interest from project managers and associated staff. In essence, a cost overrun in infrastructure projects represents a variation from the initial financial plan, which frequently has a negative impact on the project's success and the stakeholders involved. It's crucial to remember that cost overruns in infrastructure projects, which entail spending more than anticipated to get the same intended output, are frequently perceived as a failure in planning and a wasteful use of public resources. To reduce the chance of cost overruns, efficient control systems are required from the very beginning of the design process.

2.0 Literature Review

Cost overruns remain one of the most persistent and challenging issues in the construction industry worldwide. Defined as the excess of actual project costs over initial estimates, they significantly affect project viability, public confidence, and economic efficiency. Numerous studies have examined the root causes and proposed mitigation strategies, with findings highlighting both common and region-specific issues. One of the most frequently cited causes of cost overruns is poor project planning and design. Studies conducted in Jordan, India, and Denmark emphasize that inadequate initial estimates, incomplete drawings, and delayed designs play a significant role in escalating project costs (Al-Hazim *et al.*, 2017; Subramani *et al.*, 2014; Larsen *et al.*, 2015).

In Qatar, similar issues were observed, where inconsistencies between design and execution stages contributed to increased expenditure (Senouci *et al.*, 2016). Another critical factor is ineffective project management. Research from Denmark found that errors and omissions in consultant materials were among the most influential contributors to cost overruns (Larsen *et al.*, 2015). In both India and Portugal, lack of coordination, poor schedule control, and mismanagement of project processes were identified as key issues (Catalão *et al.*, 2020;

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Shinde & Minde, 2018). External and political factors also contribute significantly to cost overruns. In Portugal, a large empirical study revealed that electoral cycles, institutional weaknesses, and economic conditions had a measurable impact on cost deviations in public projects (Catalão *et al.*, 2020). Political interference, poor governance, and corruption, especially in developing countries, further compound the issue. These influences not only disrupt planning but also lead to deliberate underestimation of project costs for political gain, as noted by several researchers (Flyvbjerg *et al.*, 2004; Love & Ahiaga-Dagbui, 2018).

Environmental and site-specific conditions were also noted as contributing factors. Terrain difficulties and adverse weather were particularly problematic in infrastructure projects in the Middle East, notably Jordan and Saudi Arabia (Al-Hazim *et al.*, 2017). Moreover, unanticipated ground conditions due to inadequate site investigations further complicated construction efforts. Alongside these, market-driven variables such as inflation and rising material costs also influence overall project budgets. These are especially prevalent in countries like India and Qatar, where fluctuating prices and labor shortages have direct implications for project financials (Senouci *et al.*, 2016; Subramani *et al.*, 2014).

Geographically, certain regional patterns emerge. In the Middle East, particularly Jordan and Qatar, poor planning, payment delays, and environmental challenges are dominant causes (Al-Hazim *et al.*, 2017; Senouci *et al.*, 2016). Indian construction projects frequently suffer from land acquisition issues, regulatory delays, and price escalations (Subramani *et al.*, 2014; Shinde & Minde, 2018). In Europe, Denmark's research highlights the differentiated impact of various factors on time, cost, and quality, while Portugal's large-scale data analysis emphasizes the role of governance and political stability (Larsen *et al.*, 2015; Catalão *et al.*, 2020). The consequences of cost overruns extend beyond financial loss. They delay the delivery of essential services, erode public trust in governance, and compromise project sustainability. Large-scale public infrastructure projects often become unviable, and their economic and social returns diminish significantly due to prolonged timelines and budget inflation (Adam *et al.*, 2014). In response, scholars and practitioners suggest several mitigation measures. These include enhancing early-stage planning, increasing transparency in procurement, adopting data-driven cost forecasting models, and implementing continuous monitoring mechanisms (Senouci *et al.*, 2016; Shinde & Minde, 2018). Additionally, political insulation of project decisions and institutional reforms are crucial to ensure long-term efficiency (Catalão *et al.*, 2020).

3.0 Objectives

- To study various ongoing irrigation projects in view of cost overruns.
- Determine the percentage of overrun in minor, medium and major projects in a particular basin.
- Examine and conduct a questionnaire survey among contractors and department officials to rank the factors leading to cost escalation in water sector projects, using Garrett ranking.

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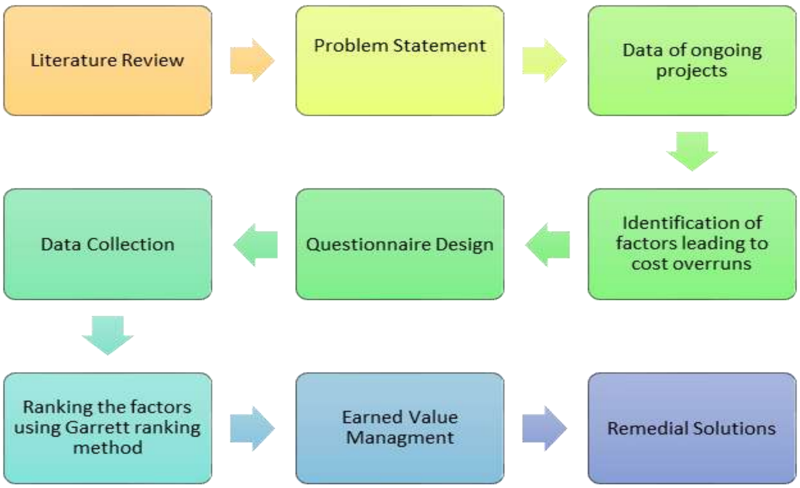
- To identify which critical factors affecting cost overrun need the most attention.
- Performing the earned value analysis for better understanding of project performance.
- To recommend corrective solutions to overcome or make protocols for those critical factors in future projects.

4.0 Research Methodology



4.1 Garrett ranking

The Garrett Ranking Technique is a method used to prioritize factors based on the perception of respondents in a survey. It's especially useful when multiple respondents rank several factors, and you want to convert these ranks into a standardized score to identify the most significant ones.

Table 1: Identified Cost Overrun Factors as per Data Obtained from Irrigation Development Corporation and CAG Report

Factor No	Factors
1	Excess due to change in D.S. R
2	Excess due to higher tender rates
3	Excess due to structural modification
4	Price escalation
5	Increase in cost of land acquisition rates
6	Increase in cost of land acquisition due to increase in command area
7	Increase in royalty rates
8	Implementation of clause 38

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9	Paucity of funds
10	Delay in land acquisition
11	Delay in approval of revised estimate
12	Claims for extra lead
13	Claims for extra work of boulders during excavation
14	Idle charges claim
15	Expenditure on Arbitration Awards
16	Payment for compensation on rehabilitated villagers
17	Conversion of open canals to PDN
18	Increase in dam height/length
19	Rework due to faulty design
20	Increase in scope of work
21	Stoppage of work due to pandemic
22	New tender process for balance work (incomplete work by previous contractor)

Table 2: Ranking of Factors based on Response of Respondents

Sr.No	*F1*	*F2*	*F3*	*F4*	*F5*	*F6*	*F7*	*F8*	*F9*	*F10*	*F11*	*F12*	*F13*	*F14*	*F15*	*F16*	*F17*	*F18*	*F19*	*F20*	*F21*	*F22*
1	1	3	8	12	3	4	9	7	5	1	13	10	4	10	16	18	14	4	20	4	22	19
2	1	2	9	14	7	6	10	6	9	4	15	12	7	12	18	19	17	6	18	4	21	22
3	1	2	10	11	4	6	10	6	7	2	14	14	6	9	17	17	19	9	21	5	22	20
4	2	3	12	14	5	3	11	9	4	3	16	12	4	11	14	19	19	7	19	7	22	21
5	4	3	7	13	5	7	8	8	6	5	16	14	5	8	18	20	18	5	22	7	21	19
6	4	3	11	11	3	3	8	10	1	1	12	13	8	13	15	17	15	8	19	7	21	21
7	2	4	12	12	3	5	9	10	5	4	15	12	8	10	19	19	18	9	21	8	21	22
8	3	6	10	12	6	5	9	11	3	2	15	10	5	10	15	18	16	6	20	8	21	18
9	2	5	10	14	5	4	11	7	7	1	16	12	4	12	18	20	17	4	18	6	21	20
10	2	5	7	12	5	6	10	9	1	1	14	10	6	11	17	19	14	5	22	6	21	22
11	5	8	12	14	4	6	11	6	4	2	11	14	7	11	14	18	18	8	18	9	22	22
12	7	9	11	13	7	7	10	9	5	3	13	12	4	9	16	17	19	7	21	7	20	21
13	2	4	9	11	3	4	10	8	2	4	13	14	7	10	15	20	16	10	20	7	21	22
14	2	4	10	11	3	5	12	6	2	1	12	13	6	9	16	17	16	8	22	7	19	22
15	4	3	8	13	5	8	11	6	1	2	15	13	4	9	17	19	17	11	19	4	22	19
16	1	6	8	14	6	7	9	7	5	1	15	14	5	13	18	20	17	7	19	4	21	19
17	1	6	10	14	6	4	11	6	2	4	16	11	8	8	14	18	18	4	22	8	21	18
18	5	3	11	12	7	7	12	9	6	3	13	14	5	10	15	20	17	9	20	6	19	19
19	3	2	12	12	7	7	9	8	8	1	14	12	8	12	19	17	16	6	21	5	22	22
20	2	2	12	12	3	5	8	10	4	2	12	14	8	9	15	19	15	8	18	4	21	21
21	2	3	11	13	3	5	9	11	3	4	15	14	6	11	19	18	13	5	21	6	20	21
22	7	4	8	13	5	6	12	10	1	1	16	11	4	10	18	19	16	10	19	7	19	22
23	4	5	8	12	4	6	10	6	1	2	13	13	7	8	14	20	17	11	18	8	19	20
24	6	5	12	11	6	3	10	9	3	2	13	13	7	13	17	17	17	11	21	8	20	18
25	6	6	7	13	6	7	9	7	6	3	15	10	4	10	15	18	18	9	20	7	20	21
26	2	2	7	11	7	3	11	6	7	1	14	12	6	12	16	18	19	4	18	9	22	22
27	2	2	11	14	3	4	11	8	7	4	15	13	5	12	16	19	16	7	22	9	21	22
28	1	3	10	15	6	4	10	9	2	1	16	12	4	10	14	20	16	6	21	10	22	20
29	1	4	9	14	7	6	12	11	3	2	13	11	8	9	17	19	14	6	22	4	22	22
30	3	4	9	12	6	5	9	10	6	3	11	14	6	11	16	19	14	10	20	4	20	21

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Table 3: Count of Number of Ranks Assigned to Each Factor

Factors	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th	21st	22nd
F1	7	10	3	4	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F2	0	6	8	6	4	4	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
F3	0	0	0	0	0	0	4	5	4	6	5	6	0	0	0	0	0	0	0	0	0	0
F4	0	0	0	0	0	0	0	0	0	0	6	9	6	8	1	0	0	0	0	0	0	0
F5	0	0	8	3	6	7	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F6	0	0	4	6	6	7	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F7	0	0	0	0	0	0	0	3	8	8	7	4	0	0	0	0	0	0	0	0	0	0
F8	0	0	0	0	0	8	4	4	6	5	3	0	0	0	0	0	0	0	0	0	0	0
F9	5	4	4	3	4	4	4	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
F10	10	8	5	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F11	0	0	0	0	0	0	0	0	0	0	2	3	7	4	8	6	0	0	0	0	0	0
F12	0	0	0	0	0	0	0	0	0	4	3	8	6	9	0	0	0	0	0	0	0	0
F13	0	0	0	8	5	6	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F14	0	0	0	0	0	0	0	3	6	8	5	5	3	0	0	0	0	0	0	0	0	0
F15	0	0	0	0	0	0	0	0	0	0	0	0	0	5	6	6	5	5	3	0	0	0
F16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	7	10	7	0	0
F17	0	0	0	0	0	0	0	0	0	0	0	0	1	4	2	7	7	5	4	0	0	0
F18	0	0	0	4	3	5	4	4	4	3	3	0	0	0	0	0	0	0	0	0	0	0
F19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	5	6	7	6
F20	0	0	0	7	2	4	8	5	3	1	0	0	0	0	0	0	0	0	0	0	0	0
F21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5	12	9
F22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	5	4	7	11

Table 4: Calculation of Percent Position and Garrett score

Rank	100(Rij-0.5)/Nj	Percent Position	Garrett Value
1st	100(1-0.5)/22	2.272727273	88
2nd	100(2-0.5)/22	6.818181818	79
3rd	100(3-0.5)/22	11.36363636	73
4th	100(4-0.5)/22	15.90909091	69
5th	100(5-0.5)/22	20.45454545	66
6th	100(6-0.5)/22	25	63
7th	100(7-0.5)/22	29.54545455	60
8th	100(7-0.5)/22	34.09090909	58
9th	100(9-0.5)/22	38.63636364	56
10th	100(10-0.5)/22	43.18181818	53
11th	100(11-0.5)/22	47.72727273	51
12th	100(12-0.5)/22	52.27272727	49
13th	100(13-0.5)/22	56.81818182	47
14th	100(14-0.5)/22	61.36363636	44
15th	100(15-0.5)/22	65.90909091	42
16th	100(16-0.5)/22	70.45454545	39
17th	100(17-0.5)/22	75	36
18th	100(18-0.5)/22	79.54545455	34
19th	100(19-0.5)/22	84.09090909	30
20th	100(20-0.5)/22	88.63636364	26
21st	100(21-0.5)/22	93.18181818	21
22nd	100(12-0.5)/22	97.72727273	12

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5.0 Conclusion

Cost overruns continue to pose a major challenge in the construction industry, especially in public infrastructure projects. The literature reveals that these overruns are primarily caused by a combination of technical, managerial, economic, and political factors. Across various countries and case studies, the most recurring issues include inaccurate cost estimation, delays in payments from clients, poor planning and scheduling, and fluctuations in material prices. Additionally, factors such as design changes during execution, inefficient contract management, and inadequate site supervision also contribute significantly.

Table 5: Conversion of Percent Position to Scores based on Garrett Table and Ranking of Strategies based on Mean Score Values

Sr.No	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	F21	F22
1	88	73	58	49	73	69	56	60	66	88	47	53	69	53	39	34	44	69	26	69	12	30
2	88	79	56	44	60	63	53	63	56	69	42	49	60	49	34	30	36	63	34	69	21	12
3	88	79	53	51	69	63	53	63	60	79	44	44	63	56	36	36	30	56	21	66	12	26
4	79	73	49	44	66	73	51	56	69	73	39	49	69	51	44	30	30	60	30	60	12	21
5	69	73	60	47	66	60	58	58	63	66	39	44	66	58	34	20	34	66	12	60	21	30
6	69	73	51	51	73	73	58	53	88	88	49	47	58	47	42	36	42	58	30	60	21	21
7	79	69	49	49	73	66	56	53	66	69	42	49	58	53	30	30	34	56	21	58	21	12
8	73	63	53	49	63	66	56	51	73	79	42	53	66	53	42	34	39	63	20	58	21	34
9	79	66	53	44	66	69	51	60	60	88	39	49	69	49	34	20	36	69	34	63	21	26
10	79	66	60	49	66	63	53	56	88	88	44	53	63	51	36	30	44	66	12	63	21	12
11	66	58	49	44	69	63	51	63	69	79	51	44	60	51	44	34	34	58	34	56	12	12
12	60	56	51	47	60	60	53	56	66	73	47	49	69	56	39	36	30	60	21	60	26	21
13	79	69	56	51	73	69	53	58	79	69	47	44	60	53	42	20	39	53	26	60	21	12
14	79	69	53	51	73	66	49	63	79	88	49	47	63	56	39	36	39	58	12	60	30	12
15	69	73	58	47	66	58	51	63	88	79	42	47	69	56	36	30	36	51	30	69	12	30
16	88	63	58	44	63	60	56	60	66	88	42	44	66	47	34	20	36	60	30	69	21	30
17	88	63	53	44	63	69	51	63	79	69	39	51	58	58	44	34	34	69	12	58	21	34
18	66	73	51	49	60	60	49	56	63	73	47	44	66	53	42	20	36	56	26	63	30	30
19	73	79	49	49	60	60	56	58	58	88	44	49	58	49	30	36	39	63	21	66	12	12
20	79	79	49	49	73	66	58	53	69	79	49	44	58	56	42	30	42	58	34	69	21	21
21	79	73	51	47	73	66	56	51	73	69	42	44	63	51	30	34	47	66	21	63	26	21
22	60	69	58	47	66	63	49	53	88	88	39	51	69	53	34	30	39	53	30	60	30	12
23	69	66	58	49	69	63	53	63	88	79	47	47	60	58	44	20	36	51	34	58	30	26
24	63	66	49	51	63	73	53	56	73	79	47	47	60	47	36	36	36	51	21	58	20	34
25	63	63	60	47	63	60	56	60	63	73	42	53	69	53	42	34	34	56	26	60	20	21
26	79	79	60	51	60	73	51	63	60	88	44	49	63	49	39	34	30	69	34	56	12	12
27	79	79	51	44	73	69	51	58	60	69	42	47	66	49	39	30	39	60	12	56	21	12
28	88	73	53	42	63	69	53	56	79	88	39	49	69	53	44	20	39	63	21	53	12	26
29	88	69	56	44	60	63	49	51	73	79	47	51	58	56	36	30	44	63	12	69	12	12
30	73	69	56	49	63	66	56	53	63	73	51	44	63	51	39	30	44	53	26	69	26	21
Mean	2279	2102	1621	1423	1988	1961	1599	1730	2125	2357	1324	1435	1908	1575	1146	894	1122	1797	723	1858	598	635
Rank	*2*	*4*	*11*	*15*	*5*	*6*	*12*	*10*	*3*	*1*	*16*	*14*	*7*	*13*	*17*	*19*	*18*	*9*	*20*	*8*	*22*	*21*

The Garrett Ranking technique further supports these findings by quantitatively prioritizing the most critical causes based on respondent perception. According to the mock

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Garrett analysis, inaccurate cost estimation and delay in client payments emerged as the top-ranked factors leading to cost overruns. These insights underscore the need for improved project planning, robust cost estimation methods, timely financial flows, and better stakeholder coordination. To mitigate cost overruns effectively, it is essential to adopt data-driven decision-making, enhance transparency in procurement processes, and strengthen project governance frameworks. Future efforts should also focus on developing early warning systems, applying predictive analytics, and incorporating sustainability and risk management practices from the planning stage onward.

Table 6: Ranking of Factors

Factor No	Factors	Rank
1	Excess due to change in D.S.R	2
2	Excess due to higher tender rates	4
3	Excess due to structural modification	11
4	Price escalation	15
5	Increase in cost of land acquisition rates	5
6	Increase in cost of land acquisition due to increase in command area	6
7	Increase in royalty rates	12
8	Implementation of clause 38	10
9	Paucity of funds	3
10	Delay in land acquisition	1
11	Delay in approval of revised estimate	16
12	Claims for extra lead	14
13	Claims for extra work of boulders during excavation	7
14	Idle charges claim	13
15	Huge Expenditure on Arbitration awards	17
16	Payment for compensation on rehabilitated villagers	19
17	Conversion of open canals to PDN	18
18	Increase in dam height/length	9
19	Rework due to faulty design	20
20	Increase in scope of work	8
21	Stoppage of work due to pandemic	22
22	New tender process for balance work (incomplete work by previous contractor)	21

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CHAPTER 46

Crane Operation in Precast Construction

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ABSTRACT

The study examines how weather conditions affect the productivity of tower cranes in precast construction projects. It analyses the crane's operational cycle in both dry and were weather, categorizing the tasks into Value-Added (VA), Non-Value-Added (NVA), Non-Value-Added – But-Necessary (NVAN) activities. By conducting site observations and reviewing video recordings, the research reveals notable differences in productivity, with delays mainly attributed to non-value-added tasks influenced by environmental factors, inefficiencies in material handling, and coordination challenges. The study highlights the need to reduce NVA activities to enhance workflow efficiency. Although the findings are based on specific weather conditions and site observations, they offer valuable insights for optimizing the crane operations and improving the resource utilization in lean construction practices, especially in adverse weather conditions.

Keywords: Tower crane; Operational cycle; Productivity; Workflow; Efficiency.

1.0 Introduction

Precast Construction is becoming more and more common Contemporary projects, particularly because it provides efficiency, quality and speed. The effective functioning of Tower cranes, which allow them to lift, move and position precast elements at the site, is the primary factor governing the successful installation of precast construction. Productivity, cost, and project timeline are directly impacted by the need for precise timing and resource management, which necessitates efficient crane operation in precast construction. However, variety of factors influence the crane's performance. Precast elements are lifted and placed by a tower crane during installation, but the efficiency is heavily influenced by the surrounding environment, particularly the weather (Feng *et al.*, 2017). Environmental Factors like extreme geator cold, strong winds and a lot of rain have a significant impact on their performance. Thus, the study presents and analyze the connection between Tower crane productivity and weather conditions recordings, the necessary information was gathered, and a comprehensive analysis of the crane's Operational cycle under various weather conditions was carried out.

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This aids in examining the impact that both wet and dry conditions have on crane productivity during preconstruction. To identify inefficiencies and help predict workable strategies for minimizing disruptions, the study divided crane activity into value added, non-value added, and non-value added but necessary categories. The necessary data was gathered through site observations and video recordings, and a comprehensive analysis of the crane's operational cycle under various weather conditions was carried out. The study emphasizes that delays caused by rain or other wet weather conditions minimizes crane performance and are primarily caused by coordination issues inefficient material handling (Chan & Lu, 2008) and other environmental factors, performance and are primarily caused by coordination issues inefficient material handling (Chan & Lu, 2008) and other environmental factors.

2.0 Literature Review.

This paper mainly explains tracking of tower crane operations on construction sites with the help of computer vision in an automatic matter (Yang *et al.*, 2014) It utilizes surveillance cameras and some image processing algorithm to track the trajectory of the jib angle, from which crane activity states are inferred. A probabilistic graphical model was used to classify the crane activities into concrete pouring and non-concrete material movement by analysis of the movements and site layout information. The authors focused on the use of video-based systems, this achieved by use of computer vision and video processing methods, (Shapira *et al.,* 2008) which are intended to enhance the monitoring process for better assessment of productivity in crane operation. Although there exist some limitations of accuracy with respect to tracking the activities such as by lighting, weather, obstructions. This study could be helpful as it gives a data driven approach to monitoring performance, which would help optimizing the material handling, scheduling techniques etc. Also, the research by (Jeong *et al.,* 2023) depicts the application of computer vision techniques for monitoring and improving the productivity of the tower cranes during the curtain wall installation. To track the path completed by a crane and explain its effectiveness and performance, the researchers utilized deep learning object detection in conjunction with the video analytic techniques. Also, by adopting these techniques, it will improve productivity of the crane in precast element lifting and placement.

3.0 Methodology

The method adopted for research here is the observational method which allows for direct watch of crane operations at construction sites. This indicates a thorough understanding of the processes which include careful monitoring of crane operations, load handling process and observance of safety procedures. This allows to directly observe the crane activities noting any in efficiencies hazards or best practices that they have seen in real time, by emerging themselves in the operational environment. The first step of methodology is the collection of primary data-these are done through face-to-face interviews of the crane operators, construction staff, and project managers in order to get insight into their problems and things they are satisfied with the operation of the crane. One of the other methods of gathering quantifiable data of crane performance and technical methods is by asking the workers to fill out the surveys. Not only the workers but also the researchers became part of the crane inspections by recording the work hours, taking the photographs and doing documentation of the work done.

Video recording process and analysis: To analyse crane operations efficiently a video based observational study was conducted. These approaches help in categorising crane activities based on real time performance under different weather conditions. These recordings provide empirical data for measuring productivity and identifying inefficiency.

The entire crane operation was recorded on site to capture dry and wet weather concreting process separately. The recordings focused on the following key crane activities.

- Waiting for the transit mixer (TM)
- Filling concrete bucket
- Removing chute
- Signaling crane operator
- Lifting bucket for pouring concrete
- Leveling concrete
- Vibrating concrete
- Finishing surface
- Cleaning tools and area.

The recorded crane operations were analysed using a work sampling technique which categorizes tasks into value added (VA), non-value-added (NVA)and non-value-added-but-necessary (NVAN) which includes lifting, swinging, positioning, waiting, coordination, signaling, bucket feeling, safety checks, communication between crane operators and workers and post operation adjustment. These processes were documented in two different environmental conditions.

Recording process for dry weather conditions: In dry weather the crane operator works under stable and predictable conditions. The dry environment ensured consistent ground stability, reducing the risk of sleepage and uncontrolled crane movement. However high temperatures led to heat stress among workers, requiring frequent breaks and increasing the non-value added (idle time). The video was captured from multiple angles ensuring a Clear View of crane moments, worker interactions and task execution. A stationary camera was positioned at an elevated point to record the inter operational cycle from lifting to placement. A mobile camera was used for Close Up shots particularly during critical stages such as bucket felling, pouring and alignment. Audio recordings were also included to track communication patterns and signal efficiency.

Recording process for wet weather conditions: In wet weather conditions crane operations were impacted by increased humidity, slippery surfaces and reduced visibility. The

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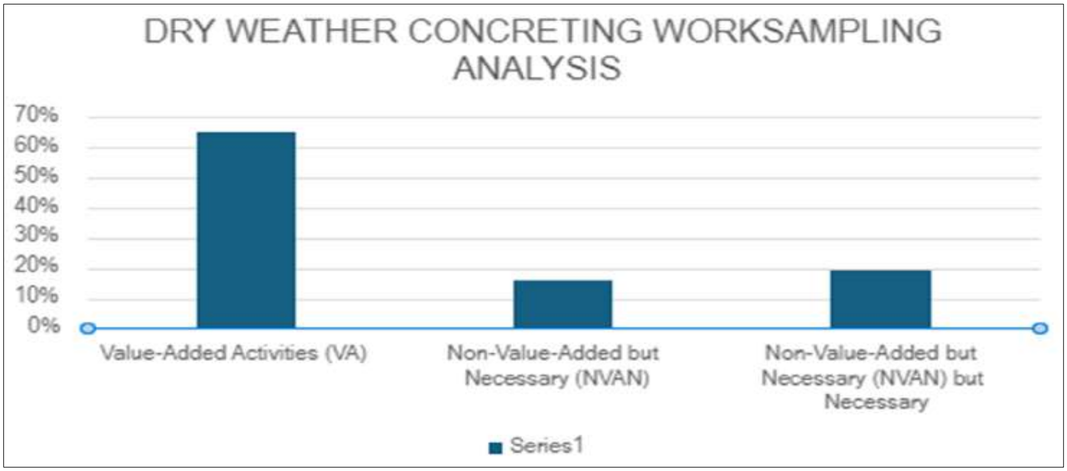
wet conditions created challenges in load stability, crane swing control and worker safety required in extra precautions and safety measures to stop the video recordings were conducted using a similar multi camera setup ensuring coverage from different angles. Additional focus was given to surface conditions how muddy and wet areas affected crane stability and movement. The time required for each activity was noted with particular attention to delays caused by weather conditions, increasing safety and rework efforts. Observations included how workers adjusted their workflow such as modifying bucket lifting speed, increasing communication frequency, and using protective measures of its environmental hazard.

Figure 1: Dry Weather Concreting Analysis



The analysis of the collected video data and work sampling observations evaluated crane performances, process efficiency, and areas for improvement. Hence, the research makes a wide view upon the analysis of time distribution among crane activities to identify all inefficiency and benchmark performance under different conditions.

Dry weather concreting analysis: The crane motions were quite continuous with very few interactions full stop the whole process duration was 9 minutes and 20 second which is 560 seconds. Breakdown of time categories depicted as value added (VA) 5minutes 15seconds 56%, non-value added (NVA) 1minute 21seconds 14%, non-value added but necessary (NVAN) 2minutes 44 seconds 30 %. The value-added task mainly included lifting, swinging, positioning, pouring and vibrating. The non-value-added task includes idle waiting time and unnecessary movements. The non-value added but necessary task includes signaling, bucket filling and lowering the bucket back.

Wet weather concreting analysis: The climate conditions impacted crane performance, thus prolonging the process duration. Total time taken was 17 minutes of 7 seconds (1027

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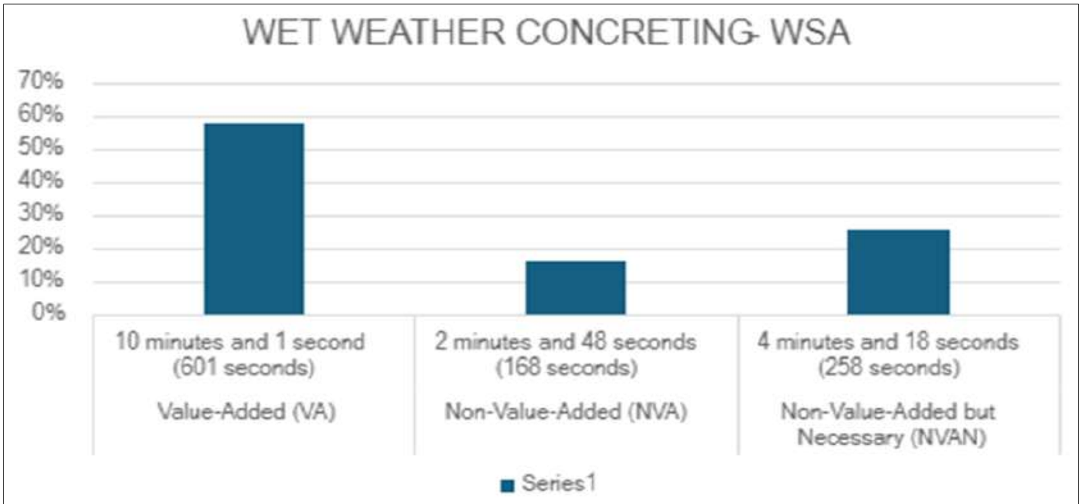
seconds). Time Categories of Value-Added: 10minutes 1second 601seconds w.r.t. 58% Non-Value-Added: 2 minutes 48 seconds 168seconds w.r.t. 16%. Non-Value-Added (NVAN): 4 minutes 18 seconds (258s) w.r.t. 26%. When that happens, these increased delays took longer time due to slippery surfaces, slower movements, and safety precautions. More NVAN tasks were done as extra signaling and cautioning was donfor stability.

Figure 2: Wet Weather Concreting Analysis



Activity	Dry Weather	Wet Weather
Waiting for TM to pour	0:00	0:39
Filling bucket from Transit Mixer	1:13	0:49
Removing the chute	0:07	0:30
Signal to crane operator	0:13	0:05
Lifting the bucket	0:24	0:04
Swinging the crane	0:40	1:11
Lowering the bucket	0:31	0:56
Positioning the bucket	1:19	2:38
Pouring concrete	1:03	6:27
Vibrating concrete	1:58	0:00
Waiting period for lifting	0:00	0:42
Lifting and Swing Time	0:52	1:03
Lowering bucket to Transit Mixer	0:38	1:42

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To know in which weather efficiency and productivity can be achieved, can be known by comparing these dry weather and wet weather analysis.

4.0 Applying Process Mapping

Value Stream Mapping (VSM) was used to increase crane operations' efficiency. This lean tool aids in detecting non-value-added operations, visualizing the present workflow, and suggesting changes to increase productivity VSM's main objectives were:

1. To see the entire crane operating cycle, from installation to lifting.
2. To quantify value-added (VA), non-value-added (NVA), and non-value-added but necessary (NVAN) activities.
3. To identify waste and suggest process improvements.
4. To estimate potential time reductions and efficiency improvements.

5.0 Result and Findings

Wet weather analysis findings: During rainy conditions, the VA work contributed to 58%, one percentage higher compared to the dry weather conditions.

SR NO.	TASK ACTIVITY	CATEGORY	ACTUAL DURATOIN (SEC)	ESTIMATED DURATION (SEC)
1	waiting for TM	NVA	39	#
2	filling concrete bucket	VA	49	49
3	removing chute	NVAN	30	
4	signal crane operator	NVAN	10	25
5	lifting the concrete bucket	VA	12	12
6	swinging crane the pouring area	VA	71	71
7	lowering bucket to pouring area	VA	12	12
8	positioning bucket above pouring area	NVAN	158	60
9	pouring concrete	VA	65	
10	pouring paused	NVA	45	
11	pouring resumed	VA	405	450
12	vibrating of concrete	VA	120	120
12	waiting for next lift	NVA	42	#
13	lifting the emptyn bucket	VA	11	
14	swing back to TM	NVA	63	50
	TOTAL DURATION		1132	849

This improvement primarily resulted from taking additional precaution measures to undertake despite unfavorable circumstances. Non-value-added (NVA) time did increase to 16% as a result of unforeseen postponements, standby waiting, and external setbacks such as rainfall

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to hinder tasks. Moreover, required non-value-added (NVAN) work accounted for 26%, largely because of mandatory safety precautions and operational limitations that could not be avoided in rainy weather.

5.1 Calculation and conclusion for wet weather

% of time saved initial duration = 1132 seconds

Optimized duration (After lean tool) = 849 seconds

Time saved =1132-849=283seconds

% of time saved = 283/1132*100 = 25%

So, 25% of the total time was saved after eliminating non-value-added activities.

Productivity and efficiency improvement: Since each cycle is 25% faster, more cycles can be completed per shift leading to a direct increase in overall productivity. Also, elimination of non-value-added tasks increases the proportion of non-value-added time, leading to an efficiency improvement of approximately 25%. Value Stream Mapping and Work Sampling have been used to lower the cycle time for rainy weather activities by around 283 seconds, or 25%. Because there were so many more inefficiencies in the wet circumstances that we were able to effectively address, the benefits were far larger in the wet than in the dry.

SR NO.	TASK ACTIVITY	CATEGORY	ACTUAL DURATOIN (SEC)	ESTIMATED DURATION (SEC)
1	waiting for the TM	NVA	60	X
2	filling concrete bucket	NVAN	66	66
3	removing chute	NVAN	10	15
4	signal crane operator	NVAN	13	
5	lifting the concrete bucket	VA	24	24
6	swinging to pouring area	VA	40	40
7	lowering to the pouring area	VA	31	31
8	positioning above the pouring area	NVAN	79	45
9	pouring the concrete	VA	63	63
10	vibrating the concrete	VA	118	118
11	waiting for next lift	NVA	0	0
12	lifting the empty bucket	VA	29	50
13	swing back to TM	VA	52	
14	lowering to the TM	VA	38	38
TOTAL DURATION			623	490

Dry weather analysis findings: In the condition of dry weather, 56% of activities were value-added, and hence most crane movements were productive. The NVA percentage was less

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at 14%, so fewer inefficiencies prevailed, though unnecessary movements and idle time did prevail. Yet NVAN activities were more at 30%, indicating that improvements in coordination and pre-planned signaling mechanisms can diminish these needed but non-productive activities. Whereas dry conditions enabled more efficient operations, further efficiency in NVAN operations could be enhanced by optimizing operations.

5.2 Calculation and conclusion for dry weather

% of time saved initial duration = 623seconds

Optimized duration (after lean tools) = 490seconds

Time saved =623 – 490 =133seconds

%of time saved =133/623*100 =21.35%

So, 21.35% of the total time was saved after applying lean tools

The same work that was initially scheduled to take 623 seconds will now be completed in 490 seconds. As a result, beginning immediately, more cycles may often be finished during working hours, which inevitably increases productivity. Overall, crane operations in dry weather had a 21.35% (133-second) shorter cycle time. With careful planning, communication aids, and crane movements, there is a great deal of potential to achieve new heights in crane operation. This could help reduce cycle time from 490 seconds further, potentially leading to greater cost savings and improved construction workflow efficiency.

6.0 Conclusion

The study on crane operations for concreting activities in both dry and wet weather has shown that huge inefficiencies lay within the initial processes. Value Stream Mapping and Work Sampling were used to identify these non-value-added activities and eliminate them, allowing for significant time savings and an increase in efficiency. The cycle time for dry weather concreting was initially 623 seconds and was shortened to 490 seconds after the changes were made, realizing a total dedicated time saving of 133 seconds, which is a reduction of 21.35%. In wet weather, it was set at 1132 seconds and changed to 849 seconds, achieving savings of 283 seconds or 25 % of the time. The large savings in wet conditions imply that there were larger inefficiencies, perhaps due to environmental factors and unoptimized workflows. Most notable was the improvement in efficiently planning crane movements and labor positioning so that workers were in place prior to the commencement of each cycle.

Also, the change from hand signals to walkie-talkies assisted in curtailing the lags in communication, thereby aiding synchronization. Another important adjustment is the optimization of the crane's movement path, which saves more time versus following a vertically horizontal lifting path; diagonal movements can be used if the bucket is empty. Efficiency improved through a higher ratio of value-added to non-value-added cycles. All of these improvements were coordinated: better planning, real-time communication improvements, and

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optimized lifting paths leading to reduced time registrations. Furthermore, additional refinement of weather-specific strategies, training of workers, and introduction of technology integration can provide gains in efficiency in the long run. A systematic elimination of delays and a concomitant enhancement of task execution will allow construction projects to become more operationally efficient (lower costs) and reduce timelines.

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CHAPTER 47

Critical Chain Project Management (CCPM) in EPC Projects

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ABSTRACT

Engineering, Procurement, and Construction (EPC) projects face constraints in time, cost, and resources, making efficient management essential. This study examines Critical Chain Project Management (CCPM) adoption in EPC projects, focusing on resource optimization, buffer management, and risk mitigation. A structured survey of industry professionals was analyzed using statistical tools to assess CCPM's impact on project duration, cost efficiency, and stakeholder satisfaction. Findings indicate CCPM reduces multitasking, enhances resource utilization, and mitigates schedule overruns. However, challenges like organizational resistance and integration issues hinder widespread adoption. Despite its potential, the success of CCPM relies on organizational buy-in, training, and technological integration.

Keywords: Critical chain project management; EPC projects; Resource optimization; Buffer management; Risk mitigation.

1.0 Introduction

Critical Chain Project Management (CCPM) optimizes resource allocation, buffer management, and risk mitigation, enhancing efficiency in Engineering, Procurement, and Construction (EPC) projects. Traditional methods like CPM and PERT struggle with uncertainties, leading to delays and cost overruns. CCPM addresses these issues by strategically placing buffers to absorb variability and protect the critical chain, ensuring smooth project execution and on-time completion.

1.1 Research objectives

- To examine the integration of CCPM in EPC projects.
- To explore the impact of CCPM on project time, safety, and quality.
- To study CCPM's role in minimizing risks and optimizing resource utilization

1.2 Research problem

Despite its advantages, the adoption of CCPM in the EPC sector remains limited.

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Many organizations continue to rely on conventional project management approaches, often due to resistance to change, lack of awareness, or integration challenges with existing frameworks. There is limited research on the impact of CCPM on key performance parameters such as project cost, duration, safety, and quality in EPC projects. Addressing these challenges requires a deeper understanding of CCPM's applicability, barriers to adoption, and potential strategies for integration into existing EPC project frameworks.

2.0 Literature Review

Critical Chain Project Management: Guofeng *et al.* (2014) introduced CCDSM to reduce rework risks, improving on-time completion but requiring further research on large- scale modeling. Roy *et al.* (2015) highlighted CCPM's impact on project performance, though its relationship with lean concepts needs clarity. Livia *et al.* (2023) demonstrated CCPM's benefits in construction but noted implementation challenges. Mohammad *et al.* (2020) compared CCPM with traditional methods, proving its superiority but identifying software limitations and cultural adoption gaps. Taynara *et al.* (2021) showed CCPM outperforms PERT/CPM but requires further study on human behavior influences. Amancharla *et al.* (2023) emphasized CCPM's effectiveness but noted limited adoption in construction.

Buffer Sizing: Shakib *et al.* (2020) introduced BSCA, reducing project duration by 15%, but real-time buffer management research is needed. Jun-Long *et al.* (2022) proposed brittle risk entropy for shortening project completion but highlighted a lack of system-perspective methods. Mona *et al.* (2017) emphasized CCPM's role in India but noted limited implementation. Geekie *et al.* (2008) proposed a mixed buffer-sizing approach requiring refinement. Bingling *et al.* (2020) introduced network decomposition for better scheduling but emphasized further testing.

Extension of Time (EoT) Claims: Eranga *et al.* (2023) emphasized excusability and criticality, identifying window analysis as reliable but lacking an integrated framework. Khaled *et al.* (2014) highlighted challenges in proving delays, calling for AI-based assessments. Haroon *et al.* (2017) identified 29 influencing factors but emphasized the need for deeper managerial delay analysis. Reuben *et al.* (2021) stressed contract management in multi-stakeholder projects, noting research gaps in developing countries. Norazian *et al.* (2013) analyzed disputed EoT claims in Malaysia, highlighting concurrent delays. Ayush *et al.* (2017) advocated adherence to contract protocols in Indian construction.

EPC Contracts: Hansen *et al.* (2015) identified 34 unique EPC characteristics, emphasizing knowledge management. Kamyar *et al.* (2019) highlighted engineering design and procurement as crucial factors. Sonawane *et al.* (2017) compared PPP and EPC contracts, emphasizing risk management. Mittal *et al.* (2020) addressed delay mitigation in EPC solar projects, advocating stakeholder coordination. Sanjay *et al.* (2019) examined price volatility, recommending revised escalation clauses.

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3.0 Methodology

3.1 Research approach

The research employs a quantitative approach, utilizing a structured questionnaire to gather data from industry professionals involved in EPC projects. This approach allows for the collection of insights regarding familiarity with CCPM, resource allocation, EoT claims, buffer management, risk management, safety and quality, challenges.

3.2 Data collection method

The primary data collection method is a questionnaire survey, administered to a target group of professionals working in fields such as construction, energy, infrastructure, manufacturing, and other sectors. The survey is structured into multiple sections like 1. General information 2. Resource allocation and prioritization 3. EoT Claims 4. Buffer management 5. Risk management 6. Project execution, safety and quality 7. Technology and software 8. CCPM challenges and future outlook. Upon completion of data collection, responses will be analyzed quantitatively.

4.0 Data analysis and Findings

4.1 Adoption level of CCPM

The adoption of CCPM in project-driven industries appears to be limited. Based on the survey results, only 6% of respondents primarily use CCPM, while the majority (66%) rely on the CPM, followed by Traditional Waterfall and Agile/Lean methodologies.

4.2 Compatibility of CCPM with existing EPC project frameworks

A majority (80%) of respondents consider CCPM to be moderately compatible with existing EPC project frameworks, indicating that while CCPM has potential, it is not a seamless fit. Only a small percentage (9%) believe it is highly compatible. To improve its integration, organizations should focus on training project teams to build awareness and competence in CCPM principles, enhance software tools to support CCPM methodologies, gradually integrate CCPM into current frameworks through pilot projects before full-scale implementation.

4.3 Impact of CCPM on reducing resource wastage

36% observed a significant reduction in resource wastage,33% noticed some reduction but not significantly, 31% saw no noticeable difference. While CCPM helps reduce resource wastage for most, a substantial portion (31%) sees no improvement, suggesting the need for better implementation strategies.

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Recommendations:

- Prioritize Key Resource Allocation Factors: Ensure that project timeline, resource criticality, and availability are systematically incorporated into planning.
- Implement buffer management strategies to mitigate frequent resource shortages.
- Optimize Waste Reduction Strategies: better tracking and analysis methods should be introduced to enhance resource utilization.
- Training and Awareness

4.4 Impact of CCPM on resolving EOT claims

- Primary Causes: Late approvals (34%), design delays (24%), supply chain disruptions (24%), and force majeure events.
- CCPM Benefits: Reduces delays (31%), improves resource utilization (24%), and enhances critical path identification (23%).

Figure 1: Benefit of CCPM in EOT

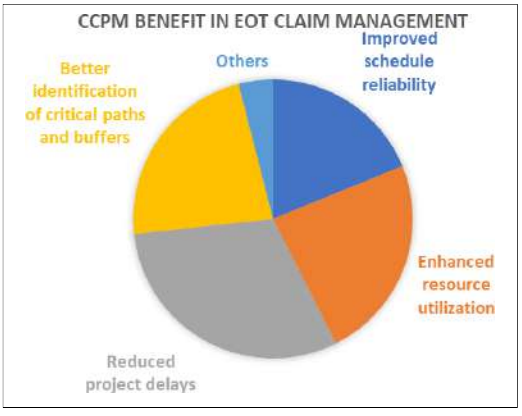
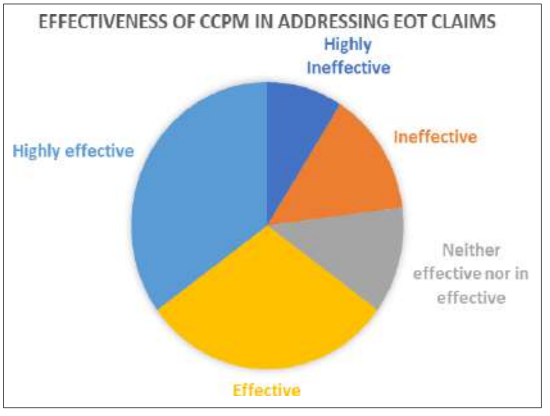


Figure 2: Effectiveness of CCPM in EoT Management



4.5 Buffer management

While 42.8% find it somewhat effective in handling uncertainties, 31.4% consider it ineffective, likely due to low familiarity, improper implementation, or unrealistic buffer sizing. Improving data collection, advanced forecasting, and targeted training programs can enhance buffer utilization and stakeholder confidence.

4.6 Risk management & uncertainty

CCPM is seen as effective in risk identification by 44% of respondents, though 31% find it ineffective, indicating inconsistencies in its application. While 48% believe CCPM helps manage schedule risks, 30% disagree, highlighting implementation challenges. Additionally, 64% feel CCPM positively impacts unforeseen challenges, but 33% see no change.

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Figure 3: Effectiveness of Buffer Management in Handling Uncertainties

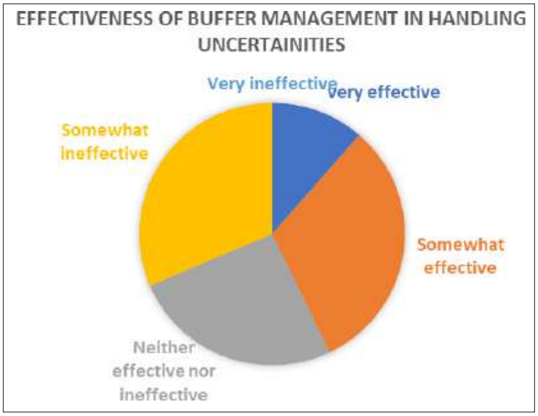
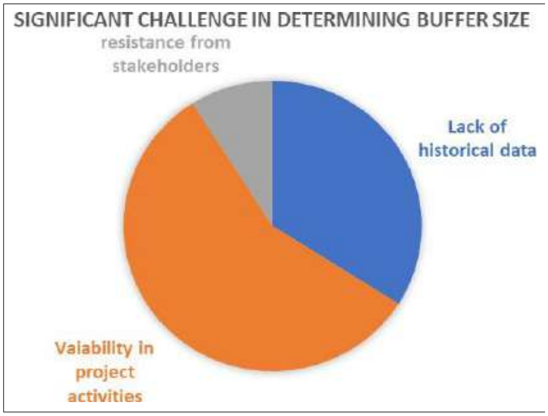


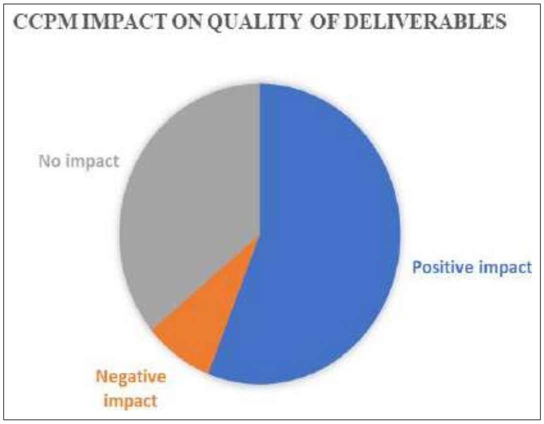
Figure 4: Challenges in Determining Buffer

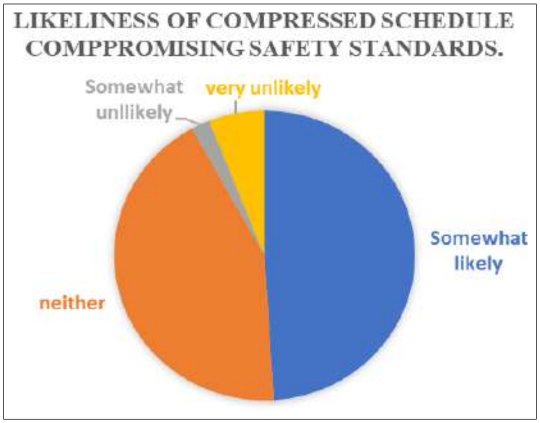


4.7 Other findings

4.7.1 CCPM's impact on quality and safety

Figure 5: CCPM's Impact on Quality and Safety





4.7.2 CCPM future outlook

The team is found to be generally open to CCPM, but the majority are still in early stages of acceptance. There is a further requirement of training, change management efforts and demonstrating clear benefits to increase strong adoption. The majority are unsure whether CCPM will become a standard methodology in their respective sectors.

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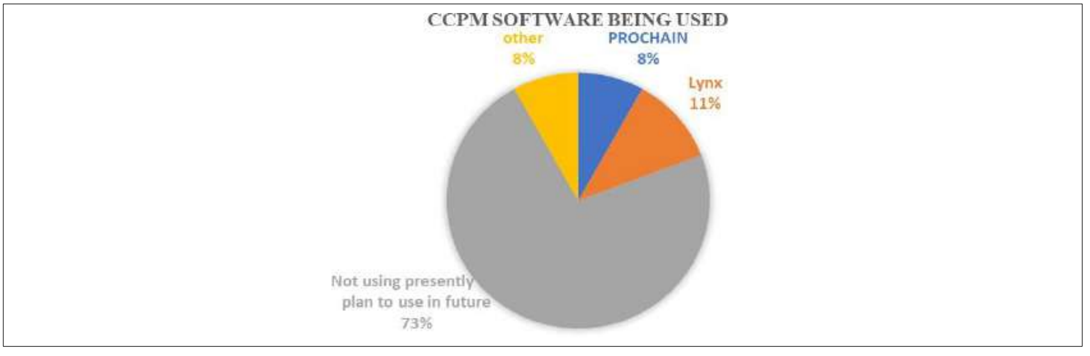
5.0 Conclusion

5.1 Key findings

- *Limited adoption and awareness:* Only 6% of industry professionals currently use CCPM. 66% of respondents were somewhat familiar with CCPM, but only 17% were highly familiar.
- *Effectiveness in resource allocation and project execution:* 50% of respondents found CCPM effective in managing resources, but 31% saw no noticeable reduction in resource wastage. CCPM significantly reduces project delays (31%) and improves critical path identification (23%).
- *Challenges in buffer management and risk mitigation:* 74% of respondents had little or no familiarity with buffer management, leading to ineffective implementation. Variability in project activities and a lack of historical data were key obstacles in determining buffer sizes.
- *Impact on safety and quality:* 49% of respondents believed compressed schedules under CCPM might pose safety risks, highlighting the need for better safety integration. While most respondents agreed that CCPM improves quality, they emphasized the importance of regular audits and enhanced quality checks.
- *Technology and software adoption:* Only 27% of respondents used CCPM software, with Lynx and ProChain being the most common tools.

Figure 6: CCPM Software Used



5.2 Limitations of the study

- *Limited industry representation:* A larger sample size with more diverse participants would enhance the reliability of findings.
- *Dependence on survey-based responses:* which may be influenced by personal biases, knowledge gaps, or subjective experiences.
- *Technological constraints:* The study did not extensively analyze the role of advanced digital tools, such as AI-driven CCPM solutions.

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5.3 Recommendations

- *Enhance awareness and training:* Organizations should invest in workshops, training programs, and pilot projects to increase CCPM adoption.
- *Improve integration with EPC frameworks:* Customization of CCPM principles to align with existing workflows can facilitate smoother adoption. A hybrid approach combining CPM and CCPM can improve compatibility.
- *Optimize resource and buffer management:* Advanced forecasting techniques and historical data analysis should be employed to determine optimal buffer sizes.
- *Encourage technology adoption:* More organizations should explore CCPM-compatible software for improved tracking and forecasting.

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CHAPTER 48

Decision-making Framework for Compensations Claimed over Extension of Time Claims

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ABSTRACT

Most construction projects are executed through contracts which are generally not easy to comprehend. Increase in size and complexities of construction projects lead to further ambiguities in the prevailing contract forms causing adversarial impacts. This includes an increase in the number and frequency of claims and disputes, besides time and cost overruns. Moreover, construction projects often face delays due to various unforeseen circumstances per say force majeure, leading to claims arising over Extension of Time (EoT) for compensation. In many cases, with approval of the Extension of Time, the claimant is eligible for further compensation for the damage sustained during the extended period. There is a need to develop a system that can assist stakeholders at every hierarchy to understand the necessity and quantify their claims prior to taking it to litigation. In this study, an attempt has been made to develop a decision-making framework to address the compensations laid over by EOT claims. A structured database was created wherein reasons for EOT along with compensation were listed. Data regarding the EOT claims for various disputes was collected through arbitration cases in the construction industry pertaining to the Indian scenario. Each of the claims was studied and the reasons behind the judgment were proved.

Keywords: Construction projects; EOT; Compensation; Arbitration cases; Decision-making framework.

1.0 Introduction

A contract, as per the Indian Contract Act 1872, is an agreement enforceable by law, made with free consent, lawful consideration, and a valid objective. In construction, contracts typically set a specific timeline for project completion. However, unforeseen challenges like adverse weather, site conditions, scope changes, material delays, or third-party disruptions often necessitate an Extension of Time (EOT). Delays impacting a project's critical path may entitle contractors to an adjustment of the contractual completion date through a contract amendment or change order.

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If a delay is beyond the contractor's control, they may seek not only an EOT but also compensation when damages exceed permissible limits. Claims must be substantiated with cost calculations for human resources, machinery, materials, profit loss, and other additional expenses incurred during the extended period. Evaluating these claims is complex, requiring assessment of entitlement, causation, delay quantification, contractual terms, and legal considerations. This project aims to develop a structured decision-making framework for assessing compensation over EOT claims. By integrating key factors, the framework will provide a transparent and equitable approach, streamline claim resolution and ensure fair outcomes for all stakeholders.

2.0 Need of the Decision-making Framework

In construction projects, delays are a common challenge that can significantly impact timelines and costs. When a project exceeds its scheduled completion period, contractors may seek an Extension of Time (EOT) to avoid penalties. However, in cases where the delay is caused by factors beyond the contractor's control—such as client-side inefficiencies, delayed approvals, or unforeseen site conditions—contractors may also claim compensation for additional expenses incurred.

The need for this study arises from the complexities involved in assessing and deciding compensation, claims over EOT. There is often ambiguity in determining whether a contractor is entitled to compensation and to what extent.

Inconsistent decision-making can lead to disputes, financial losses, and delays in project execution. The claims and dispute resolution process in construction and other large projects can have significant time and cost implications. Delays caused by claims often result in extended project timelines, which in turn increase labour and material costs, as well as administrative and legal expenses. Extended conflicts also consume valuable resources and can strain relationships among project stakeholders, further complicating the process. With predefined criteria and standardized processes, communication remains transparent, and conflicts can be resolved more quickly. A well-defined decision-making framework can help the Stakeholders to minimize unnecessary major cost burdens incurred by filing misguided and infructuous claims.

This study aims to develop a systematic approach to analyse compensation claims over EOT, considering legal, contractual, and practical aspects. By establishing clear guidelines, the study will help project stakeholders—including contractors, engineers, and clients—make informed decisions, minimize conflicts, and improve financial planning in construction projects. Every other Construction Project is unique and complex in its own way, and so are the Claims and Disputes arising from the delays and non-conformity in execution of the contract. The Dispute Resolution Mechanism followed for each case is subjective to the Arbitrator. This limits the decision-making effectiveness of the Framework for the Stakeholders.

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3.0 Decision-making framework

3.1 Data collection

A total of 54 Arbitration Awards were collected from different Arbitrators pertaining to Indian Construction Industry. These awards were thoroughly studied and were segregated according to our Project scope. 26 Arbitration Awards were found where the client awarded Extension of Time to the Contractor on account of delay attributed to the client. In these cases, the Contractor asked for extra Compensation for the damages sustained by them during the extended period for maintaining their day-to-day expenditure.

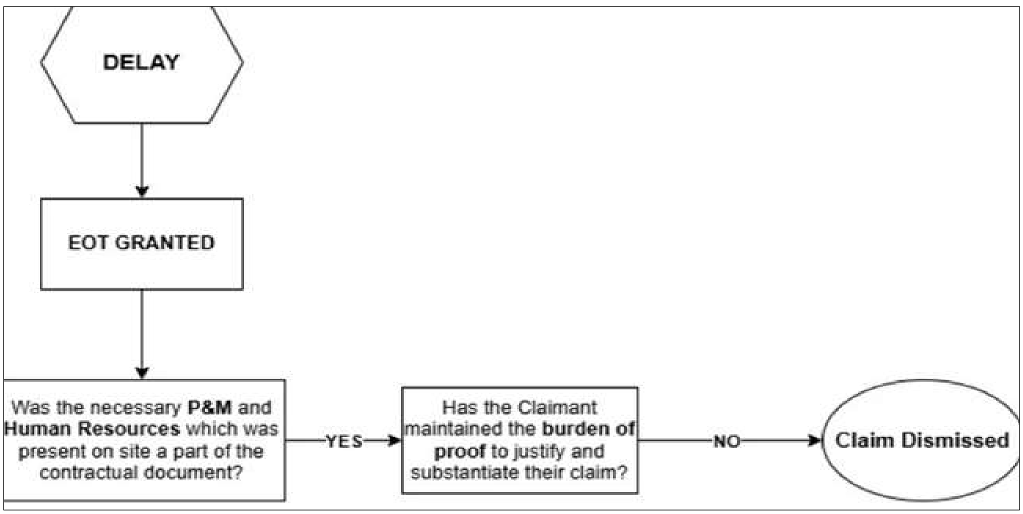
3.2 Data analysis

Out of 54 cases, 26(67%) relevant cases were found which were further segregated into four categories i.e. Escalation, Extra cost, Loss of profit, Legislation. Out of these categories, claims related to extra cost were found to be greater in number. Total 30 cases which is 61% of all the cases, were found from 54 awards. When seeking compensation for delays, a contractor must first verify whether the contract includes provisions for deploying Plant & Machinery (P&M) and Human Resources on-site. Proper documentation is essential to substantiate claims for additional costs incurred due to project delays.

3.3 Development of decision-making framework

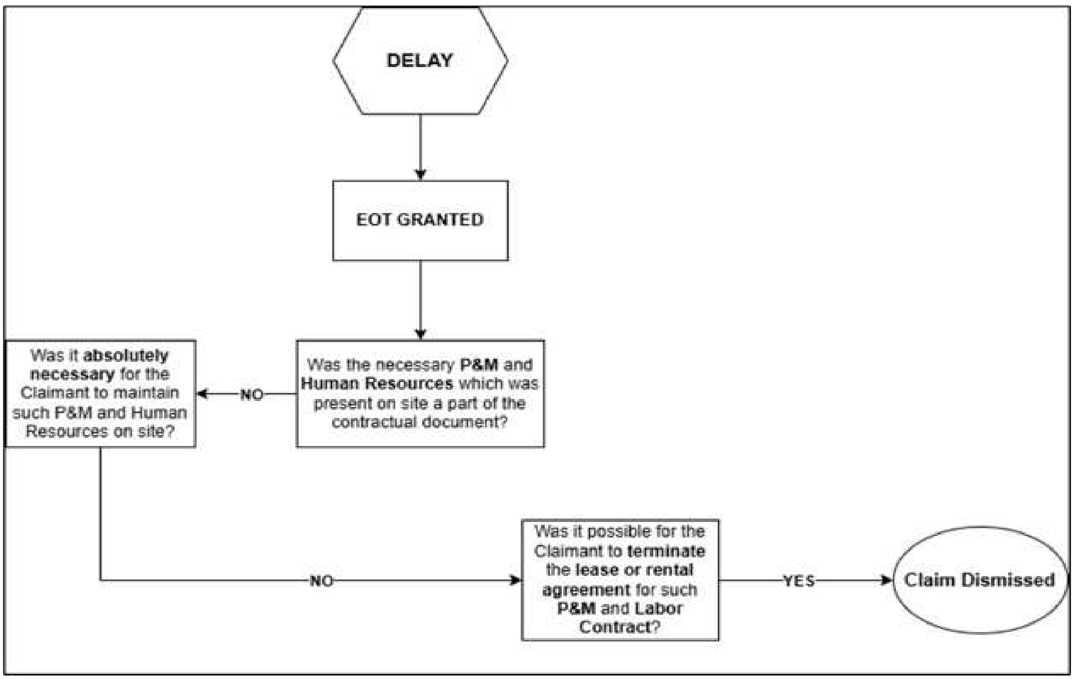
Flowchart- Logic 1 outlines the process for evaluating a contractor's claim for compensation due to project delays.

Figure 1: Flowchart- Logic 1



When a delay occurs and an Extension of Time (EOT) is granted, the first step is to determine whether the contract explicitly requires the contractor to maintain Plant & Machinery (P&M) and human resources on-site. If there is no such contractual obligation, the claimant has the option to terminate rental or labor contracts, and any claim for compensation is dismissed. If the contract does mandate these resources, the claimant must provide sufficient documentary evidence, such as muster rolls or payroll records, to justify the claim. Failure to provide this evidence results in the dismissal of the claim. This process ensures that claims are substantiated and align with contractual provisions.

Figure 2: Flowchart- Logic 2



Flowchart- Logic 2 determines the validity of a contractor's compensation claim after an EOT is granted. If maintaining P&M and labor on-site was not contractually required, the claim is dismissed. If required, but termination of rental or labor agreements was possible, the claim is also dismissed. Only claims with contractual obligations and supporting evidence are considered The flowchart- Logic 3 outlines the conditions under which a compensation claim is awarded after an EOT is granted. If the contractor was required to maintain P&M and labor on-site, had a valid labor or rental contract, and notified the Engineer in Charge (EIC) of damages due to idle resources, the claim is considered. The claimant must also provide documentary evidence such as salary slips, attendance registers, and maintenance receipts to substantiate the claim.

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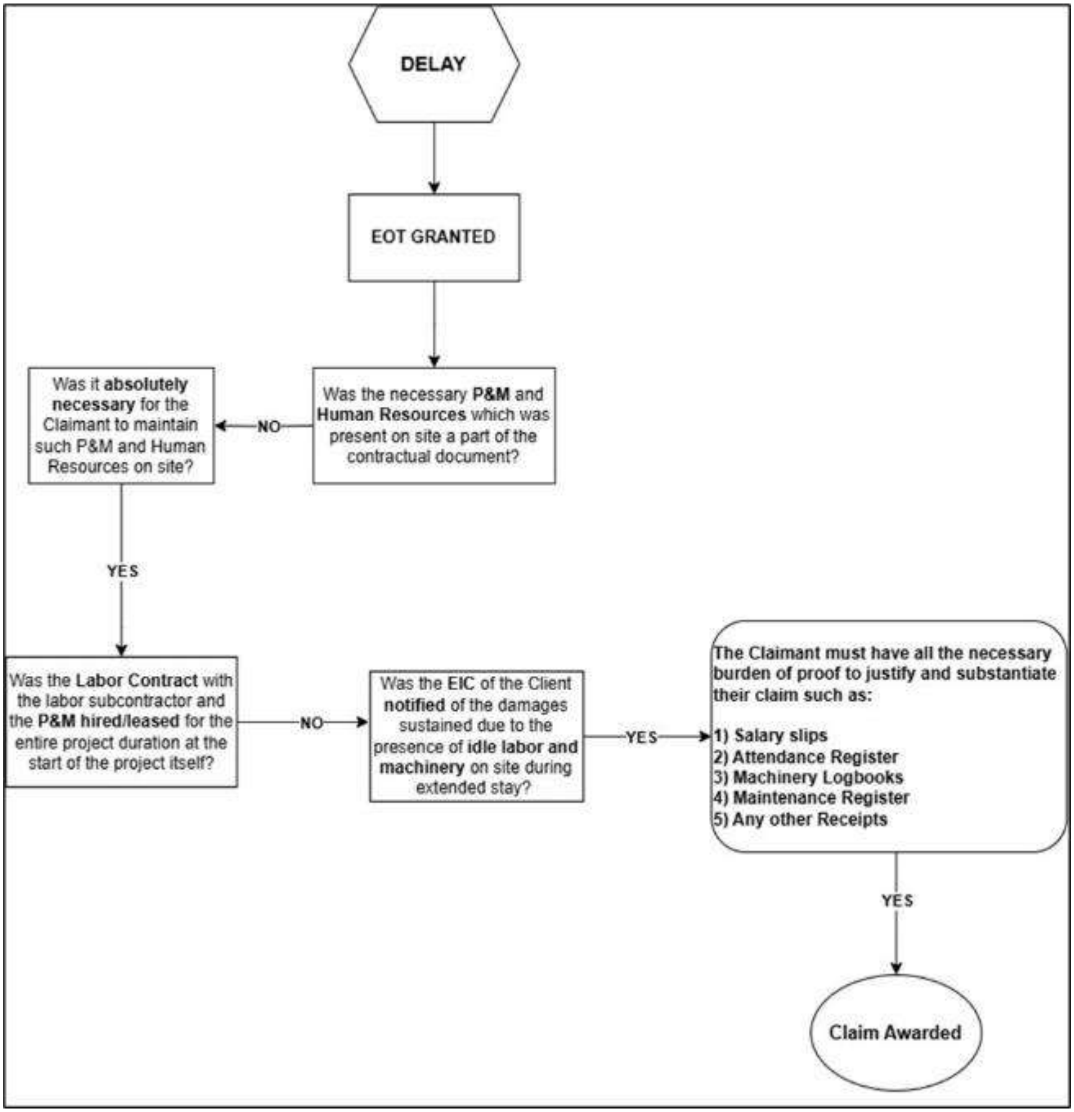
Figure 3: Flowchart- Logic 3



Flowchart- Logic 4 explains the conditions under which a compensation claim is awarded after an EOT is granted. If labor and P&M were hired for the entire project duration from the start, the claim is valid even if the EIC was not notified. However, the claimant must provide documentary evidence such as salary slips, attendance registers, and maintenance records to substantiate the claim.

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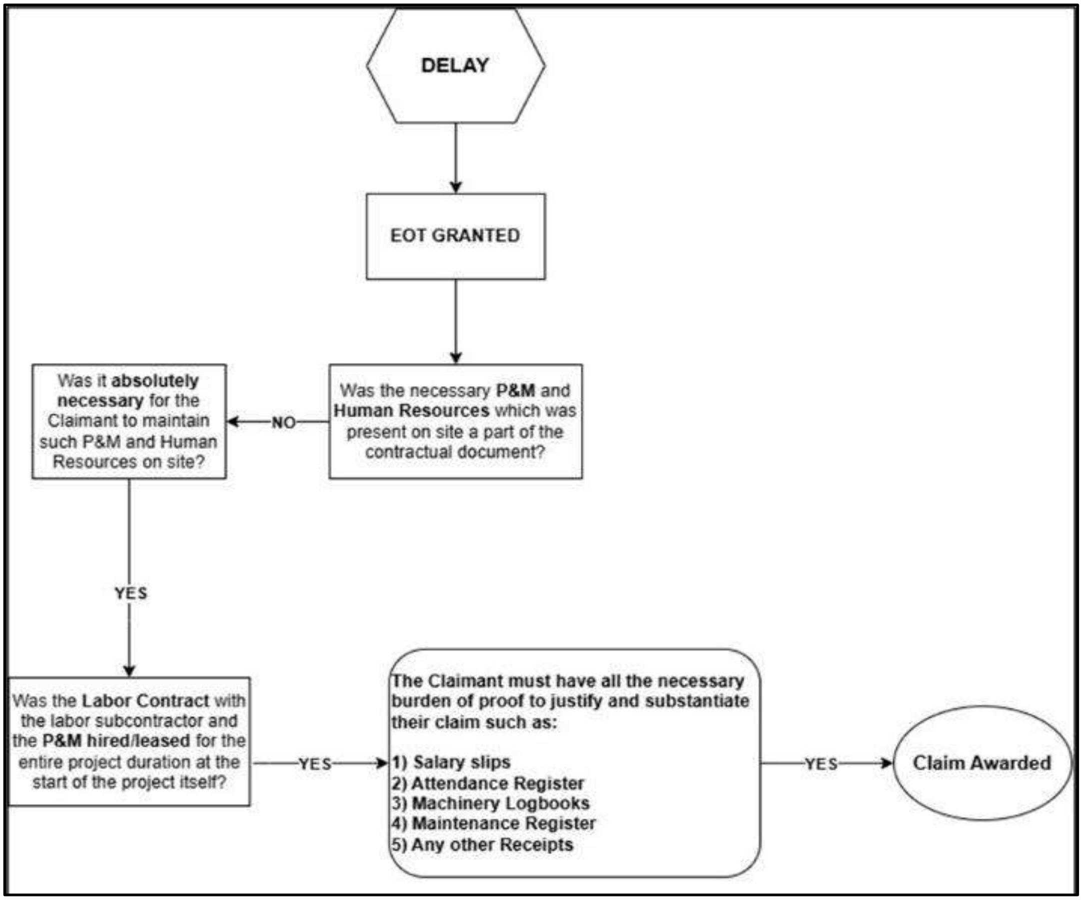
Figure 4: Flowchart- Logic 4



The framework has been developed after careful study of the arbitration awards. An attempt was made to understand the reasoning behind the judgments by the Arbitrators. The framework, structured using multiple flowcharts, ensures that only well-substantiated claims with valid contractual provisions and supporting evidence are considered. By providing a systematic approach to claim evaluation, this framework minimizes conflicts, improves financial planning, and strengthens dispute resolution mechanisms. The most important aspects that a claimant should consider before going for a claim are-

1. The contractual provision for such a claim.
2. Notification to the EIC at the right time for the dispute.
3. Maintaining all documentary evidence for justification and substantiation of claims.

The following framework offers claimants an organized method for requesting compensation for project delays by applying the logical reasoning found in arbitration disputes.

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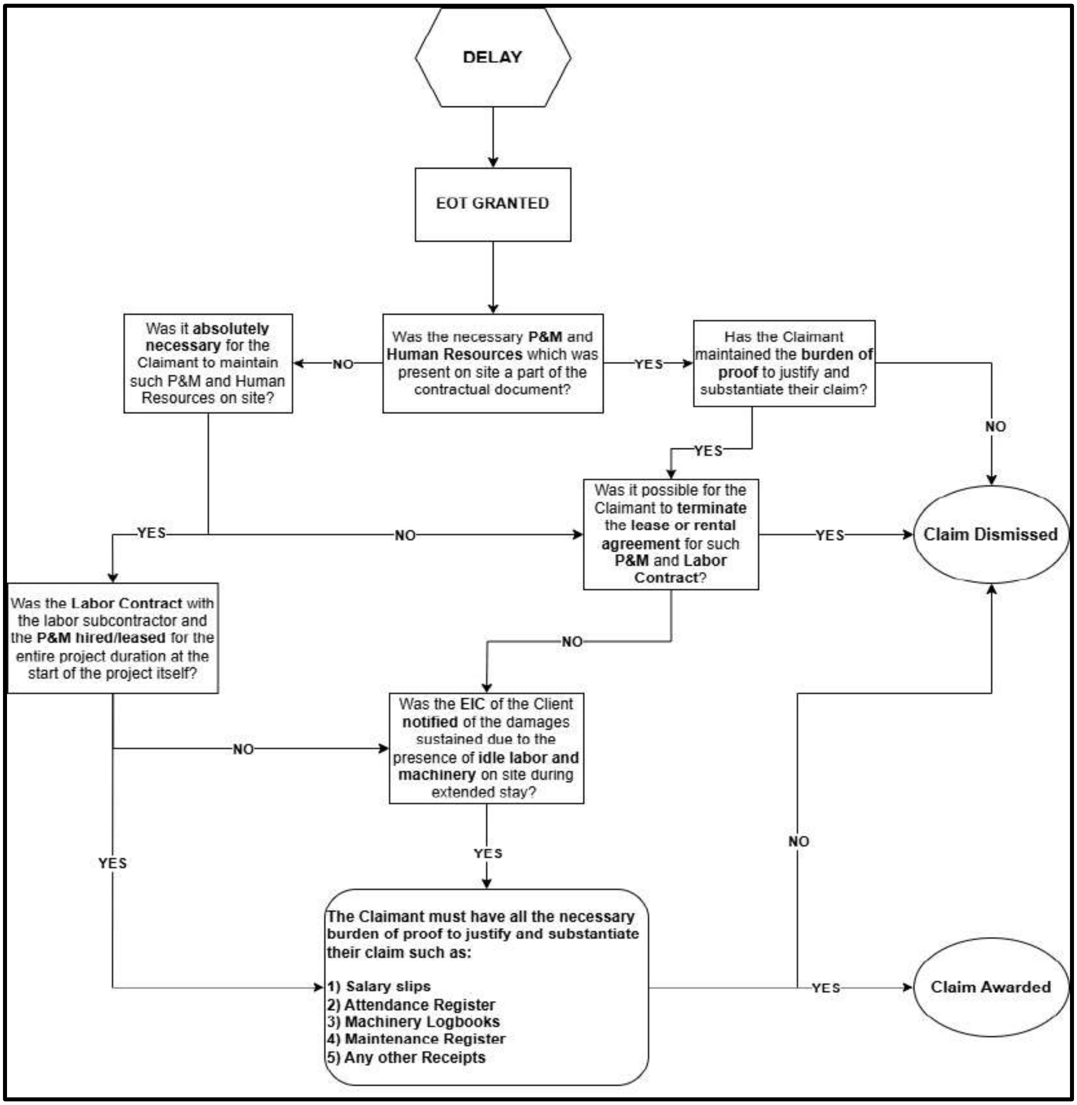
Figure 5: Flowchart - Framework for Losses Incurred due to Idle Labour and P&M



4.0 Conclusion

This study developed a structured Decision-Making Framework for evaluating compensation claims arising from Extension of Time (EOT) in Indian construction projects. Delays often lead to disputes and financial losses, making informed decision-making crucial for stakeholders. Analyzing 54 arbitration cases, it was found that 26 involved EOT claims where

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contractors sought compensation for extended stay costs. These claims were classified into four categories: escalation claims due to inflation, extra cost claims for idle labor and machinery, loss of profit claims from delayed completion, and legislative changes leading to additional costs.

The framework provides a structured approach for arbitrators to assess claims based on key factors, including contractual provisions for labor and machinery, obligations during the extended period, contract terms, timely notification to the Engineer-in-Charge (EIC), and supporting documentation such as salary slips, logbooks, and receipts. By offering a systematic evaluation method, the framework enhances transparency, ensures fair compensation, and minimizes disputes. While designed for the Indian construction sector, it provides a foundation for improving claim resolution, strengthening contract clarity, and promoting industry-wide best practices.

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CHAPTER 49

Design a Framework for Conversion of Existing Buildings into Green Buildings

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Dipesh Agarwal[1] and Arpita Mathur[2]

ABSTRACT

Conventional buildings, which frequently contribute significantly to energy use and resource depletion, are being reevaluated in light of the growing pressure to address environmental concerns. In order to maximize energy efficiency, lower operating costs, and lessen environmental effect, this research offers a thorough framework for transforming existing conventional structures into green buildings. This study's main goal is to create a workable solution that can be easily applied to many kinds of buildings and advance sustainability in the built environment. In order to determine practical techniques for retrofitting conventional structures, the research used a mixed-methods approach, analyzing case studies, existing literature, and expert interviews. Important conclusions show that incorporating green building principles, like water conservation, energy-efficient systems, and sustainable materials, can result in significant resource and pollution savings. In particular, putting these measures into practice not only improves a building's environmental impact but also provides owners and tenants with substantial financial gains. Homeowners, building managers, and legislators can all benefit from this paradigm, which offers practical insights into converting traditional buildings into sustainable settings. The goal of this research is to increase knowledge about green building techniques so that people and communities may make wise decisions that will lead to a more sustainable future.

Keywords: Green buildings; Retrofitting buildings; Energy efficiency; Effects on the Environment; Sustainable energy; Conserving water; Emissions of Carbon; Quality of indoor air; Changes in climate; Intelligent HVAC systems; Monetary rewards.

1.0 Introduction

Green or sustainable buildings try to make a lesser environmental impact by less dependence on fossil fuels, greater energy efficiency, water conservation, and sustainable material usage. These constructions put occupant health and comfort first, building environments that foster well-being while conserving resources.

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Due to urbanization, resource decline, and global warming, green building practices have moved from niche to mainstream in the construction sector. The construction sector has always been a contributor to environmental concerns such as pollution, global warming, and loss of natural resources because of unchecked development and growth in population. Green building methods were thus formed to minimize non-renewable resource use, reduce waste, and enhance energy efficiency. They employ renewable sources of energy, sustainable materials, and innovative technologies to design structures with a smaller environmental impact and optimal human health and productivity.

Green buildings are made energy-efficient by technologies like smart HVAC systems, improved insulation, and energy-efficient lighting. Water conservation is also an important aspect, attained through low-flow fixtures, rainwater harvesting systems, and drought-resistant landscaping. The use of sustainable materials, which are recycled, renewable, or locally available, also decreases environmental footprint by reducing waste and promoting a circular economy. Apart from environmental advantages, green buildings also yield considerable economic benefits.

Although construction costs are higher in the beginning, long-term energy consumption, water usage, and maintenance expense savings are considerable. Green buildings also command greater market value and are becoming highly desirable to tenants and customers who prioritize sustainability. Additionally, the green building industry generates jobs, boosts local economies, and saves operational expenses. Overall, society benefits.

Lastly, green buildings enhance community resilience by enabling sustainable urban planning and providing healthier, more comfortable working and living environments. They assist in developing social responsibility and environmental stewardship in communities, ensuring a quality life for future and present generations. As sustainable building continues to improve, it will continue to be an essential instrument in responding to environmental issues and creating a more sustainable future.

2.0 Literature Review

Several studies highlight that in order to prevent environmental deterioration and guarantee sustainable urban development, eco-friendly building techniques—such as energy efficiency, the use of renewable energy, and sustainable materials—are essential. Research highlights the benefits of subterranean construction in terms of preserving temperature control and conserving land, while green building technologies like BIM optimize water and energy use. Reducing resource use and reliance on traditional energy sources is made possible by green technology like recycled concrete and renewable power sources like solar energy. Designing a sustainable urban future that successfully addresses resource issues and climate change requires combining several techniques, such as the usage of Zero Energy Buildings.

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2.1 Green buildings

Pawar, (2012). Case Study 1st Internals-Alternative Building Materials-15CV653, March, CV. By emphasizing sustainability, green buildings seek to lessen the negative effects of construction on the environment and human health. The main goal is to reduce reliance on nonrenewable resources while increasing resource efficiency, which includes material reuse and recycling. The significance of green construction methods in advancing environmental sustainability is emphasized by the Journal of Engineering Research and Studies. In particular, energy saving, resource optimization, and the use of sustainable, alternative building materials are intended to lower the carbon footprint of buildings.

Green building approaches have been characterized as both exciting and demanding in India. On the one hand, the nation has made great progress in promoting the recovery and recycling of construction materials, which contributes to the preservation of natural resources and energy. However, there have been a number of obstacles to the shift to green buildings, such as logistical, financial, and technological ones. Notwithstanding these challenges, the government has played a critical role in raising awareness and encouraging energy-efficient building practices. This focus on sustainability in construction methods is part of a larger worldwide trend toward more ecologically friendly and sustainable building methods.

2.2 Evaluation of existing buildings

Bansal *et al.*, (2013). "Evaluation of existing buildings' green quotient." Volume 3, Issue 5, International Journal of Advanced Research (2013). A Delhi case study on an organization's strategies for enhancing a building's performance. The following issues were assessed: Water audit to identify the building's high water consumption locations and identify areas for improvement. Waste audit to determine how much solid waste is produced overall, how much is recycled, and how much is dumped in landfills and burned. Condition audit to ascertain the building's components' present state and anticipate remaining useful life. Thermal comfort, air quality, lighting levels, and noise levels are all included in the thermal audit. These were examined to determine their present performance and areas for improvement.

2.3 Green building energy conservation with solar photovoltaic systems

Pate *et al.*, (2013), "Energy saving of green building using solar photovoltaic systems." Innovative Research in Science, Engineering, and Technology: An International Journal (May 2013), (Vol. 2, Issue 5). The solutions for energy-efficient futuristic structures are outlined in the paper. Better, greener buildings will result from the use of the newest technologies in construction. The largest users of materials, energy, and water are buildings. The concept of green buildings encourages the use of recyclable and recycled materials as well as renewable energy. In comparison to normal buildings, green buildings must save 36-40% of water, 30-40% of energy, and 25-40% of material. High thermal insulation, rainwater collection, terrace gardening, ventilation, and energy-efficient equipment are characteristics of green buildings.

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2.4 Energy efficiency

Xia & Fan, (2018). Planning for energy-efficient building retrofits to comply with green building regulations. Environment and Building, (136, 312-321). In order to lower overall energy consumption, including operating energy as well as the embodied energy needed to extract, process, transport, and install construction materials, green buildings usually include a number of energy-saving strategies. Reducing air leakage via the building envelope—the barrier separating conditioned and unconditioned spaces—is one important tactic used by designers. Operating energy usage is greatly decreased by reducing this leakage. Designers frequently install high-performance windows and add more insulation to the building's walls, ceilings, and floors to further increase energy efficiency. Passive solar building design is a common energy-saving strategy in low-energy dwellings. In order to minimize the need for artificial heating and cooling, windows and walls should be positioned to optimize solar gain in the winter and to be shaded in the summer by porches, awnings, and trees. Furthermore, by letting more natural light into the structure, well-placed windows, sometimes known as "day lighting," can lessen the demand for electric lighting throughout the day. Solar water heating is another energy-saving feature that can further reduce energy costs by using solar energy for heating. The building's environmental effect can be considerably decreased by integrating on-site renewable energy sources like solar, wind, hydro, or biomass. However, the costliest part of the process is frequently integrating power generating into the building design. In the end, these tactics result in more sustainable building practices by increasing a building's energy efficiency and helping it satisfy green building compliance requirements.

2.5 Water efficiency

Sheth (2017). Water-efficient green construction technologies. International Journal of Scientific Research and Engineering Innovation, 1(3), (5–10). Two of the main objectives of sustainable building methods are water conservation and quality preservation. The demand for aquifers in many areas is greater than their ability to recharge, which presents a serious problem with water use. Water efficiency is therefore becoming more and more important in building design. To lessen reliance on outside water supplies, one important tactic is to rely more on on-site water collection, purification, and reuse, as much as is practicable. Facilities can, for example, install dual plumbing systems, which recycle water for flushing toilets and set aside water for things like washing cars.

Throughout the building's life, these methods aid in ensuring that water is used effectively. Additionally, by using less water for daily tasks, water-saving technologies like low-flow showerheads and ultra-low flush toilets greatly minimize wastewater generation. Additionally, by encouraging reuse and lowering the overall sewage load, bidets might lessen the need for toilet paper. Water conservation initiatives can be strengthened, and more environmentally friendly, sustainable water management solutions can be promoted by incorporating these technologies into building designs.

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2.6 Waste reduction

Reddy *et al.*, (2015). A method for achieving zero energy building standards is the hybrid solar and kitchen waste-based plant for green buildings. Journal of Engineering and Technology International Research (IRJET), 2. The environmental impact of water treatment plants and wells in green buildings can be decreased using a number of techniques. Using grey water, which includes wastewater from appliances like dishwashers and washing machines, is one such tactic.

After treatment, this water can be used for non-potable purposes like car washing or toilet flushing, or it can be used for subsurface irrigation. Additionally, rainwater harvesting systems reduce the demand for drinkable water by collecting and storing rainwater for later use. However, the cost and energy consumption of centralized wastewater treatment systems might be high. The transformation of waste and wastewater into fertilizer is an alternate strategy that reduces these expenses and offers additional advantages. To create liquid fertilizer, for instance, human waste can be gathered at the source and delivered to a semi-centralized biogas facility, where it is mixed with other biological waste. In addition to producing organic nutrients for the soil, this process produces carbon sinks, which take carbon dioxide out of the atmosphere.

3.0 Objectives of the Case Study

- To select and study the energy consumption of an existing residential building.
- To conduct a cost benefit analysis of an existing building after implementation of green building technologies.
- To develop a framework for converting an existing building into a green building.

4.0 Research Methodology

In order to create a sustainable transformation framework for Block A2 of Avon Vista Society with regard to waste management, HVAC systems, energy efficiency, and water conservation, this study uses a mixed-methods design. Interviews, focus groups, site observations, questionnaires, and secondary data (maintenance records, utility bills) will all be used to collect data. Quantitative data will undergo statistical analysis and cost-benefit analysis, while qualitative data will undergo theme and SWOT analysis.

The system includes improved waste management (segregation, composting), energy efficiency retrofitting (solar power, intelligent meters), water conservation measures (rainwater collection, greywater reuse), and HVAC improvements (smart thermostats, energy-efficient equipment). Expert and local input will verify that the system is workable and well received by the community for successful deployment.

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4.1 Data collection methods

4.1.1 Qualitative data collection

Interviews: Conduct semi-structured interviews with residents of Block A2, architects, engineers, and policymakers to obtain insights on:

- Current patterns of water and electricity usage.
- Practices related to waste management.
- Performance of the HVAC system and resident comfort levels.
- Challenges and chances related to retrofitting.
- Focus Group Discussions: Facilitate discussions with residents to gather their expectations, concerns, and recommendations for the framework.
- Site Observations: Perform physical inspections of Block A2 to evaluate:
- The existing systems for water supply and drainage.
- The electrical infrastructure and patterns of energy consumption.
- Mechanisms for waste disposal.
- The design and performance of the HVAC system.

4.1.2 Quantitative data collection

Surveys: Distribute structured questionnaires to all 84 flats in Block A2 to obtain data regarding:

- Monthly consumption of water and electricity.
- Habits surrounding waste generation and disposal.
- Residents' satisfaction with the HVAC system.
- Secondary Data: Gather data from:
- Utility bills (water and electricity) over the past year.
- Maintenance records of the HVAC system.
- Logs related to waste management.
- Energy and Water Audits: Perform audits to:
- Identify locations of high energy and water consumption.
- Assess the efficiency of the HVAC system.

4.2 Data analysis methods

4.2.1 Qualitative data analysis

- *Thematic analysis:* Assess interview transcripts and focus group discussions to pinpoint recurring themes, including:
- Elevated energy and water consumption.
- Ineffective waste management practices.
- Inefficiencies in the HVAC system and discomfort for residents.

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- SWOT Analysis: Execute a SWOT analysis to determine the feasibility of retrofitting Block A2, concentrating on:
- *Strengths:* Pre-existing infrastructure, residents' interest in sustainability.
- *Weaknesses:* Excessive energy consumption, outdated HVAC system.
- *Opportunities:* Possibilities for solar energy, rainwater harvesting.
- *Threats:* Financial limitations, resistance to change.

4.2.2 Quantitative data analysis

- Statistical Analysis: Evaluate survey data using statistical methods to:
- Determine average water and electricity usage per flat.
- Recognize trends in waste generation and disposal.
- Gauge resident satisfaction regarding the HVAC system.
- Cost-Benefit Analysis: Conduct a cost-benefit analysis for suggested retrofitting measures, which include:
- Installation of solar panels and energy-efficient lighting.
- Upgrading the HVAC system to enhance energy performance.
- Introducing water-saving solutions (e.g., low-flow fixtures, rainwater harvesting).

4.3 Framework design

The framework was crafted based on insights derived from data analysis and centers on the following essential areas:

4.3.1 Water conservation

- *Rainwater harvesting:* Create a system to gather and store rainwater for non-potable applications (e.g., gardening, flushing).
- *Greywater recycling:* Establish a system for treating and reusing greywater from sinks and showers.
- *Low-flow fixtures:* Suggest the installation of low-flow faucets, showerheads, and dual-flush toilets in every flat.

4.3.2 Electricity efficiency

- *Solar panels:* Design a solar energy system to be installed on the rooftop for generating clean electricity.
- *Energy-efficient lighting:* Recommend replacing standard lighting with LED options.
- *Smart meters:* Suggest the installation of smart meters to track and enhance energy consumption.

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4.3.3 Waste management

- *Waste segregation:* Create a system for separating waste at the source (organic, recyclable, non-recyclable).
- *Composting:* Formulate a composting system for organic waste.
- *Recycling partnerships:* Forge partnerships with local recycling organizations for effective waste management.

4.3.4 HVAC system upgrades

- *Smart thermostats:* Recommend the installation of smart thermostats for improved temperature regulation.
- *Improved insulation:* Plan enhancements to building insulation to minimize energy loss.

4.3.5 Implementation plan

- *Timeline:* Create a comprehensive timeline for the execution of the framework.
- *Budgeting:* Deliver a cost assessment for each element of the framework.
- *Monitoring and evaluation:* Develop a system for tracking and assessing the effectiveness of the retrofitting actions.

4.3.6 Validation

- *Expert feedback:* The suggested framework was validated through insights from specialists in sustainable architecture, green building design, and HVAC systems.
- *Resident feedback:* Shared the framework with residents of Block A2 and collected their input to ensure community acceptance and address any issues raised.

4.3.7 Ethical considerations

- *Informed consent:* Secured informed consent from all participants prior to conducting interviews and surveys.
- *Confidentiality:* Preserved the confidentiality and anonymity of participants by employing coded identifiers.
- *Transparency:* Ensured transparency during data collection, analysis, and reporting processes.
- *Bias mitigation:* Reduced researcher bias by utilizing standardized protocols and involving multiple researchers in the data analysis process.

4.3.8 Limitations

- *Scope:* The research is confined to Block A2 of Avon Vista Society, and the results may not be applicable to other buildings or communities.

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- *Financial constraints:* The effectiveness of the framework relies on the availability of financial resources for retrofitting initiatives.
- *Resident participation:* The readiness of residents to embrace sustainable practices is essential for the project's success.
- *Data accuracy:* Dependence on self-reported information from surveys and interviews may lead to biases.

5.0 Framework

The following are the main goals of the Avon Vista Wing A2 Green Building Conversion:

- *Energy efficiency:* Reduce energy use by 35% by implementing energy-saving measures such solar panels, LED lighting, double-glazed windows, high-efficiency HVAC systems, and battery storage. Conserve 40% of water by using rainwater collecting, greywater reuse, and energy-efficient fixtures.
- *Trash management:* Use a 3-bin system, compost, and recycle to reduce trash by 75%.
- *Indoor air quality:* Use IAQ sensors, low-VOC materials, and fresh air supplies to maintain WHO air quality requirements.
- *Sustainable materials:* Use at least 50% recycled or sustainable materials in concrete and green roofs, such as fly ash and recycled steel. 80% of the population should be involved in the community through workshops, feedback mechanisms, and rewards.
- *Certification:* Track waste, water, and energy metrics to earn LEED Gold certification in 18 months.

Implementation Plan:

- *Phase 1 (0–6 months):* Upgrade windows, lighting, insulation, and water and energy use.
- *Phase 2 (6–12 months):* Install waste management systems, solar panels, and rainfall collection.
- *Phase 3 (12–18 months):* Engage residents, track performance, and submit a LEED Gold application.

6.0 Conclusion

This study used a thorough methodology that included data collecting, observation, and analysis of appliance efficiency, overall energy demand, and usage patterns to successfully investigate the target residential building's energy consumption. By identifying peak usage periods, pointing out places where energy was being wasted, and highlighting conservation options, the thorough analysis yielded insightful information about the building's energy performance. The results demonstrated the possibility for large reductions in energy expenditures and environmental effects, and they emphasized the significance of optimizing

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energy consumption. The building's sustainability has been greatly improved by the incorporation of eco-friendly elements. Significant energy savings and a smaller environmental impact have been achieved by the installation of a 2.0 m² vermin composting system, a vertical garden, LED lighting, grass pavers, and a rooftop solar power system. In particular, the composting system saved ₹6,640 a year, while the vertical garden improved air quality and helped save ₹3,00,000. The solar system produced 9,000 kWh yearly, saving ₹31,708.8 in energy expenditure; LED lighting decreased power costs by ₹60,480; and the usage of grass pavers resulted in savings of ₹2,56,000. When taken as a whole, these eco-friendly projects saved more than ₹6,00,000, greatly increasing the building's energy efficiency.

Additionally, a comprehensive model for converting the building into a green building was developed as a result of the careful examination of energy usage trends. The concept emphasizes key sustainability components like increasing energy efficiency, using environmentally friendly materials, conserving water, and integrating renewable energy sources. The transition to a sustainable building is not only possible but also successful thanks to this organized framework, which offers a realistic, step-by-step method for transforming the building into an eco-friendly, energy-efficient structure.

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CHAPTER 50

Developing a Business Plan for Creating a Real Estate Construction Firm

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ABSTRACT

The article submits the framework of the business plan in setting up a real estate building company, Apex Constructions, with the motive towards green and innovative construction methodologies. Along with rising urbanization, housing space as well as commercial space is being looked for increasingly. Apex Constructions, the company, will cater to this requirement with the implementation of green building concepts and newer technology construction methods from a vision angle of delivering ecologically friendly as well as financially effective solutions. Government infrastructural development, commercial developments, and residential complex developments are the firm's target market and lean towards buildings designed with preference to sustainability and energy efficiency. Financial planning of solid strength lies with the business model, whereby they use a combination of pre-sales, developer equity, and banking financing for sustaining operations. A formal marketing strategy employing both traditional and digital media will enhance brand recognition and establish trust. The organization will also focus on project management excellence with an emphasis on cost control, quality, and timely delivery. Since the global building industry has a projected 5% average yearly growth rate, Apex Constructions is looking to take advantage of the surge in trends of smart buildings and green building. By offering reliable, quality, and sustainable building solutions, the firm hopes to become a leader in the evolving property scene, creating long-term value for clients and stakeholders.

Keywords: Real estate construction; Sustainability; Green building technologies; Project management; Urbanization.

1.0 Introduction

Offering quality, environmentally friendly designs, Apex Constructions is a modern real estate development firm hoping to transform building methods in urban and suburban locations. The building sector is growing as the pace of urbanization rises and the need for homes, businesses, and combination structures rises as well (Barrett 2022). Apex Constructions aims to meet this need by offering building solutions combining ecological concerns with formal and practical requirements.

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Serving private homeowners, contractors, real estate developers, commercial property investors, public sector customers needing dependable and high-quality construction solutions adaptation for today's needs, we are a firm with many faces. Using the rising trends in construction technology and green building materials as well as solid project management ideas, our company is committed to lifting the standard in the building sector (Sciences & Chidinma 2012). Our objective is creating environments that improve life, not just completing one project and then on to the next and the next. We have great expertise in environmentally friendly building and make use of modern construction techniques, goods and technologies in line with efficient building standards. This method not only solves the evolving needs of the market but also presents Apex Constructions as a leader in the shift toward a more sustainable building concept (Vos *et al.*, 2016). Apex Constructions is well situated in a metropolitan area where the strategy calls for efficient use of proximity to current high-end markets and low running expenses. Combining the administrative anchor with the flexible, high-tech project execution mechanism allows one to deliver projects with the intended correctness, flexibility, and speed. Our operational approach additionally emphasizes on the great contact with the suppliers as well as the dependable network of qualified subcontractors, which enables to regulate the resource allocation, quality, and time-sensitive variables (Dinna *et al.*, 2020).

As part of our expansion plan, a strong marketing strategy using both traditional and digital channels to raise brand recognition and trust is very important (Jelonek & Nguyen 2022). Our polished website and regular social media activity help our online presence to let clients see our portfolio, learn more about our commitment to excellence, and contact our personnel. We will also engage with trade publications, real estate exhibits, and professional groups to cultivate a reputation for quality and inventiveness in the construction company. Our customers are our first concern; we promise a seamless procedure from beginning to end via honest and open communication (Wei & Chris 2012).

The financial stability and scalability of Apex Constructions are derived from a comprehensive financial plan meant to preserve strong profit margins and maximize income possibilities. Focusing on metropolitan and suburban sites with high demand can help to produce a varied portfolio of projects with stable revenue (Anene *et al.,* 2019). Our sources of income government contracts, mixed-use buildings, homes, and businesses give consistency and scope for growth. Effective project completion, cost control, and a rising clientele will provide consistent cash flow, which Apex Constructions expect to break even in the first two years. Not just a construction firm, Apex Constructions is committed to excellence, sustainability, and creativity in the real estate sector (Coiacetto 2009). As urban surroundings evolve and customer demands rise, our dedication to quality and ethical construction will help us to establish ourselves as a dependable partner having a major impact on the building industry (Liu *et al.,* 2018). Faced with the demands of the modern world, Apex Constructions is ready by focusing on sustainable development and value-driven results, therefore leaving a legacy of quality and dependability for many years to come (Lindholm *et al.*, 2006).

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1.1 Company and domain name

Company Name: Apex Constructions: Apex Constructions has been created to represent energy, innovation, and development in construction. The name "Apex" distinguishes us in an oversaturated marketplace by representing an energetic, forward-thinking approach. This is true to our intent to provide the real estate world with new and original ideas while retaining the highest sustainability and quality. ApexConstructions.com shall be a colorful online gateway through which we get to communicate our brand values, promote our services, and exhibit our portfolio. The site will be an active gateway through which potential clients are able to see our work and understand more about our dedication towards constructing better, greener places. It shall include project galleries, client testimonials, and tutorial materials on green construction techniques. There will also be an integrated client portal on the site through which customers can readily interact with our project management staff, access files, and track progress. ApexConstructions.com will further be search engine optimized so that it reaches more individuals and becomes a prime source for high-quality construction services. Our goal is to position Apex Constructions as a top company in the development of real estate in urban and suburban areas through our online presence.

1.2 Market analysis and research

Industry Overview: A major player in the world economy, the building industry has expanded greatly, mostly in response to the real estate market. The building sector is expected to keep growing due to elements like infrastructure development, urbanization, and the requirement of residential and commercial space. With an eye on developing nations and places becoming more urbanized, current industry assessments indicate that the worldwide building market is likely to rise at a compound annual growth rate (CAGR) of 5%. Future building methods will change in response to growing demand for intelligent, sustainable, and energy-efficient constructions. Particularly in cities, infrastructural projects, commercial structures, and residential buildings are constantly in demand in areas where population is rising fast. With the most recent advancements in environmentally friendly and green buildings, real estate developers and property owners are seeking for construction companies that give sustainability and cost-effective top priority without sacrificing quality.

1.3 Target market

The primary target market for Apex Constructions includes:

Urban Residential Market:

- *Demographics:* Homeowners, investors, and middle-class to upper-class urban developers in need of new housing projects, mixed-use developments, and apartment complexes.
- *Geographic Focus:* There is a considerable demand for residential spaces in major metropolitan centers that are undergoing substantial expansion and urban sprawl because of the growing population and the limited availability of available dwellings.

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Commercial Market:

- *Demographics*: Developers of commercial real estate, corporations in need of office space, and retailers seeking customized building solutions for their stores.
- *Geographic Focus*: Emerging commercial centers and urban business districts include locations that may be modified to meet the demands of contemporary businesses, such as co-working spaces and mixed-use projects.

Government and Institutional Projects:

- *Demographics*: Contracts with the local and federal governments for civic buildings, affordable housing, and public infrastructure.
- *Geographic Focus*: Regions with government-led building projects focused on social housing, transit and public welfare.

Real Estate Developers:

- *Demographics*: For residential, commercial, and industrial projects, large developers are looking for dependable, effective, and superior construction services.
- *Geographic Focus*: Real estate hotspots in quickly emerging areas, suburban growth zones, and high-demand metropolitan areas.

1.4 Competitive analysis

Direct Competitors:

- Big, reputable construction companies with a wide range of projects under their belts. These businesses often provide a variety of services, such as design, development, and construction management.
- More specialised, smaller businesses that cater to certain sectors, such luxury residences or eco-friendly structures, and provide more specialised services at a higher price point.

Indirect Competitors:

- Local building firms and contractors that could have cheaper costs but lack the creativity, attention to sustainability, and substantial resources required for complicated or large-scale projects.
- It might be difficult for property developers to get contracts in certain markets if they have in-house construction teams or depend on subcontractors.

1.5 Market trends

Sustainability and Green Building:

- In the real estate building sector, sustainability has emerged as a significant trend. Demand for eco-friendly structures, energy-efficient designs, and the use of sustainable materials is rising as people become more conscious of climate change and the effects that construction has on the environment.

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- Clients looking to lower their operating expenses and carbon impact are increasingly pursuing green building certifications like LEED (Leadership in Energy and Environmental Design).

Technology Integration in Construction:

- The building industry is increasingly embracing new technologies like 3D printing, drones for surveying, building information modeling (BIM), and robotics. Through faster, more precise, and more efficient building projects, these technologies save budgets and deadlines.
- Demand is moving to favor high-tech, energy-efficient buildings as automation and smart building technologies get more prevalent.

Post-Pandemic Demand for Residential and Commercial Spaces:

- The COVID-19 outbreak has impacted on the demand for retail, office, and housing spaces, therefore influencing the real estate market. Though suburban residential property is more in demand, the commercial real estate market is evolving as more businesses seek hybrid workspaces and flexible office layouts.

1.6 Market size and growth opportunities

In 2023, the size of the international construction sector was predicted to be over $12 trillion, and it is likely to expand rapidly over the following several years. Particularly with regard to the construction of companies and residences, the real estate sector is expected to be quite important for the growth of this market. Emphasizing ecologically friendly and innovative building solutions will help Apex Constructions to seize this expanding business. The middle class's rise in emerging countries, the shift toward sustainable urban development, and government infrastructure spending show likewise great economic possibilities. These trends demonstrate how addressing the evolving requirements for smart, sustainable, and modern architecture may help Apex Constructions to become a major influence in both developed and underdeveloped nations.

2.0 Literature Review

The building sector, which is marked by changing technological and market patterns, is plagued with specific challenges and opportunities for companies. This literature review discusses several research studies concerning building materials, technology innovation, business models, and operational strategies that affect the building sector. Through investigating technology environments, construction health and safety, and business strategy impact, this review presents insights into the present and the future that are propelling success in construction businesses. The discoveries of these investigations will guide creating a business plan that is specific to industry needs, competitive activity, and marketplace demand.

Pradoto *et al.* (2021) present an overall view of Indonesia's development of steel and concrete construction material technology, with a focus on the history of development and

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development in the future of construction material technology. The research highlights policymakers to formulate an overall understanding of construction material innovation to improve technological growth and implementation in Indonesia. Interviews, surveys, and literature reviews were used as research tools to collect relevant information about the market. Ghosh *et al.* (2022) carried out a comprehensive study of digital technologies in construction, with emphasis on such emerging technologies as BIM, blockchain, and IoT.

Scientometric mapping and weighted mind-map analysis were used in their study to investigate trends and worldwide influence of the technologies. Their study chose noteworthy topics like sustainability, safety for construction workers, and systems as noteworthy clusters to be noteworthy areas, offering a blueprint for the effective integration of digital technologies into building construction. Ahmad *et al.* (2012) spoke about the use of Building Information Modeling (BIM) in landscape architecture, exhibiting its need for expert landscape architects to innovate and effectively work alongside other experts employing BIM technology. The study indicates the imperative necessity for the development of professional BIM software for landscape architecture to enhance design productivity and collaboration, which is essential for the development and integration of the industry with other fields of construction in the future.

Li *et al.* (2021) examined the structure, relationship, and requirements of urban street spaces, suggesting an integral intelligent decision-support system for urban design. Their system has infrastructures, services, maintenance, and management elements, illustrating how intelligent technologies are capable of improving urban construction processes. This model is a template for the application of engineering management across different industries under Industry 4.0. Cao *et al.* (2021) presented a thorough literature review of health and safety in construction, highlighting the changing challenges and innovative research directions in this field. In their study, they investigated the fragmentation of health and safety research, suggesting a more integrated approach to deal with new norms and practices in the construction sector to create safer and more efficient working environments. Sternberg (2014) also explained how building and land development companies influence the city form, i.e., the tendency towards “postmodern landscapes.” Sternberg says construction companies no longer pay attention to manufacturing commodities but instead to their branding and iconic products. This new focus has redesigned cityscapes such that companies concentrate on marketable images to sell to consumers.

Jang *et al.* (2019) further investigated the influence of business models on the international performance of construction firms. Through their study, they established availability of funds, geographic diversification, and application of business model type to have considerable impacts on profitability, revenue growth, and market performance. This establishes the importance of strategic planning by construction enterprises to achieve success across borders. Takima *et al.* (2016) conducted a study on the effect of disasters on construction companies in Malaysia, examining the psychosocial factors that influence workers before and after natural and man-induced disasters. According to their study, the quality of work,

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employment, and career development are influenced by disasters, and firms are required to take such issues into consideration while developing crisis management policies in order to avoid disruption and maintain productivity. Kalel *et al.* (2015) were concerned with planning projects among small-scale Indian construction firms, specifically analyzing the application of registration systems in allocating resources. It was confirmed in the study that proper planning of labor, materials, and equipment, though comparatively less in number, is crucial in the timely completion of construction projects. It highlights the necessity for sophisticated project planning techniques among small-scale contractors. Onyechere *et al.* (2023) studied financial management practices among construction companies in Delta State, Nigeria, and emphasized the importance of formal planning, corporate governance, and management of resources in order to enhance financial performance.

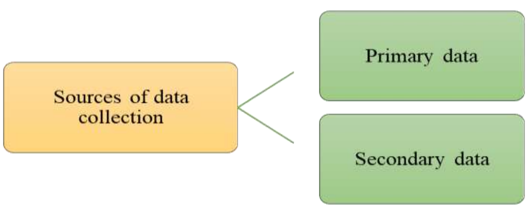
The study revealed that effective financial practices have a critical contribution towards profitability and operational efficiency in construction companies. Marichova (2019) illustrated how intangible assets such as knowledge, people, and systems are responsible for the competitive edge of a company. She posited that an integrated business model, being the economic basis of strategic actions, is at the heart of organizational success. The study emphasizes the need for construction companies to tackle internal and external challenges through operational changes at a strategic level. This review of the literature identifies the multifaceted dynamic of the construction sector, touching on numerous subjects ranging from technology and health and safety to business models and operational efficiencies. All the studies add to an appreciation of the forces driving successful construction companies, with significant insights into the changing dynamics of the sector.

3.0 Research Methodology

3.1 Primary data collection

Primary data will be collected in the form of surveys, interviews, and focus groups with the key industry stakeholders like real estate investors, builders, architects, and government policy makers. Surveys will collect customers' expectations regarding pricing, quality, and timeline, whereas market challenges will be assessed through interviews. Focus groups will enable discussion on customer satisfaction and green construction practices.

Figure 1: Sources of Data Collection



Source: compiled by author

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3.2 Research design

The study design will involve descriptive and explanatory methods. Current industry trends, customer tastes, and regulatory factors will be described through descriptive research, while explanatory research will uncover relationships among market forces. Qualitative and quantitative methods will be employed to incorporate primary and secondary data into formulating an extensive business plan for the construction company.

3.3 Data collection methodology

This study will collect primary information from real estate stakeholders through surveys, interviews, and focus groups. Secondary data will be derived from industry reports, academic papers, and case studies to offer a broader understanding. Both the data complement and supplement each other to offer balanced analysis, providing insights into customer needs, trends, and competitors' activities for the business plan.

3.4 Secondary data sources

Secondary data is to be sourced from reports, research reports, market research reports, and industry reports. They will provide background information on competitor strategies, consumer trends, and industry trends. With the enhancement of secondary data with primary observation, the study will offer thorough insight into the market and shape the development of an effective business plan.

4.0 Result and Discussion

4.1 Detailed budget breakdown

- *Land acquisition:* Includes the purchase price, legal fees, and taxes. Research local market rates and regulations in Pune.
- *Construction costs:* Labor wages, material costs (cement, steel, etc.), machinery rentals, and utilities.
- *Permits and approvals:* Costs for environmental clearances, zoning permissions, and government sanctions.
- *Marketing and sales:* Advertisements, social media campaigns, real estate expos, brochures, and sales commission.
- *Operational costs:* Staff salaries, software tools, office expenses, and transportation.
- *Contingency funds:* Reserve 10-15% of the budget for unforeseen expenses like material price hikes or project delays.

4.2 Project overview

- Location: Ravet, Pune
- Project Type: G+4 Luxurious Studio Apartment

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- Total Floors: 4
- Total Flats: 12 (3 Flats per Floor)
- Total Land Area: 6000 sq. ft
- Project Duration: 24 to 36 months

4.3 Land acquisition
- Total Land Area: 6000 sq. ft
- Land Price per sq. ft: ₹2,500 (Approximate Market Rate in Ravet)
- Total Land Cost: ₹1,50,00,000

4.4 Construction details
- Total Built-Up Area: 14,400 sq. ft (Each Flat: 1,200 sq. ft Approx.)
- Construction Rate per sq. ft: ₹3,500
- Total Construction Cost: ₹5,04,00,000

4.5 Cash flow statement (monthly)
Monthly Cash Flow for G+4 Studio Project

Table 1: 24-Month Plan (Aggressive Timeline)

Month	Activity	% of Cost	Monthly Expense (₹)
1-3	Land Purchase, Legal Fees	30	162900000
4-6	Design, Permits, Approvals	5	27150000
7-12	Foundation & Structural Work	25	67875000
13-18	Walls, Roofing, Electrical, Plumbing	15	40725000
19-24	Interiors, Elevator, Parking, Landscaping	25	67875000
24	Final Approvals & Miscellaneous	5	8145000

Source: Compiled by author

4.6 Average monthly cash flow (24-month plan): ₹67,87,500

The 24-Month Plan (Aggressive Timeline) ensures rapid project execution, allocating funds in structured phases to maintain efficiency and financial discipline. The initial three months focus on land acquisition and legal formalities, covering 30% of the total cost. In the next three months (4-6), 5% of the budget is allocated to design, permits, and approvals, enabling smooth regulatory processing. The foundation and structural work take place between the months 7-12, utilizing 25% of the funds. Moving forward, walls, roofing, electrical, and plumbing are completed in months 13-18, consuming 15% of the total cost. The final major phase (months 19-24) includes interiors, elevators, parking, and landscaping, utilizing another 25% of the budget. Lastly, in month 24, 5% of the funds are allocated for final approvals and

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miscellaneous expenses, ensuring project completion and readiness for occupancy. This timeline accelerates development, enabling quicker market entry and potential early returns on investment.

Table 2: Additional Costs

Item	Total Cost (₹)
Security Systems	15,00,000
Landscaping & Common Areas	20,00,000
Parking Facilities	25,00,000
Contingency Fund (10% of total cost)	1,50,00,000
Advertising Budget	5,00,000
Facebook Ads (₹15,000 per month)	3,60,000
Hoarding (₹20,000 per month)	4,80,000
Brochures (₹20,000 per month)	4,80,000
Total Miscellaneous Costs	2,23,20,000

Source: compiled by author

The Additional Costs section covers essential expenses beyond construction and land acquisition, ensuring the project's overall functionality, security, and market reach. Security systems (₹15 lakh) and landscaping & common areas (₹20 lakh) enhance the safety and aesthetics of the project, while parking facilities (₹25 lakh) provide convenience for residents. A contingency fund of ₹1.5 crore (10% of total cost) safeguards against unforeseen expenses. Advertising and marketing costs, including a general budget of ₹5 lakh, Facebook Ads (₹3.6 lakh), hoardings (₹4.8 lakh), and brochures (₹4.8 lakh), support brand visibility and sales efforts. Together, these components amount to ₹2.23 crore, ensuring smooth execution, project appeal, and successful market penetration.

Table 3: 36-Month Plan (Extended Timeline)

Month	Activity	% of Cost	Monthly Expense (₹)
1-6	Land Purchase, Legal Fees	30	81450000
7-12	Design, Permits, Approvals	5	13575000
13-18	Foundation & Structural Work	15	40725000
19-24	Walls, Roofing, Electrical, Plumbing	15	40725000
25-30	Interiors, Elevator, Parking, Landscaping	25	67875000
31-36	Final Approvals & Miscellaneous	10	27150000

Source: compiled by author

4.7 Average monthly cash flow (36-month plan): ₹45,25,000

The 36-Month Plan (Extended Timeline) follows a structured approach, spreading expenses over a longer period to ensure steady financial management and controlled execution. The first six months are dedicated to land acquisition and legal fees, utilizing 30% of the total cost. In the months 7-12, 5% of the budget is allocated to design, permits, and approvals,

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ensuring compliance with regulatory requirements. Foundation and structural work are completed between the months 13-18, consuming 15% of the funds, followed by walls, roofing, electrical, and plumbing in months 19-24, also accounting for 15% of the cost. In the months 25-30, interiors, elevators, parking, and landscaping are implemented, utilizing 25% of the total budget. Finally, in the months 31-36, 10% of the funds are allocated for final approvals and miscellaneous expenses, ensuring smooth project handover and completion. This timeline allows for a balanced financial flow, reducing monthly cash flow stress while maintaining construction momentum.

Table 4: Material List and Estimated Costs (Per Sq. Ft.)

Material	Unit	Cost per Unit (₹)	Cost for 1,000 Sq. Ft. (₹ Lakhs)
Cement (OPC/PPC)	Bag (50 kg)	400	4
Steel (TMT Bars)	Ton	65,000	6.5
Bricks (Fly Ash/Red Clay)	1,000 bricks	7,500	3
Sand (River Sand/M-Sand)	Cubic ft.	50	2.5
Aggregates (10mm, 20mm, 40mm)	Ton	1,500	2
Ready Mix Concrete (RMC)	Cubic Meter	5,000	6
Plumbing Materials (Pipes, Fittings, Valves)	Lot	Varies	2.5
Electrical Materials (Wires, Switches, MCBs, Panels)	Lot	Varies	3
Tiles (Flooring & Wall Cladding)	Sq. Ft.	70	3.5
Wood & Plywood (Doors, Windows, Cabinets)	Sq. Ft.	150	4.5
Paint & Finishing Materials	Liter	300	2
Glass (Windows & Partitions)	Sq. Ft.	250	2
Roofing Sheets/Concrete Slabs	Sq. Ft.	350	3.5
Sanitary Fixtures (Toilets, Sinks, Faucets, Showers)	Set	15,000	2.5
Hardware & Miscellaneous	Lot	Varies	2
Labour & Machinery Costs	-	-	10
Other Contingencies & Miscellaneous Costs	-	-	5

4.8 Estimated total cost per 1,000 Sq. Ft. = ₹60.0 Lakhs

The Material List and Estimated Costs provide a detailed breakdown of construction materials and their estimated expenses per 1,000 sq. ft., ensuring a clear understanding of resource allocation. Key components include cement (₹4 lakh), steel (₹6.5 lakh), bricks (₹3 lakh), sand (₹2.5 lakh), and aggregates (₹2 lakh), forming the structural foundation. Ready Mix Concrete (₹6 lakh), plumbing (₹2.5 lakh), and electrical materials (₹3 lakh) contribute to building integrity and functionality. Flooring, woodwork, glass, and roofing add aesthetic and structural elements, while sanitary fixtures (₹2.5 lakh), paint, and finishing (₹2 lakh) enhance interiors. Labour and machinery costs are estimated at ₹10 lakh, with other contingencies at ₹5 lakh, leading to a total estimated cost of ₹60 lakh per 1,000 sq. ft. This estimation ensures cost efficiency while maintaining high construction quality.

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4.9 Funding and loan sources

- Developer Equity Contribution: 30% (~ ₹2,63,16,000)
- Bank Loan: 50% (~ ₹4,38,60,000)
- Customer Pre-Sales & Investment: 20% (~ ₹1,75,44,000)
- Stakeholder Investment: 4 stakeholders invested ₹1 crore each (~ ₹4,00,00,000)

4.9 Loan process details

- *Eligibility check & loan application:* The developer presents to the bank a thorough business strategy, cost projections, and project viability report starting the financing procedure. This covers predicted returns as well as financial statements and market research. Before advancing with the approval procedure, the bank then assesses the developer's creditworthiness, historical project experience, and financial stability.
- *Approval & sanctioning:* Once the first evaluation is over, the bank authorizes the loan depending on project viability, lending capacity, and available collateral—which may include pre-booked apartments or the land—which serves as security. Usually depending on the quality of the papers and financial institution verification, the approval procedure lasts from thirty to sixty days.
- *Disbursement schedule:* Multiple rounds of disbursement of the loan amount coincide with project milestones to guarantee methodical cash allocation. The first step, at thirty percent, addresses legal expenses and property purchase. Foundation and structural work fall in the second phase, 25%. Interior and finishing employ the third phase, (20%). The fourth phase (15%) backs landscape and parking projects. Approvals and other project costs divide the last phase—10%—between them. These organized disbursements reduce risks and guarantee regulated money flow.
- *Repayment Plan:* After a 24-to-36-month moratorium, loan repayment starts and gives the developer time to finish building and start making money. Flat sales, rental revenue, and developer equity returns provide a source of repayments. Based on the bank's terms and current state of the market, the interest rates fall between 8 and 12%.
- *Risk management & compliance:* Strict compliance policies banks implement help to reduce operational and financial risks. Frequent project inspections guarantee correct money use and loan requirements are followed. Compliance checks provide financial discipline by means of funds issued only when the building progress satisfies set standards, therefore preserving transparency and lowering default risks.

5.0 Conclusion

Development of a real estate construction company necessitates a risk management plan combining project execution and cost planning. This proposal features a G+ 4 Luxurious Studio Apartment project in Ravet, Pune, covering financing sources, acquisition of land, construction

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costs, and land reclamation. Lending on a systematic basis prevents money flow breakdown through the adoption of eligibility tests, staggered disbursement, and repayment dates. Two financial models—24-month aggressive and 36-month extended timeline—offer flexibility in capital management and implementation. Estimation of construction cost facilitated through an exhaustive list of materials and cost analysis is made to be budget-effective. Further, improvement in sales and visibility is a marketing strategy involving internet ads, hoardings, and brochures. The financial model increases the project viability by introducing developer equity, bank finance, stakeholder financing, and consumer pre-sales. This strategy is a solid base for a profitable real estate development company through the inclusion of risk management strategies and taking advantage of market analysis of customers ready for new banking services. The interplay between astute marketing, operational excellence, and organized finance in India's thriving real estate industry assures profitability and sustainability over the long term.

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CHAPTER 51

Developing a Framework to Address Challenges in Urban Road Development: A Case Study of Pune City

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Omkar Sawant[2] and Nilesh Agarchand Patil[2]

ABSTRACT

This paper identifies that urban road development faces various risks, including poor planning, high cost, bureaucracy, and environmental factors in fast-growing urban cities such as Pune in India. Such pertaining problems have resulted in poor perhaps standards of the roads hence leading to traffic jams, car tracks, encroachment, and insecurity throughout the lives of the people as well as the transport systems throughout the regions. The purpose of this research is to: outline these challenges and propose a framework capturing them so that, improvement strategies can be implemented effectively to improve efficiency and sustainability for urban road projects. In this research data collection encompassed both qualitative data collection tools. Secondary data were collected by conducting paper and electronic literature searches and analyzing published case studies of typical urban road projects in different countries. The primary data collection was through visual data of road concerns in Aundh, Pune. The study identified growth constraints such as Poor condition of roads; Drainage problems; Lack of provision for pedestrians; and Coordination not effective. Therefore, assigning the study a set of objectives will provide a framework comprising infrastructure development, policy and regulatory reforms, increased stakeholder cooperation, implementation of sustainable construction practices, and efficiency of community engagement. This framework is designed to rationalize and facilitate road developmental procedures, integrate environmental concerns, and meet community requirements. Pursuing this line, the study helps enhance the road infrastructure in urban cities, promote economic development, and provide better, secure transportation systems in Pune and other emerging cities.

Keywords: Urban road development; Infrastructure challenges; Sustainable practices; Stakeholder coordination; Pune city.

1.0 Introduction

In areas around Pune, India, where population, number of cars owned, and economic activities are on the rise, there is a greater need for speedy road construction.

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The contemporary strategies for urban road development in Pune are hampered by a combination of poorly conceived and executed plans, limited financial resources, bureaucratic impediments, and environmental concerns (Kale, 2023). With the persistence of alarming population increase in the cities, unrelieved population pressure over the already extended trunk and other services has caused traffic jams, accidents, and environmental threats. These challenges are critical to guarantee not only efficient mobility but improvement in the living conditions of inhabitants as well. The road network is the most critical asset of a nation, as it not only supports economic activities but also fortifies the financial stability of any nation. The road network of India is the foundation of its transportation system, facilitating domestic and international trade, connecting rural areas to urban centers, and enabling the mobility of its citizens. India has one of the world's greatest road networks, with a total of over 5.5 million kilometers of roadways, which include expressways, national highways, state highways, district roads, and rural roads (Khanani, 2021).

Road infrastructure is the most critical public resource, as it facilitates the exchange of goods and services between large cities, small communities, and rural areas. In India, economic activities are stimulated by the presence of well-maintained and efficient road infrastructure, which reduces transportation costs, improves access to markets, and enhances regional integration. It is also essential in agriculture, as it facilitates the expeditious and efficient conveyance of agricultural produce from rural areas to urban markets. Furthermore, it enhances the overall quality of life for citizens by providing essential connectivity for social services, including healthcare, education, and emergency services (Matu, 2020).

1.1 Purpose of the study

The purpose of this study is to identify and address the challenges encountered in urban road development, focusing on Pune City's infrastructure issues. Through the analysis of existing road conditions and developmental constraints, this research aims to propose a practical framework that incorporates infrastructure development, policy reforms, stakeholder cooperation, sustainable construction practices, and community engagement. This framework is intended to guide effective improvements in road infrastructure that align with urban sustainability goals, promoting safe, secure, and efficient transportation systems. The study ultimately seeks to contribute to enhanced urban mobility and economic development, offering a model that could be adapted for use in other rapidly growing urban areas facing similar challenges.

1.2 Scope

This study focuses on urban road development in Pune city, India, and aims to examine the challenges faced in the development and maintenance of urban road infrastructure. The scope covers issues related to poor road conditions, inadequate drainage systems, lack of pedestrian provisions, and ineffective coordination among various stakeholders involved in road

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development. By analyzing both primary and secondary data, the study emphasizes the need for a comprehensive framework to address these challenges, specifically targeting urban areas experiencing rapid population growth and increased demand for efficient transportation systems. The research will be limited to Pune city, with a case study on road conditions in the Aundh area, while also considering comparative insights from other global urban road projects.

1.3 limitations of the study

- *Time constraints:* The study's limited timeframe may have impacted the depth of data collection and analysis.
- *Geographical scope:* The findings from this study are primarily relevant to Pune and may not be directly applicable to other cities, though they offer insights that could be adapted.
- *Response bias:* While every effort was made to collect honest feedback, there may have been response bias in the surveys and interviews, as participants may have been influenced by social or political considerations when discussing urban road issues.

2.0 Literature Review

2.1 Introduction

This literature review examines existing research on urban road development, focusing on connectivity, safety, and effective planning. Urban road networks are essential for a city's functionality, impacting traffic flow, accessibility, and residents' quality of life. Rapid urbanization, especially in cities like Pune, poses significant challenges to road infrastructure. The review explores how factors such as network complexity, residential area size, and intersection density affect connectivity. It also highlights trends and strategies in road safety, emphasizing design and regulatory measures. These insights inform the development of a comprehensive approach to improving Pune's urban road systems.

2.2 Challenges in urban road development

The socio-economic effects of road infrastructure in peri-urban areas were studied by (Khanani, 2021), who focused on the cities of Kisumu (Kenya) and Accra (Ghana). Khanani's findings revealed that road development projects improved accessibility and employment but also resulted in gentrification, displacing low-income residents and altering the social fabric. This highlights the need for policies that address socioeconomic disparities in infrastructure development to balance benefits across communities. Khanani (2021) examined the potential and challenges of Automated Driving Systems (ADS) in urban transport. Shladover argued that while ADS has attracted significant attention, deployment remains slow due to technical, regulatory, and infrastructural challenges. His research suggested that ADS adoption will likely follow the advancement of electrification and connectivity, providing cities with time to prepare for this shift in urban mobility. Chen (2021) analyzed the impact of road network topology on public transportation in China, finding a significant correlation between road network

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centralization and public transportation utilization. The study argued that a centralized and axial-shaped road network enhances public transport frequency, suggesting that urban planners should consider network layout in developing efficient public transport systems to promote sustainable urban mobility.

2.3 Sustainable road infrastructure practices

The integration of strategic planning and transition management is essential for sustainable urban road infrastructure, as highlighted by (Chen, 2023) in their study on Ugandan town councils. They explored how transition management mediates the relationship between strategic planning systems and sustainable urban road infrastructure development. Using a descriptive cross-sectional survey design and path analysis, they found that transition management plays a partial mediating role (path coefficient = .435), suggesting that effective knowledge-sharing among stakeholders is crucial for collective problem-solving and achieving sustainable road outcomes. The significance of sustainable urban road development is further examined by (Wang, 2024), who applied the Triple Bottom Line theory—emphasizing economic, social, and environmental dimensions—to assess urban roads' sustainability. They developed a comprehensive evaluation system using an analytic hierarchy process to create sustainability indicators across these dimensions. This framework provides a sustainable development model for urban roads, confirming the theory's effectiveness in fostering balanced development in urban infrastructure planning (Matu, 2020).

2.4 Policy and governance in urban road projects

In the context of rural and urban settings, (Shamdasani, 2021) highlights the economic benefits of improved rural road infrastructure in India, where road connectivity influences agricultural production by enhancing labor mobility and crop diversification, ultimately supporting poverty reduction. (Kale, 2023) review sustainable project planning for road infrastructure in India, advocating for life cycle cost analysis and other tools to ensure the sustainability and resilience of infrastructure projects in line with Vision 2030 goals. (Shah, 2024) underscores the challenges facing urban transportation in India, such as increased motorization, congestion, and outdated regulations, which affect public health and the environment. Shah calls for integrated land-use planning, improved public transit, and non-motorized transport promotion to mitigate urban transportation inefficiencies and environmental impacts (Wanume, 2023).

2.5 Research gap

The research gap in urban road development, particularly in Pune city, lies in the lack of a comprehensive framework that integrates infrastructure development, policy reforms, and stakeholder cooperation. While existing studies address individual challenges, there is limited research on a holistic approach to improving road systems in rapidly urbanizing cities, with a focus on sustainability and community engagement.

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3.0 Research Methodology

3.1 Introduction

The research methodology outlines the process of collecting, analysing, and interpreting data to develop a comprehensive framework to address the problems in urban road development, focusing on Pune City. The methodology for this study includes a mix of qualitative and quantitative approaches to gather detailed insights from both primary and secondary sources. This Figure 1 illustrates the research methodology workflow, outlining the sequential steps from identifying the problem, reviewing literature, collecting and analysing data, to developing a framework, validating findings, and providing recommendations, culminating in the conclusion.

3.2 Research methods used

A mixed-method approach was adopted, incorporating both qualitative and quantitative techniques to ensure a comprehensive analysis. The study commenced with an extensive literature review to identify prevalent challenges in urban road development. This was followed by field surveys where primary data was collected using geotagged photos, enabling an objective validation of the issues identified in prior research. Observations during site visits helped in capturing real-time conditions, while systematic documentation ensured data authenticity. The combination of these methods provided a holistic understanding of urban road infrastructure problems, aiding in the formulation of effective recommendations.

3.3 Research procedure

The research procedure followed a structured framework as illustrated (Figure 1) in the flowchart below:

- *Problem identification:* Key challenges in urban road development were identified through literature review.
- *Literature review:* Secondary data was gathered from previous studies to establish a theoretical foundation.
- *Data collection:* Geotagged photographs of urban roads in Pune city were taken to capture real-time conditions.
- *Observations:* Site visits and visual inspections were conducted to document and analyze road-related issues.
- *Framework development:* A structured approach was formulated to assess and categorize road infrastructure problems.
- *Validation and recommendations:* Findings were validated through comparative analysis, and recommendations were proposed based on research insights.
- *Conclusion:* The study's key findings were summarized, providing valuable input for future urban road development planning.

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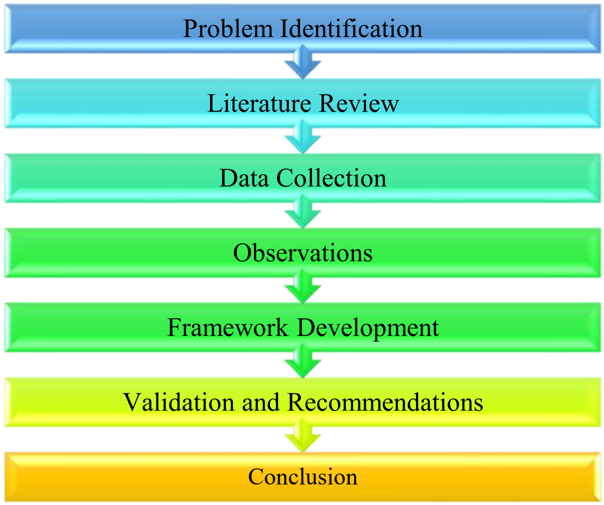
Figure 1: Flow Chart of Methodology



4.0 Data Collection and Analysis

This section describes the data collecting and analysis procedure used to detect and assess concerns with urban road development in Pune. The study used both secondary and primary data to get a thorough grasp of the challenges. Secondary data served as a theoretical underpinning, while primary data corroborated the conclusions via actual observations. The examination of this data led to the construction of a strong framework to handle the difficulties.

4.1 Secondary data collection

The secondary data collection process involved an extensive review of literature, including:

- Academic journals focusing on urban road development frameworks.
- Government policy documents and reports related to Pune's infrastructure development.
- Case studies and research papers highlight challenges in urban planning and road infrastructure.

The focus was on identifying recurring themes such as traffic congestion, inadequate road maintenance, lack of integration between road development and urban planning, and the absence of sustainable practices. Relevant statistical data on Pune's population growth, vehicle density, and road capacity were also gathered to provide contextual insights. The analysis of various studies highlights a wide range of road infrastructure challenges that impact urban and rural transportation systems. Several researchers have identified recurring issues that contribute to inefficient road networks, safety concerns, and urban mobility constraints. Bele (2012) identified multiple problems affecting road conditions, such as potholes, which lead to frequent

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surface damage and increased maintenance costs. Other significant concerns include open manholes, which pose safety hazards, and poor street lighting, which increases accident risks.

The study also noted issues such as frequent digging for utility works, causing prolonged disruptions, and speed breakers without warning signs, leading to abrupt braking and accidents. Additionally, delayed response to road repairs, lack of parking facilities, misaligned drain covers, and overall inefficiencies in road maintenance were highlighted. Wang (2024) focused on waterlogging and poor drainage, which result from inadequate drainage systems, disrupting traffic and damaging infrastructure. The study also mentioned unpaved roads or temporary closures due to a lack of resources, which affect accessibility. Traffic congestion was noted as a persistent issue, along with the lack of bicycle lanes, discouraging sustainable transport. Moreover, concerns such as the absence of disabled-friendly infrastructure and obstructions caused by public transport vehicles were identified as barriers to efficient urban mobility. Matu *et al.* (2020) discussed issues related to traffic management, including malfunctioning traffic signals, which contribute to accidents and congestion. The study highlighted the lack of pedestrian crossings, increasing risks for pedestrians, and poorly managed traffic diversions during construction, leading to avoidable delays and inefficiencies.

Zhao *et al.* (2017) examined narrow or inadequate roads that fail to accommodate growing traffic volumes. The research also pointed to road width management issues, which disrupt traffic flow efficiency. Zhao (2019) identified poor road surface quality, which leads to vehicle damage and higher maintenance costs. Additionally, frequent traffic diversions without notice were reported as a significant inconvenience. Other concerns included noise pollution from traffic, affecting urban residents' quality of life, and road space encroachment by unauthorized vendors and other entities, reducing available space for movement. Wanume *et al.* (2023) also addressed the encroachment of road space, emphasizing its impact on pedestrian and vehicular mobility. Furthermore, the study pointed out poor road planning, which results in inefficient infrastructure development and resource misallocation.

Shi *et al.* (2019) focused on broader urbanization challenges, particularly urban sprawl, where rapid expansion occurs without adequate road planning, leading to inefficiencies. Additionally, traffic-generated pollution was identified as an issue resulting from increased vehicle usage on poorly designed roads. Fekadu Zeliku (2022) emphasized governance and community involvement, highlighting the lack of community participation in road development decisions, which often leads to poor infrastructure outcomes. The study also noted weak institutional structures, where disorganized local governance results in ineffective road projects.

Shamdasani (2021) addressed issues specific to rural areas, including rural connectivity gaps, which hinder economic development and market access. Additionally, the study discussed the lack of maintenance strategies, which leads to deteriorating road conditions over time, and inadequate last-mile connectivity, limiting access to essential services and economic opportunities. Zhang *et al.* (2023) explored challenges within gated communities, identifying restricted road networks that contribute to external congestion. The study also highlighted low

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road network density, reducing travel efficiency, and poor pedestrian access, which discourages walking and increases dependency on private vehicles. Overall, the collective findings from these authors reveal that road infrastructure issues are diverse and interconnected, impacting mobility, safety, and urban sustainability. Addressing these challenges requires a strategic approach, including improved planning, governance, maintenance, and community engagement.

Table 1 Summary of issues identified by different authors points out the issues founded by each author which are very relevant to the study and which is mentioned in the table below with the description of the issues.

Table 1: Summary of Issues Identified by Different Authors

Author	Issues	Description
Khumbelo Bele (2012)	Potholes	Frequent road surface damage causing unsafe conditions and additional maintenance costs.
	Open Manholes	Unsecured manhole covers leading to accidents and financial liabilities.
	Poor Street Lighting	Insufficient illumination increasing accident risks and reducing security.
	Frequent Digging for Utility Works	Continuous digging without proper coordination, causing prolonged road closures and damage to infrastructure.
	Speed Breakers Without Warning Signs	Improperly marked speed bumps causing abrupt braking and potential accidents.
	Delayed Response to Road Repairs	Inefficient handling of road issues leading to prolonged unsafe conditions.
	Lack of Parking Facilities	Insufficient designated parking areas leading to illegal parking and traffic obstruction.
	Misaligned Drain Covers	Improperly installed or damaged drain covers posing hazards to pedestrians and vehicles.
Yilin Wang (2024)	Waterlogging and Poor Drainage	Inadequate drainage systems causing frequent waterlogging, disrupting traffic and damaging infrastructure.
	Unpaved Roads or Temporary Closures	Roads left unpaved or temporarily closed due to lack of resources, leading to poor accessibility and inefficiencies.
	Traffic Congestion	Overburdened road networks unable to handle increasing vehicular loads, leading to delays and economic losses.
	Lack of Bicycle Lanes	Absence of dedicated cycling paths discouraging sustainable and safe commuting options.
	Lack of Disabled-Friendly Infrastructure	Insufficient accommodations for disabled individuals, such as ramps or tactile surfaces.
	Obstruction by Public Transport Vehicles	Unregulated stops by buses and other public transport vehicles obstructing traffic flow.
Johnson Matu et.al	Malfunction of Traffic Signals	Poor maintenance and delayed repair of traffic lights, leading to increased accidents and traffic congestion.

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(2020)	Lack of Pedestrian Crossings	Insufficient or unsafe pedestrian crossings contributing to accidents involving walkers.
	Poorly Managed Traffic Diversions During Construction	Inefficient handling of traffic during construction leading to unnecessary congestion and delays.
Guoliang Zhao *et al.* (2017)	Narrow or Inadequate Roads	Insufficiently wide or improperly designed roads that fail to accommodate growing traffic volumes.
	Road Width Management	Mismanagement of road width allocation affecting traffic flow efficiency.
Pengjun Zhao (2019)	Poor Road Surface Quality	Deterioration of road surfaces due to inadequate maintenance, increasing vehicle wear and tear.
	Frequent Traffic Diversions Without Notice	Unplanned diversions causing confusion and delays.
	Noise Pollution from Traffic	Excessive noise from vehicles impacting the quality of life in urban areas.
	Encroachment of Road Space	Unauthorized use of roadways and sidewalks by vendors and other entities, reducing available space for vehicles and pedestrians.
Paul Wanume *et al.* (2023)	Encroachment of Road Space	Unauthorized use of roadways and sidewalks by vendors and other entities, reducing available space for vehicles and pedestrians.
	Poor Road Planning	Ineffective planning leading to inefficient road usage and resource wastage.
Ge Shi *et al.* (2019)	Urban Sprawl	Rapid urban expansion without proper road infrastructure planning causing inefficiencies.
	Traffic-Generated Pollution	Increased vehicle usage on poorly designed roads leading to higher emissions.
Fekadu Zeliku (2022)	Lack of Community Participation	Low engagement of residents in road development decisions resulting in poor outcomes.
	Weak Institutional Structures	Disorganized local government institutions leading to ineffective road development.
Yogita Shamdasani (2021)	Rural Connectivity Gaps	Poor road links in rural areas limiting economic growth and market access.
	Lack of Maintenance Strategies	Poor planning for road upkeep, causing higher costs and reduced usability over time.
	Inadequate Last-Mile Connectivity	Poor infrastructure in rural areas reducing access to economic opportunities and services.
Yu Zhang et.al (2023)	Gated Community Road Issues	Restricted road networks within gated communities causing external congestion.
	Lack of Road Network Density	Low road connectivity leading to inefficiencies in travel and accessibility.
	Poor Pedestrian Access	Lack of pedestrian-friendly routes within residential areas, discouraging walking and increasing dependency on vehicles.

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4.2 Secondary data analysis

The secondary data was systematically analysed to extract key challenges and trends:

1. *Identification of core issues:* The analysis highlighted significant challenges such as poor traffic management, inadequate road width, lack of proper maintenance, and limited use of modern urban planning tools.
2. *Assessment of existing frameworks:* A review of current frameworks revealed their limitations in addressing Pune's evolving urban demands. Issues like insufficient stakeholder involvement and outdated planning methodologies were identified as critical weaknesses.
3. *Benchmarking best practices:* Successful urban road development models from other cities were examined, providing insights into best practices that could be adapted for Pune's context.

5.0 Conclusion

This research paper aimed to identify and analyze key challenges in urban road infrastructure by utilizing secondary data from past studies. Through an extensive literature review, common road-related problems such as potholes, poor drainage, traffic congestion, encroachments, inadequate pedestrian infrastructure, and lack of proper road maintenance were identified. These issues have significant implications on urban mobility, road safety, and economic efficiency. Additionally, various research studies provided insights into potential solutions, emphasizing the need for improved drainage systems, better traffic management, sustainable urban planning, and enhanced regulatory measures.

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CHAPTER 52

Development of a Framework for Sustainable Development in the Domain of SWM using the Participatory Approach: Case of Pune

Anil Kashyap[1] *and Subham Visaria*[2]

ABSTRACT

Waste management has been a significant concern as cities expand, posing environmental risks. Using a participatory approach, the research attempts to present a framework for waste-to-energy (WTE) conversion within local communities using the participatory approach. Stakeholders provide insights through the survey conducted in the study area such that the solutions are socio-economically feasible and locally adapted. The study identified that the lack of proper integration of technological interventions, awareness, and community engagement desist the population from adapting the initiatives at community and individual levels. The proposed framework emphasized the need to educate the citizens to contribute towards waste collection, segregation, and WTE. This intervention highlights sustainable urban practices, less reliance on landfills, improved resource recovery, and an emphasis on using renewable energy in local communities. The framework highlights the action plan for Pune's municipal authorities, community members, garbage collection personnel, environmental NGOs, and commercial sector partners to develop WTE solutions, reflecting the participatory approach. The participatory method addresses common concerns by engaging residents early in decision-making. This framework promotes adopting contextually appropriate solutions that are efficient, sustainable, and aligned with the city's environmental goals and are most preferred by the respondents in the study area. In addition to technology selection, the participatory model emphasizes transparency and accountability through regular feedback mechanisms, allowing Pune's residents to contribute to its ongoing improvement. The framework is further validated using cost-benefit analysis (CBA) to demonstrate the environmental and economic benefits of the WTE project, ensuring that it remains responsive to evolving needs and environmental standards. Hence, this study frames the novel approach towards the sustainability pathway emphasizing the WTE with the participatory approach.

Keywords: Waste management; Circular Economy; Waste-to-energy; Participatory approach; Sustainability.

1.0 Introduction

The pressure on the municipalities is immense, to collect, to dump the collected waste

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involving working regressively throughout the year. According to the Central Pollution Control Board of India, the per capita waste generation has increased from 0.26kg/per to 0.89kg/day. Landfills remain the optimal choice for the municipalities for the disposal of waste but there remains a potential threat to them as they come up with lots of issues about environmental concerns and health hazards for the workers as well (Hui *et al.*, 2006). A few cities in India like Pune have shown a positive approach toward SWM, which this paper has highlighted. An observation was built based on data received from the departments and site visits, the main focus has been laid on the collection of waste, but a major lag has been observed over the further steps like segregation, treatment, disposal, and recycling.

Kumar & Agrawal (2020) Through this study, a focus is placed on reusing the SW and creating a framework for waste-to-energy through a participatory approach.(Tozlu *et al.*, 2016) The role of citizen participation and how it affects the cycle of WTE have been discussed in detail. Many attempts have been made in the past few years to resolve SWM-related problems, but they have not been effective as the generation of waste is much more than processed waste. Most of the issues have been seen during the collection of mixed types of waste, and implementation of the policies regarding the treatment system. (Kalyanasundaram *et al.*, 2023) After the introduction of the SDGs, the Government of India has laid mandates for the right treatment of the MSW and its disposals. While there are very few such technologies and methods introduced for doing it rightly. Now with the circular economy being in the focus, energy generation was also added to the agenda, and discussion was laid over conversion 'waste-to-energy'.(Dolla & Laishram, 2021)

The gap that was identified after ground-truthing and through the secondary data collected from the government officials was, that citizen participation was missing, and achieving the goal of WTE could play a major contributor to this aim. (Srivastava *et al.*, 2015)This study highlights the importance of citizen participation and forming a framework to achieve the WTE conversion which could be implemented in all the major cities throughout the country by doing a study on the selected site in PCMC. The research objectives of the study are:

- To identify literature in the field of SWM using a participatory approach.
- To interpret the parameters of SWM through the lens of a participatory approach.
- To analyze the parameters of SWM in the study area.
- To recommend the framework for SWM in the study area for sustainable development in the domain of SWM using a participatory approach.

2.0 Methodology

Using the mixed method with quantitative and qualitative approaches leads to this study in identifying the possible solutions and also give socially feasible and economically acceptable solutions. This combination will also strengthen the reliability of the conclusion concerning the objective. The image is a flowchart representing a structured research methodology. It outlines

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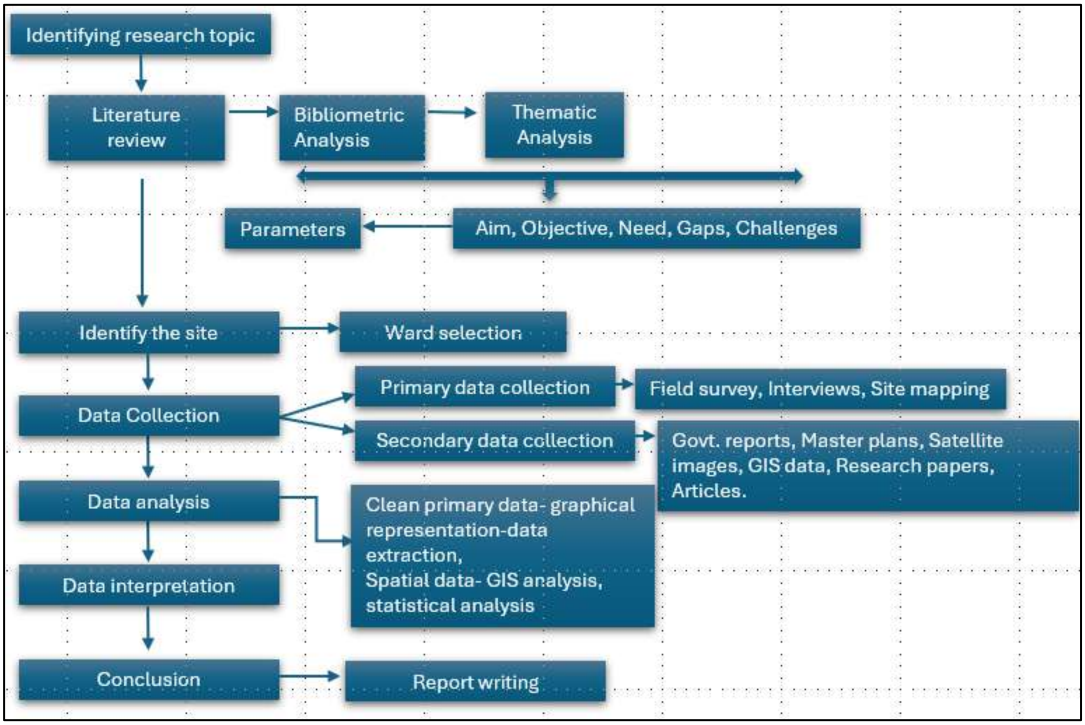
the steps involved in conducting a research study, particularly in fields like geography, urban planning, or environmental studies.

Figure 1: Methodology Used for Study



2.1 Data collection

Conducting field surveys, interviews, and site mapping. Gathering information from government reports, master plans, satellite images, GIS data, research papers, weather, and hydrological data. Processing and examining collected data using- GIS & Remote Sensing, Big Data Analysis, Spatiotemporal Analysis (data over space & time), Statistical Analysis, Data Interpretation

2.2 Conclusion and report writing

Summarizing findings, concluding, and documenting them in a research report. Purpose of the Flowchart- Provides a systematic approach for conducting research. Help researchers plan, collect, analyze, and interpret data efficiently. Ensures a logical flow of activities in research.

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2.3 Qualitative method

This method includes detailed interviews with stakeholders like municipal officials, activists, waste management workers, and local people living in the study zone, having a one-to-one conversation with the citizens living in the vicinity of the landfill zone. Going on-site and observing the management of the process and validating the information received from the above processes.

2.4 Quantitative method

Data collection from primary sources, i.e. the people living near the landfill sites to know about the importance of waste dumping and its harmful impact on the environment. Data collection from secondary sources of government departments like PCMC & PMC which will be the baseline for understanding and proposing solutions to the issue.

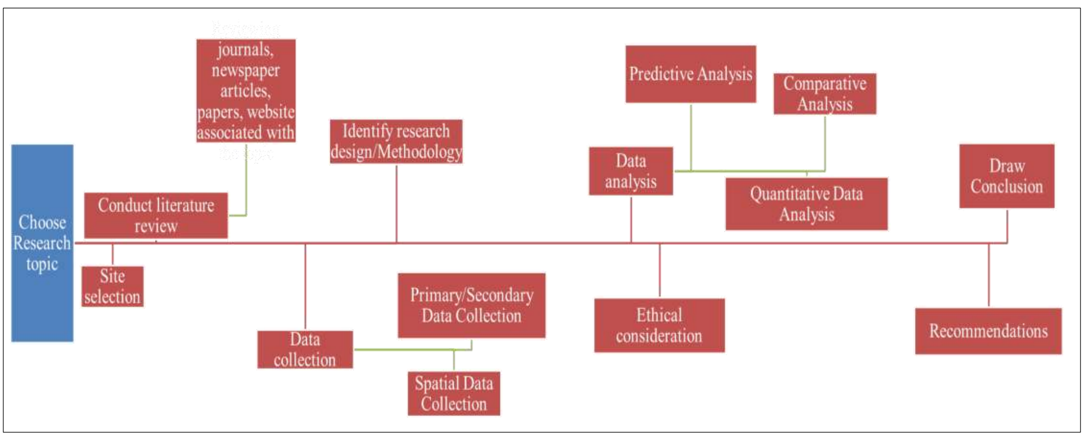
2.5 Participatory research method

With the help of the inputs received from the community, and data received from government officials and residents, areas with high volumes of waste generation could be identified and a specific proposal could be implemented for such areas. Government agencies could help arrange community workshops to educate participants about the benefits of WTE and encourage their participation in achieving its goal.

2.6 Analytical method

Analyzing the setting up of the WTE initiative in Pune through a SWOT analysis. GIS mapping can play a significant role in analyzing areas with high waste generation, collection, and potential WTE sites. Decision-making would become rational through GIS.

Figure 2: Flow of Study



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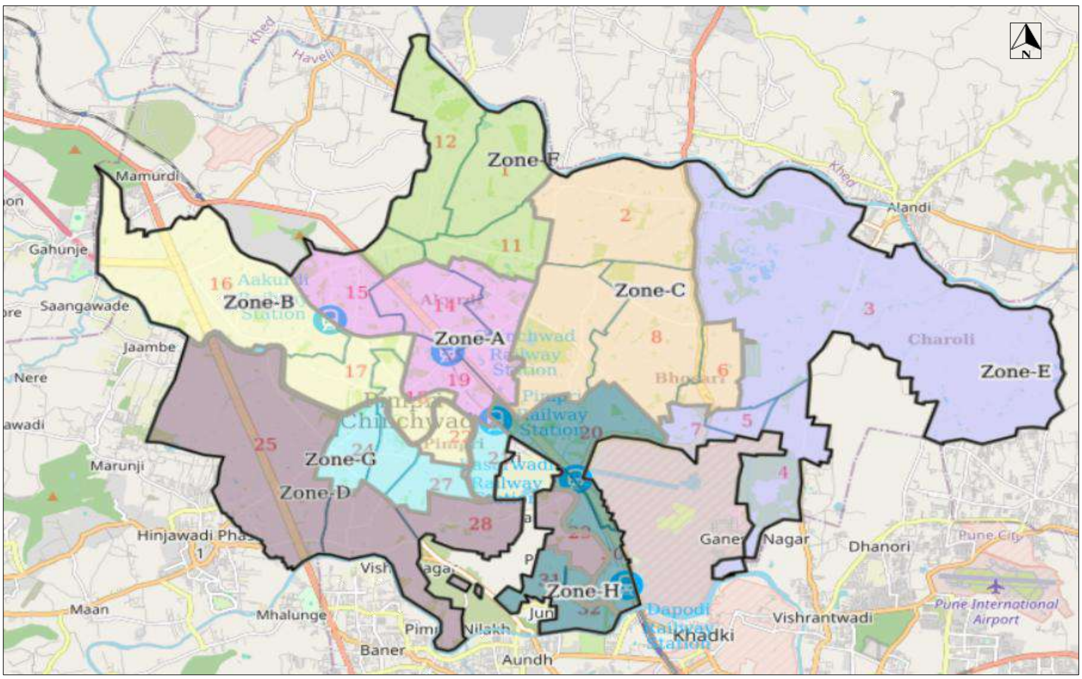
2.7 Site selection

Pune, one of India's rapidly growing cities, faces significant challenges in managing its increasing waste generation due to urbanization and population growth. With a diverse demographic and a thriving industrial sector, Pune generates substantial amounts of municipal solid waste daily. As the city strives to improve its waste management practices and address energy shortages, waste-to-energy (WTE) conversion emerges as a promising solution. This approach not only reduces the volume of waste sent to landfills but also generates renewable energy, contributing to a more sustainable future for Pune's PCMC. The image (Figure 3) represents the administrative boundary map of PCMC (*Pimpri-Chinchwad Municipal Corporation*). The map shows different ward boundaries and zoning divisions of the city. These boundaries help in municipal governance, planning, and infrastructure development.

Figure 3: PCMC Ward Map



3.0 About PCMC (Pimpri-Chinchwad Municipal Corporation)

Pimpri-Chinchwad is a major industrial and residential city in Maharashtra, India. It is located near Pune and forms a part of the Pune Metropolitan Region (PMR). The city is administered by the Pimpri-Chinchwad Municipal Corporation (PCMC). PCMC is divided into

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multiple zones and wards for governance and municipal management. Each ward has elected representatives (corporators) who work under the municipal administration. The Municipal Commissioner is the chief executive officer responsible for implementing policies and infrastructure projects.

3.1 Key features of the PCMC administration boundary map

The map shows the different numbered administrative wards. The Mumbai-Pune Highway (NH-48) and other major roads are visible. The map covers both industrial zones (like MIDC) and residential areas. The map includes neighboring regions like Pune, Alandi, and Talegaon. The Pavana River runs through the city, influencing land use and infrastructure.

3.2 Importance of PCMC

Home to major industries like automobiles (Tata Motors, Bajaj Auto), IT parks, and manufacturing units. Rapidly growing city with modern housing projects, malls, and metro connectivity. Includes BRTS (Bus Rapid Transit System), Pune Metro extension, and road expansion projects. Presence of reputed schools, colleges, and hospitals.

4.0 Governance and Planning

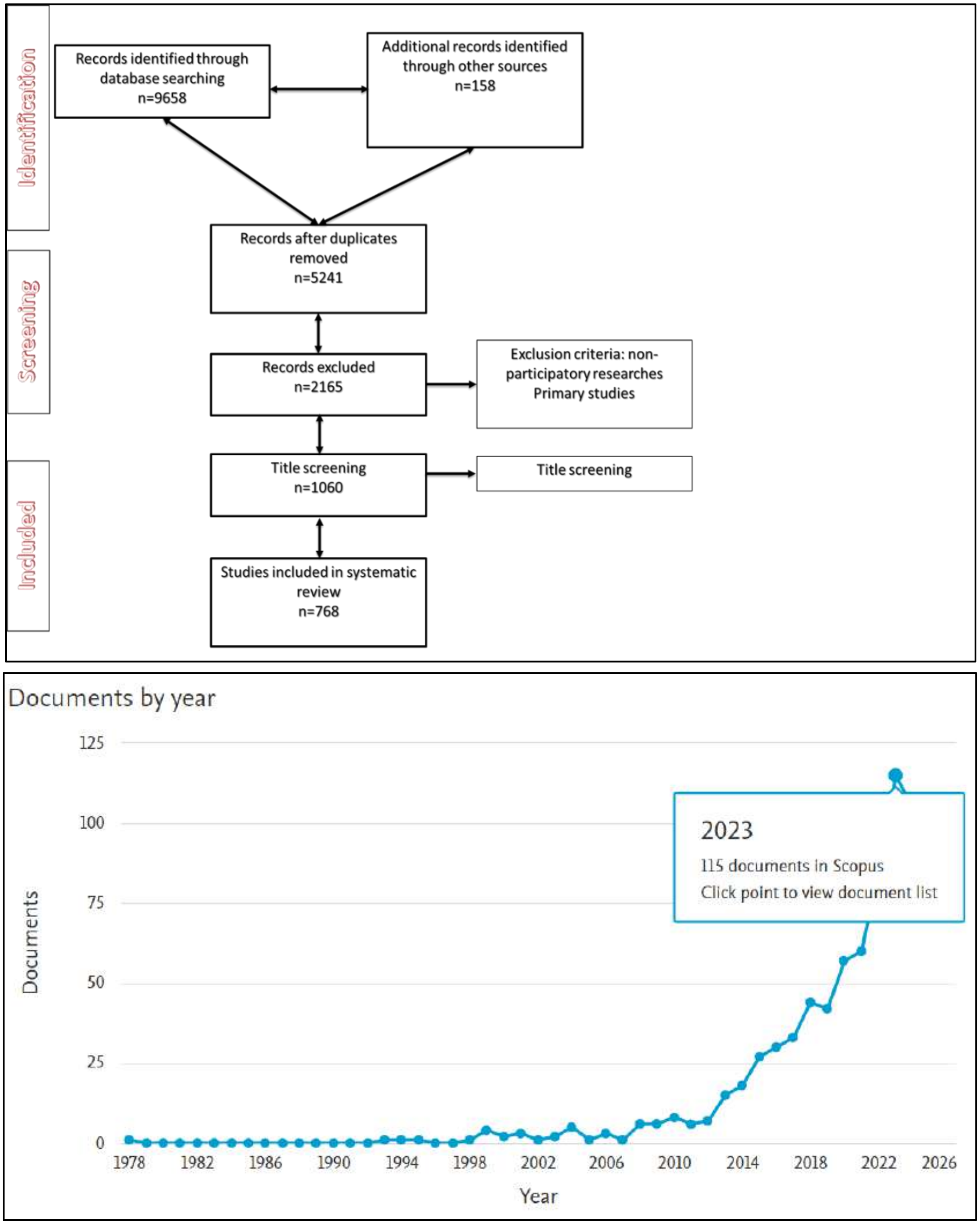
PCMC governs civic services like water supply, roads, waste management, and urban planning. The city follows a *Development Plan* (DP) to manage growth and infrastructure. Smart City Initiatives are also in place. PCMC is implementing technology-driven solutions for urban management. Image 4 is a PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) flow diagram, which is commonly used in systematic reviews and meta-analyses to track the selection process of studies.

4.1 Key features of the image

4.1.1 Stages of study selection

- *Identification:* The initial number of records identified from databases or other sources.
- *Screening:* The number of records after duplicates are removed, followed by the exclusion of irrelevant studies.
- *Flowchart structure:* Typically, PRISMA diagrams follow a top-to-bottom structure. Numbers at each stage indicate how many studies were retained or excluded. It helps researchers transparently report their selection process. Ensures reproducibility in systematic reviews.

Figure 4: Literature Review Process



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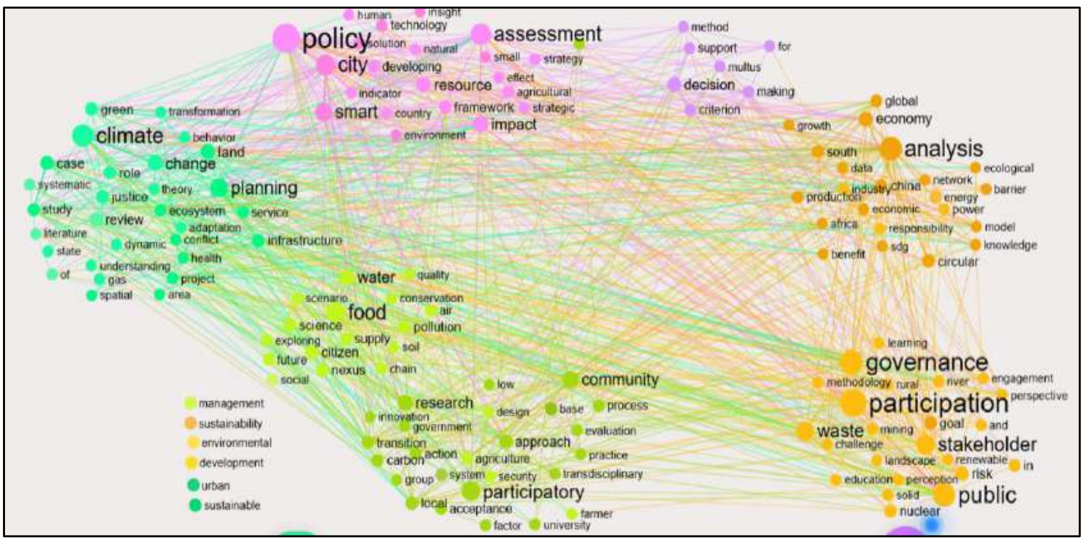
The image (Figure 5) is a network visualization of keywords and their relationships, likely from an academic or scientific domain. It consists of interconnected words in various colors, which appear to represent different thematic clusters. *InfraNodus* is the software used for getting results.

4.2 Clusters of words

- *Green (sustainable & environmental):* Words like climate, planning, food, water, research.
- *Yellow/Orange (governance & participation):* Words like analysis, economy, governance, and participation.
- *Pink/Purple (policy & decision making):* Words like policy, city, resource, assessment, and decision.
- *Connections (edges):* Lines connecting words indicate relationships or co-occurrence. Denser connections suggest frequent associations.
- *Font size & node size:* Larger words indicate higher relevance or frequency in the dataset.
- *Possible purpose:* This could be a bibliometric analysis, topic modeling, or keyword co-occurrence map, visualizing research trends or themes in sustainability, governance, and urban planning.

Figure 5: Network Visualization



4.3 Data collection

The following data set Table 1 has been received from the official Department of Solid Waste Management, PCMC. The image is a ward map of Pimpri-Chinchwad Municipal Corporation (PCMC), which is part of Pune's metropolitan area in India.

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4.3.1 Key features of the map

- *Zonal divisions:* The map is divided into multiple zones (e.g*., Zone-A, Zone-B, Zone-C, etc*.), with boundaries for each zone marked. The zones contain numbered wards (e.g., 16, 19, 7), which likely correspond to electoral or administrative units within the PCMC.
- *Key areas:* The map labels prominent locations such as railway stations (e.g., Chinchwad Railway Station, Pimpri Railway Station). Areas like Akurdi, Charholi, and Hinjewadi are shown within their respective zones.
- *Color coding:* Different zones are represented by various colors, aiding in distinguishing between them.
- *Surrounding landmarks:* Areas outside the PCMC boundaries like Pune International Airport and neighborhoods such as Dhanori and Baner are also visible on the map.

This kind of map is typically used for Municipal Administration, managing urban planning, civic issues, and governance aiding understanding ward boundaries for local elections. The Table 2 represents garbage collection data across different zones of PCMC (*Pimpri-Chinchwad Municipal Corporation*). It provides details on the number of households and commercial establishments covered, the type of vehicles used for collection, and the average amount of garbage collected daily (*in metric tons per day, MTs/day*).

4.4 Key data components in the table

- *Zones & Wards:* The table categorizes garbage collection based on different zones (A, B, C, D, E, F, G, H) in PCMC. Each zone consists of multiple wards, which are identified by numbers.
- *Households & Commercial Coverage:* The table lists the approximate number of households and commercial establishments covered in each ward. The number varies significantly across wards, indicating differences in population density and commercial activity.
- *Type of Vehicles & Capacity:* The table mentions Mini Tippers as the vehicle type in Zone A, while for other zones, vehicle type and capacity details are missing. These vehicles are responsible for collecting garbage from the specified areas.
- *Insights from the Data***:** High Household & Commercial Coverage: Some wards (e.g., ward 14 in Zone A, Ward 2, 4, 9, 8, 5 in Zone F) have a large number of commercial establishments, indicating areas with high business activity. Residential areas also vary, with some wards having more than 20,000 households covered. Some wards (e.g., Ward 2, 4, 5 in Zone B) have very few commercial establishments, while others have over 3,000 businesses, showing major commercial hubs.

The type of vehicle and carrying capacity is only mentioned for Zone A but is missing for other zones. The garbage collection data (MTs/day) is not filled in, which is crucial for waste management planning.

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5.0 Proposed Framework

This framework comes from digging into the Pune waste management study and thinking about how to make waste-to-energy (WTE) work with people at the heart of it. It's about getting Pune—Pimpri-Chinchwad area to cut down on landfills, turn trash into power, and build something that lasts. Through this study, we're aiming for a bigger picture which include turning Pune into a city that handles waste smartly—less dumping, more energy, and folks pitching in. Goal is to get people sorting trash better, pick WTE tech that fits Pune, keep things open and honest, and tie it all to India's sustainability targets. Through this framework, we aim to break down the process into five key components that work together: getting people involved, selecting the right technology, collaborating with the city, disseminating information, and monitoring progress.

Based on the study and literature review we went through, one of the outcomes that we came to is that people aren't engaged enough. An effort has been made to involve them more through various methods, including neighborhood meetups to determine where waste accumulates and what people want to do about it, and setting up small groups in each ward—called waste squads—to monitor sorting and pickup. One-on-one or through quick surveys to hear what they think about WTE ideas could be yet another method to keep them involved. People trust the plan more when they help shape it.

WTE's is the ultimate solution to the increasing pollution crises inclined with participation of the citizen. Look at the waste breakdown from the study—wet stuff like food scraps, dry stuff like plastic, green waste from markets. Composting for the organic waste, burning or gasifying the dry junk for power. Using later technologies like maps (like those GIS ones mentioned) to find location for WTE setups. Starting small with a test run in a factory-heavy area where businesses toss out a lot. Coordinating with green groups (NGO) and businesses to pool in money or know-how for WTE projects. Push sorting rules hard—maybe a fine for slacking or a perk for doing it right. Waste moves smoother, and WTE fits into the *Smart City Plans*.

The study says people's participation is less. Run some ads or talks—hit schools, homes, markets; about why sorting matters and what WTE can do. Show waste workers the ropes on handling stuff safely and splitting it up. Hand out flyers or tips in Marathi and Hindi to make even the locals to come up and participate. Observation is the key, keeping track of the process can boost the results as we can monitor positives and negatives of the aspects. Integrating a technological aspect maybe through an app or a spot on PCMC's site.

Check in every few months with a quick pros-and-cons rundown, like that SWOT analysis of the situation. Crunch some numbers yearly—how much does it cost versus what we save or earn? The plan stays sharp and bends with what people need. The first six months are crucial in analyzing the outcome. Based on the analyzed outcome, the way forward can be plotted.

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Working on STRENGTHS; OPPORTUNITIES based on received output provided by the citizens and the THREATS and WEAKNESS highlighted during the observation stage can help building up a robust framework.

6.0 Conclusion

The data highlights the scale of waste collection efforts in PCMC across different zones and wards. It can be used to analyze the efficiency of garbage collection and resource allocation, such as increasing the number of vehicles in high-density areas. Completing missing data (vehicle types, MTs/day collection details) would improve waste management planning.

Table 1: Waste Received in Different Months

Total quality received	Sep-23			Oct-23			Nov-23			Dec-23			Jan-24		
	PP	Com	WC	PP	Com	WC	PP	Com	WC	PP	Com	WC	PP	Com	WC
Wet waste	13984.3	13984.3	13984.3	14642.03	14642.03	14642.03	12907.61	12907.61	12907.61	13645.09	13645.09	13645.09	14267.32	14267.32	14267.32
Wet waste processed	13984.3	13984.3	0	14642.03	14642.03	0	12907.61	12907.61	0	13645.09	13645.09	0	14267.32	14267.32	0
Compost produced	447.50	447.50	0	468.55	468.55	0	413.05	413.05	0	477.58	477.58	0	499.36	499.36	0
Compost sold/used	447.50	447.50	0	468.54	468.54	0	413.05	413.05	0	477.58	477.58	0	499.36	499.36	0
Dry waste	25970.84	0	25970.84	27192.34	0	27192.34	23971.27	0	23971.27	25340.88	0	25340.88	26496.45	0	26496.45
Dry waste processed	25970.84	0	0	27192.34	0	0	23971.27	0	0	25340.88	0	0	26496.45	0	0
Plastic	7271.84	0	7271.84	7613.86	0	7613.86	6711.96	0	6711.96	7095.45	0	7095.45	7419.01	0	7419.01
Non recyclable	1298.54	0	0	1359.62	0	0	1198.56	0	0	1267.04	0	0	1324.82	0	0
Cloth	1558.25	0	0	1631.54	0	0	1438.28	0	0	1520.45	0	0	1589.79	0	0
Glass	519.42	0	0	543.85	0	0	479.43	0	0	506.82	0	0	529.93	0	0
Paper	1038.83	0	0	1087.69	0	0	958.85	0	0	1013.64	0	0	1059.86	0	0
Carboard	233.74	0	0	244.73	0	0	215.74	0	0	228.07	0	0	238.47	0	0
Packing material	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Metal	285.68	0	0	299.12	0	0	263.68	0	0	278.75	0	0	291.46	0	0
RDF	13504.84	0	0	14140.02	0	0	12465.06	0	0	13177.26	0	0	13778.15	0	0
Rubber	259.71	0	0	271.92	0	0	239.71	0	0	253.41	0	0	264.96	0	0
Hazardous waste	7.99	0	7.99	8.37	0	8.37	7.38	0	7.38	7.8	0	7.8	8.15	0	8.15
Revenue generated		46707			469			31537			62335			62335	

Table 3 represents waste collection data from all wards of Pimpri-Chinchwad Municipal Corporation (PCMC) over 14 months (*Feb-23 to Mar-24*). It categorizes waste into different types and tracks their collection month by month. Monthly Data (*Feb-23 to Mar-24*): The columns represent monthly tracking of waste collection for each category. However, the actual numerical values are missing, meaning the table might be used for recording or analyzing trends over time.

6.1 Purpose and use of this data

Monitoring Waste Trends: Helps PCMC track the quantity and type of waste generated in different wards. Planning Waste Management Strategies: Identifies seasonal trends (e.g., more green waste in monsoon, more hotel waste during festivals). Optimizing Waste Collection & Recycling: Helps in resource allocation, such as deploying more vehicles for dry/plastic waste recycling. Assessing Environmental Impact: Helps in understanding the proportion of biodegradable vs. non-biodegradable waste.

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Table 2: Zone-wise Waste Collected by Vehicles

Zones	Wards	Approx. household covered	Approx. number of commercial covered	Type of vehicle	Carrying capacity of vehicle	Avg. amount of garbage collected (MTs/day)
A	10	18521	1020	Mini Tipper		3.250
	14	18910	4145			2.500
	15	20567	1430			3.000
	19	22331	2571	Compactor	0.65	9.000
B	16	18757	2690			16.000
	17	23990	500	Compactor		9.000
	18	17560	970			16.000
	22	24550	43		8000	
C	2	25985	3018			1.800
	6	15077	393	Mini Tipper		2.600
	8	19850	3000			2.600
	9	16838	405		0.65	2.600
D	25	23451	1485			16.000
	26	23397	1600	Compactor		16.000
	28	24136	1534			16.000
	29	23100	1395		8000	9.000
E	3	18491	355			2.600
	4	23590	1016	Mini Tipper	3.900	3.900
	5	14700	816			2.600
	7	19015	436			1.800
F	1	24725	1002			2.700
	11	28890	2400	Mini Tipper		2.250
	12	24985	3850			1.800
	13	19211	297		0.65	2.600
G	21	20049	2824			
	23	17989	2200	Mini Tipper		3.000
	24	17839	3200		0.65'	
	27	17964	1850	Compacto	8	16
H	20	20980	1200	mini Tippe	0.600	3
	30	22455	729			16
	32	22912	930	Compactor		12
	40	18785	940		12000	12

Table 3: Categorization of Waste Received over a Year

INBOUND WB (all wards)	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24
CHICKEN WASTE	392530	450405	439265	421010	414965	412135	347725	323610	414920	411685	443465	449460	403765	464785
DRY WASTE	18995275	22222620	22512085	22247515	23759905	25299945	25327230	26183625	24794175	20961155	21871670	24007765	21783755	24594170
GHATAK WASTES	175	340	130	130	155	1220	345	345	345	345	1175	1175	995	995
GREEN WASTE	600795	667660	654585	668365	837990	857520	808795	746720	890925	797010	833450	878225	975850	927480
HOTEL WASTE	1474225	1614105	1652560	1765065	1796655	1843435	1775840	1737130	2078005	1704715	1913995	1825730	1701830	1739050
JALPARNI	2280385	3581685	3673445	3087335	2492120	832730	832730	832730	36420	25345	1305	1305	1615	1615
MANDAI	103540	104480	109155	103205	179785	666265	594080	600295	579180	536535	647890	602710	582425	638605
MATTI SOIL	44925	44925	44925	44925	44925	44925	44925	44925	44925	44925	44925	6150	1223665	1296010
MIX WASTE	1403940	507570	449225	623720	992330	1493985	1282800	1382395	3813915	4848630	4327130	3830300	3190395	3926630
NALA WASTE	9335	7550	8610	439595	737225	228685	16190	16600	7710	7710	1705	53490	40990	34310
PLASTIC WASTE	10440	645	595	1120	655	870	755	1090	6965	685	1860	80	225	1095
SLS	3279710	3301110	3904155	3781410	3726355	4217715	4023865	4009750	4265535	4476250	4508410	4567985	4452225	4460610
WET WASTE	9855580	11000455	10153830	10163540	10195060	9898810	9438480	9199225	9779285	8030110	9243620	9725795	9148200	10241640

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7.0 Observations

On the basis of the primary and secondary data collected, the framework has been designed based on the participatory angle this study's pushing feels right. Without locals on board, any fancy tech will flop. I noticed during site visits that mixed waste is a huge issue. Everything's tossed together, which messes up recycling or WTE plans. If we could get neighborhoods to sort at home, maybe through small incentives or school campaigns, it'd lighten the load on PCMC's end. The GIS maps mentioned could help pinpoint where to start wards with tons of shops or homes, like Zone F, seem like good spots for a trial run.

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CHAPTER 53

Development of Real Estate Business in Maharashtra

Yashraj Suresh Bhosale[1], Udayraj Pandharinath Chakor[2], Aditya Pralhad Tingre[2] and Niraj Prakash Patil[2]

ABSTRACT

This study introduces key factors responsible for successful business development in Maharashtra real estate and analyses existing strategies employed by real estate companies. The real estate industry is influenced by investor behaviour, knowledge, risk management, and demographics. A framework is proposed to help companies establish business by analysing market trends, supply-demand dynamics, and opportunities across different segments. The study also aims to forecast future market conditions and understand the diverse needs, preferences, and behaviour patterns of various customer segments, for the residential buyers, to strategize development projects and marketing efforts accordingly. A comprehensive methodology for real estate business development involves a strategic, research-driven approach that aligns market demands with innovative solutions. The process begins with in-depth market analysis to identify trends, target demographics, and emerging opportunities. Feasibility studies assess financial viability, risks, and returns on investment. Strategic partnerships with architects, contractors, and financial institutions streamline project execution. The goal is to create value, assess risks, ensure profitability, and align business objectives for sustainable growth. Market research and analysis help identify target demographics, demand trends, competition, and economic conditions. Feasibility studies assess financial viability by evaluating development costs, funding options, projected revenues, risks, and regulatory constraints, ensuring projects align with financial goals. Strategic planning and partnerships with investors, contractors, and suppliers secure funding and streamline development. Marketing and sales strategies position properties in the market through digital marketing, social media, real estate networks, and traditional advertising to attract buyers, tenants, and investors.

Keywords: Real estate development; Real estate business strategies; Operational challenges; Marketing strategies.

1.0 Introduction

Carrying out the business development in real estate has to do with the identification of opportunities that can be translated into prospects.

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It, therefore, aims at forming partnerships with like-minded people in order to boost the momentum of the business. The real estate sector in India is dynamic and competitive such that marketing and strategic planning will have to form the basis for differentiating such firms in business. Key stages include land acquisition, financing, design, construction, and finally sales. The other decisive factors of the real estate scenario in Maharashtra are those of investor behavior, market knowledge, risk management, and demographics. This study can provide insight related to expanding-related strategic decision-making and increasing service quality. Real estate is important for the urban expansion as it provides housing, schools, hospitals, and commercial spaces. It leads to economic progression by adapting to ever-changing population dynamics and lifestyle changes. Demand forecasting is the most important thing in making investment decisions based on the fact that in Maharashtra, housing demand depends on income levels, locational advantages, and infrastructure facilities.

1.1 Need for the study

To ensure growth and profitability within its real estate sector, the state of Maharashtra will have to adopt a strategic business approach. Real estate development plays an important role in urban infrastructure, and meeting housing demands, while also being significant to economic stability. Transitioning from one stage of city development to another, businesses have to adapt to changing demographics and market conditions. The present study highlights the important factors influencing the sector and provides a framework to enhance the sustainability and competitiveness of industry business.

1.2 Objectives

This research explores and evaluates the Success Factors Influencing the Real Estate Sector in Maharashtra by the identification of business models and trend analyses. It investigates the supply-demand equation, the kind of buyers, and whether RM is financially feasible to think of further actions to develop the strategic development plan and marketing program. There will also be an investigation of urbanization and infrastructure development trends to tap into future investment opportunities. Effective business strategies would be initiated to earn profits and continue in operation.

1.3 Problem definition

This research addresses critical issues, including:

- The impact of demographics on real estate preferences.
- Emerging market niches and untapped opportunities.
- Key factors influencing buyers' decisions in real estate transactions.
- Effective marketing strategies for different buyer segments.
- Regulatory and policy challenges affecting real estate development.
- The influence of macroeconomic factors on real estate investments.

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1.4 Scope of work

This study touches upon the difficulties that developers face with compliance, finance, volatility, and some key stakeholder`s management. It highlights the formulation of business and marketing strategies for real estate developers and companies wanting to expand. The research will showcase views from developers, project managers, and buyers who belong to the age group of 22-45, located in metros such as Mumbai, Pune and other cities in Maharashtra. The findings should assist the businesses in identifying the opportunities for growth and efficiently approaching the obstacles in this field.

2.0 Literature Review

Several Studies Highlighted Various factors that influenced the factors development of real business in real estate. Bakri *et al.*, (n.d.) identified various success factors such as leveraging the 4Ps of marketing, ensuring operational efficiency and market dynamics. Hassan *et al.*, (2021) studied various factors that can influence the real estate buying decision, which will be beneficial to various researchers, developers and other professionals related to the industry. While Hoang-Tien (2022) identified various matrix for analyzing the strategies used by the real estate developers. The key strategy identified was SWOT matrix. Additionally, strategic matrices like the BCG, McKinsey, and Arthur D. Little (ADL) models aid in assessing market position, business growth potential, and investment strategies. These frameworks collectively help real estate developers refine their strategies and improve decision-making. Parrikar (2018). Provided a comprehensive analysis of critical factors shaping the Maharashtra real estate sector. By examining affordability, market dynamics, and policy implications, the study provided a valuable takeaway for real estate business development project. Basu (n.d.) explored various objectives to study the trends in major global housing markets, growth phases of housing in India, understanding the national housing shortage and to study the various housing market segments of Pune city.

3.0 Research Methodology

The research methodology is a combination of quantitative and qualitative research methods. It includes both primary and secondary data collection methods to analyse Growth, development and challenges that a real estate developer faces from initial days of the business and in the later stages of the business. The methodology consists of all the Market trends, Business opportunities and the challenges faced by the developers. The main aim of Data collection was to understand:

- The key factors influencing real estate development in Maharashtra.
- The challenges faced by developers and solutions for business growth.
- The preferences and decision-making factors of real estate buyers

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Both Primary and Secondary data was used to analyse the current market trends, the strategies used by the developers to establish themselves into the Real Estate Market, their preferred method to create a brand reputation in the market, marketing strategies used to establish credibility and trust with potential buyers. The survey form for the potential buyer helped used in understanding the preferred type of project and the sources used by potential buyers to get information about the ongoing real estate projects.

3.1 Data collection methods

Two surveys were conducted: one with professionals in development and real estate regarding the challenges in business, investment prospect, and marketing strategies; and the other with potential buyers, ages 23 to 45, on their preferences for purchasing decisions, decision-making factors, and preferred marketing channels. Case studies of Maharashtra-based real estate firms provided some insights into successful business strategies and common challenges.

3.2 Data analysis methods

A structured approach was used to analyse the data:

- *Qualitative analysis:* Descriptive statistics and thematic analysis identified patterns in market trends, business strategies, and stakeholder perspectives.
- *Quantitative analysis:* We analysed numerical data obtained from surveys, to quantify trends and relationships within the real estate sector.
- *Content analysis:* The primary objective of content analysis is to identify the key trends in real estate business development, to understand the stakeholder perspective, to evaluate the marketing and business strategies used by the developers The Content analysis is systematic divided into key areas like
    - Market Trends and Demand Analysis
    - Challenges in Real Estate Development
    - Business and Marketing Strategies

This systematic content analysis provides an objective and well-organized evaluation of Maharashtra's real estate sector. The study offers data-backed insights to assist developers, investors, and policymakers in making informed decisions. The structured approach ensures reliability, accuracy, and a holistic understanding of the opportunities and challenges in the market.

4.0 Data Analysis and Findings

The research conducted on the development of the real estate business in Maharashtra aimed to identify key factors influencing real estate development, challenges faced by developers, and buyer preferences. The study utilized both primary and secondary data

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collection methods, including surveys from real estate developers, employees, and potential buyers. Below are the key findings from the research. The sample size for the data was from 100 respondents. Some of the key respondents were like Founders, developers, project managers, sales managers and buyers. An Online Survey form was created to collect data from all the respondents.

4.1 questionnaire development

The questionnaire was divided into Eight sections

- Challenges Faced by Real Estate Developers in Maharashtra.
- Factors Influencing Real Estate Demand in Maharashtra.
- Factors Influencing Real Estate Purchase Decisions.
- Preference for Ready-to-Move vs. Under-Construction Properties.
- Marketing Strategies for Real Estate Developers.
- Property Type Preferences Among Buyers.
- Importance of Brand Reputation in Buyer Decisions.
- Preferred Marketing Channels for Real Estate Buyers.

The questionnaire primarily used closed-ended questions, including multiple-choice questions & Likert scale ratings, to ensure consistency and facilitate quantitative analysis. Additionally, open-ended questions were included to capture respondent qualitative insights. A pilot study of 10 respondents was conducted to study test the clarity and reliability of the questions. Few modifications were made based on the feedback of the respondents

Table 1: Descriptive Table on Challenges Faced by Real Estate Developers in their Initial Days

Challenge	Mean Score	Mode	Standard Deviation	Key Insights
Securing funding or investment	3.76	5	1.23	Financial constraints are a major hurdle for developers.
Understanding market demand	3.57	5	1.21	Moderate difficulty in understanding market trends and buyer preferences.
Building a reliable team	3.57	3	1.06	Mixed perceptions; some find it manageable, while others struggle.
Finding suitable land or properties	3.80	5	1.18	Land acquisition is the most challenging factor due to high costs and scarcity.
Navigating legal and regulatory requirements	3.66	5	1.20	Legal complexities and compliance issues are significant barriers.

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4.2 Detailed research on perspective of developers, managers and buyers from the state of Maharashtra

4.2.1 Challenges faced by real estate developers in Maharashtra

The study identified several challenges faced by real estate developers when starting and running their businesses. The following table summarizes the key challenges and their severity based on a Likert scale (1 = Least Challenging, 5 = Most Challenging):

4.2.2 Factors influencing real estate demand in Maharashtra

The study aimed to find out the most important factors that influence the demand for real estate projects in Maharashtra. The following table presents the key factors and their impact on demand:

Table 2: Descriptive Analysis on Factors Influencing Real Estate Demand in Maharashtra

Factor	Mean Score	Mode	Standard Deviation	Key Insights
Land price and acquisition	4.27	5	1.02	High land costs significantly impact demand.
Return on Investment (ROI)	3.76	5	1.19	ROI is a key consideration for investors.
Target audience	4.05	5	1.11	A well-defined customer base is crucial for demand.
Market competition	3.88	4	1.04	Competitive pricing and market entry strategies are important.
Future growth potential	4.22	5	1.08	Buyers and investors prioritize long-term value appreciation.
Proximity to market	3.88	5	1.05	Accessibility to key locations influences demand.
Tax incentives	3.52	3	1.12	Financial benefits are considered but are not the primary driver of demand.
Zoning and development laws	3.92	5	1.10	Regulatory policies impact project approvals and demand.

4.2.3 Factors influencing real estate purchase decisions

The study examined the factors that influence buyers' decisions when purchasing real estate. The following table summarizes the key factors and their importance:

4.2.4 Preference for ready-to-move vs. under-construction properties

The study analyzed buyer preferences for ready-to-move-in (RTMI) properties versus under-construction properties. The following table summarizes the findings:

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Table 3: Descriptive Analysis on Factors Influencing Real Estate Purchase Decisions

Factor	Mean Score	Mode	Standard Deviation	Key Insights
Location	4.38	5	0.89	Location is the most critical factor for buyers.
Price	4.12	4	1.02	Affordability and budget considerations are crucial.
Reputation of developer	3.89	5	1.08	Buyers prefer trusted and well-established developers.
Property type	3.75	4	1.06	Buyers consider property type but prioritize location and price.
Amenities	3.82	4	1.07	Amenities add value but are secondary to location and price.
Return on Investment (ROI)	4.05	5	1.04	Buyers consider future appreciation and rental income.

Table 4: Analysis on Preference for Ready-to-Move vs. Under-Construction Properties

Preference	Frequency	Percentage (%)	Key Insights
Ready-to-Move (RTMI)	41	51.25%	Majority prefer RTMI properties due to immediacy and lower risk.
Under-Construction	14	17.50%	Fewer buyers prefer under-construction properties due to delays and risks.
Not Sure	25	31.25%	A significant portion of buyers are undecided, influenced by pricing and trust.

Table 5: Descriptive Statistics Analysis on Marketing Strategies for Real Estate Developers

Marketing Strategy	Mean Score	Mode	Standard Deviation	Key Insights
On-Time Delivery	4.32	5	1.10	Timely project completion is the most effective trust-building strategy.
Marketing & Branding Campaigns	4.00	5	1.12	Strong branding and marketing campaigns enhance credibility.
Customer Testimonials	3.78	4	1.11	Testimonials are moderately effective in building trust.
Social Media Engagement	3.79	5	1.13	Social media is increasingly important for customer interaction.
Demonstration Projects	3.92	5	1.14	Physical project showcases help in building buyer confidence.

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4.2.5 Marketing strategies for real estate developers

The study identified the most effective marketing strategies used by real estate developers to build trust and credibility with potential buyers. The following table summarizes the key strategies:

4.2.6 Property type preferences among buyers

The study also examined buyer preferences for different types of properties. The following table summarizes the findings:

Table 6: Analysis on Property Type Preferences among Buyers

Property Type	Frequency	Percentage (%)	Key Insights
Residential	48	48.00%	Residential properties are the most preferred type.
Mixed-Used Properties	36	36.00%	Mixed-use properties are gaining popularity due to convenience.
Commercial	16	16.00%	Commercial properties have a niche demand among investors.

4.2.7 Importance of brand reputation in buyer decisions

The study analysed the importance of brand reputation in influencing buyer decisions. The following table summarizes the findings:

4.2.8 Preferred marketing channels for real estate buyers

The study identified the most preferred marketing channels used by buyers to inquire about and purchase real estate properties. The following table summarizes the findings:

Table 7: Analysis on Importance of Brand Reputation in Buyer Decisions

Importance Level	Frequency	Percentage (%)	Key Insights
Very Important	37	37.00%	Brand reputation is a key factor for a significant portion of buyers.
Important	43	43.00%	A majority of buyers consider brand reputation important.
Neutral	18	18.00%	Some buyers are less influenced by brand reputation.
Not Important	2	2.00%	Only a small percentage of buyers disregard brand reputation.

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Table 8: Analysis on Preferred Marketing Channels for Real Estate Buyers

Marketing Channel	Frequency	Percentage (%)	Key Insights
Websites (99acres, Magic Bricks)	42	42.00%	Online property websites are the most preferred channel.
Social Media	14	14.00%	Social media is the second most popular channel for property inquiries.
Outdoor Hoardings	15	15.00%	Traditional outdoor advertising still holds value.
Events/Expos	12	12.00%	In-person events and expos are effective for engaging buyers.
Newspaper/Magazines	7	7.00%	Print media has a niche audience.
Company Portal	10	10.00%	Official company websites are used by a small percentage of buyers.
Television	4	4.00%	Television ads are less effective for real estate marketing.
Pamphlets	2	2.00%	Pamphlets have the least impact on buyer decisions.

5.0 Summary of Key Findings

- *Challenges for developers:* Land acquisition and securing funding are the most significant challenges. Legal and regulatory hurdles also pose substantial difficulties.
- *Factors influencing demand:* Land price and future growth potential are the most influential factors in real estate demand.
- *Buyer preferences:* Location, price, and ROI are the most critical factors influencing purchase decisions. Ready-to-move-in properties are preferred over under-construction ones. RTMI properties are mostly preferred by the buyers as it involves lower risk.
- *Marketing strategies:* On-time delivery and strong branding are the most effective strategies for building trust. Digital marketing and social media are increasingly important.
- Residential properties are preferred by most of the buyers, while mix-use properties are gaining popularity due to convenience of use.
- *Brand reputation:* Over 80% of buyers consider brand reputation important or very important in their purchase decisions.
- *Marketing channels:* Online property websites and social media are the most preferred channels for buyers.

6.0 Conclusion

The study points out that with the right mix of demographic targeting, digital marketing, and financial planning, a real estate project in Maharashtra could be a success. 79

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Developers who tap the evolving preferences of buyers in terms of location, affordable prices, and brand credibility find themselves far ahead of the rest in this competitive marketplace. As technology transforms the real estate field, these marketing strategies must flip to data-driven digital ones that are able to create effective engagement, valuable customer insights, and many options aired around cost.

Developers need to be flexible to changes in the market, interest rates, and changing government policies. the integration of the smart city infrastructure, blockchain-based property transactions, and AI-enabled property management systems shall drive the next level of growth in the real estate sector of Maharashtra. With urbanization increasing, and an increasing requirement for modern housing solutions, companies involved in construction that persist with sustainability, digital marketing, and flexible financing will naturally flower in this evolutionary stage. Maharashtra remains the most fertile ground for the growth in real estate as a whole in India despite the challenges of high land acquisition prices, regulatory delays, and volatility in the market. Strategic investments into emerging cities, green infrastructure, and technology-showered developments will take the sector toward its sustainable growth phase. The results of this study lay out a clear roadmap for the developers and investors to steer Maharashtra towards the future of real estate. To create long-term value and shape the urban fabric in Maharashtra, real estate players need to adopt customer-centric business models along with smart technologies, while also ensuring compliance with evolving policy regulations.

7.0 Limitations of the Study

The Research involves data from some of the main cities like Mumbai, Pune & others which are real estate hotbeds. The findings may not be suitable for smaller cities. The responses might not represent all the stakeholders from the real estate industry. The data gathered for this research is based on surveys and responses from industry professionals and prospective customers. Since these were based on self-reported data, the reliability of their findings could be affected by individual bias, expectation, or intent. Likewise, social desirability may have affected the response of their respective respondents-other-than just what was market behaviour. Notwithstanding these difficulties, this study provides the essential research for some key factors affecting real estate development in Maharashtra. However, these constraints give a great opportunity for future studies to elaborate and build upon these findings for a more comprehensive understanding of the reality sector.

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CHAPTER 54

Development-Centric Urban Regeneration for Socio-Economic and Environmental Revitalization

Komal Handore[1] *and Avanti Ingole*[2]

ABSTRACT

Urban regeneration has emerged as a transformative process for revitalizing cities that address urban areas socio-economic, environmental degradation, and infrastructural challenges. This research focuses on Yavatmal, a mid-sized city in Maharashtra, India, historically dependent on agriculture which faces issues such as economic stagnation, infrastructural deficits, and social disparities. The research aims to formulate a holistic urban regeneration strategy tailored to Yavatmal's needs emphasizing context-specific solutions by integrating Geographic Information Systems (GIS) and Multi-Criteria Decision-Making (MCDM) techniques. The study employs GIS for spatial analysis, mapping underutilized infrastructure, and assessing regeneration potential, while MCDM facilitates prioritization of interventions based on sustainability, economic feasibility, and stakeholder inputs. The focus lies on fostering socio-economic revitalization, environmental sustainability, and enhanced infrastructure utilization to improve urban livability and social cohesion. This approach aligns with Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 8 (Decent Work and Economic Growth). The study emphasizes the importance of dormant infrastructure assets, creating economic hubs, and targeted skill development as key strategies to boost employment opportunities and economic growth. The research adopts a phased implementation approach that balances short-term goals with long-term sustainability with metrics to assess the impact of these initiatives on quality of life and socio-economic growth. This research not only provides actionable solutions for the city but also offers a replicable model for similar urban centers in India facing similar challenges largely overlooked how urban regeneration can transform underutilized resources, enhance socio-economic conditions, and create resilient, vibrant, and inclusive cities, contributing to sustainable urban growth.

Keywords: Urban regeneration; MCDM; Sustainable development, Socio-economic revitalization, Environmental degradation, Community resilience

1.0 Introduction

Urbanization is a characteristic of the contemporary age. Globally, two billion additional people are expected to live in cities between 2000 and 2030.

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Thus, cities today serve as the centers of almost 80% of global economic activity (Wahba *et al.*, 2019). The United Nations predicts that by 2050, over 70% of the world's population will reside in urban areas (Kumara, 2018). In most urban settings, the infrastructural base is insufficient to support this increase in population (Wahba *et al.*, 2019). Due to rapid urbanization, significant changes have occurred in urban areas, which have a significant impact on the environment and the spatial structure of the city. Currently, 54% of the population resides in urban areas (Kumara, 2018). Rapid industrialization and urbanization are now significant drivers of environmental degradation and have forced metropolitan areas to handle a large increase in population (Kumara, 2018). The conversion of agricultural land, increased pollution, congestion, decreasing open spaces, and inadequate infrastructure are all problems associated with urbanization (Kumara, 2018).

Urban regeneration is an effective response to the increasing demand for land use and infrastructure, which promotes more rapid urban growth (Wahba *et al.*, 2019). Urban regeneration is used to revitalize deteriorating cities, enhance socioeconomic conditions, and ensure environmental sustainability (Neves *et al.*, 2024). Sustainable urban regeneration is the rebuilding of urban spaces and the repurposing of their resources. (Li *et al.*, 2024). It focuses on action, policy, and process interventions in urban areas to mitigate socio-economic challenges by reducing environmental risks, ecological footprints, and the overall quality of the environment within urban systems (Li *et al.*, 2024). Supporting urban regeneration initiatives aids in reimagining a second life for underutilized urban areas and deteriorating communities (Romanelli *et al.*, 2022). Successful urban regeneration requires thorough planning and active involvement from every stakeholder involved.

1.1 Evolution of urban regeneration strategies and policies

Urban regeneration has its roots in the 19th-century industrial revolution, which emphasizes the need for structured city planning. In the post-war period, reconstruction in cities and the economy, followed by deindustrialization, created a social void (Cerreta & Rocca, 2021). Since the 1940s, urban regeneration has been an approach used to combine social concerns with economic and physical growth. In the UK, policies to rebuild war-damaged areas and address the legacy of 19th-century slums were implemented and were similar to U.S. urban policies (Magalhaes, 2015). During the late 1960s and early 1970s, the UK introduced policies that matched the modern urban regeneration concepts (McCarthy, 2016). In the 1970s, the concept of urban regeneration emerged as a policy area to improve social inclusion, boost economic activity, and restore environmental quality in deteriorating neighborhoods (Magalhaes, 2015).

Cities began to realize their significance in both regional and national economies in the late 1980s (Cerreta & Rocca, 2021). In the late 1990s, regeneration policies in the UK returned to area-based initiatives with a greater focus on addressing housing, healthcare, education, employment, and public space improvements through targeted intervention (Magalhaes, 2015).

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Figure 1: Decade-wise Evolution of Urban Regeneration Policies and Strategies

19th Century (Industrial Revolution)

Structured city planning emerges

1940s (Post-War Reconstruction)

- Urban regeneration begins as a structured planning approach.
- Reconstruction efforts focus on rebuilding war-damaged areas.

1950s (Deindustrialization & Urban Decline)

- Economic and social void created by deindustrialization.
- Urban policies address physical and economic redevelopment.

1960s (Social Regeneration & Policy Development)

- "Social regeneration" emerges to address inner-city slums.
- UK & US policies focus on mass housing & modern infrastructure.

1970s (Urban Regeneration as a Policy Area)

- Regeneration focuses on social inclusion, economic growth & environment.
- UK introduces policies aligning with modern urban regeneration.

1980s (Economic-Driven Urban Regeneration)

- Cities recognize their role in regional and national economies.
- London's Canary Wharf project revitalizes local economies.

1990s (Area-Based Regeneration Policies)

- Focus on housing, healthcare, education, employment & public spaces.
- Targeted interventions for social and economic improvements.

2000s (Financial Crisis & Slowdown in Regeneration)

Weakening real estate markets delay regeneration initiatives.

2010s (Economic Regeneration & Global Expansion)

- UK focuses on economic regeneration via grants & tax incentives.
- Countries like South Korea & China adopt urban regeneration strategies.

Present (Sustainable & Inclusive Urban Regeneration)

- Shift from demolition-based policies to sustainability-focused strategies.
- Emphasis on social, economic, and environmental balance.

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The majority of regeneration initiatives in the UK and Europe were delayed down by the financial crisis of the mid-2000s because of the weakening real estate markets (Magalhaes, 2015). In 2010, the UK coalition government prioritized economic regeneration via grants and tax incentives for funding projects that increased employment and the economy (Jones & Evans, 2013). Recently, countries like South Korea, which industrialized rapidly and experienced rapid, unplanned urbanization, have pursued urban redevelopment policies (Shin, 2009). China is looking for solutions to stop the urban deterioration brought on by its fast urbanization (He & Wu, 2007). Although the policies frequently focus on destruction and reconstruction, they are becoming more aware of the limitations of this approach (Magalhaes, 2015).

Historically, Indian cities were defined by high population density within compact spaces and primarily nonagricultural livelihoods (Hawley, 1971). Despite the expansion of urban sprawl, inner-city neighborhoods which are frequently the oldest areas of a city face several social, economic, and environmental problems (Pankaj, 2018). Inappropriate land use, deteriorating infrastructure, pollution, congestion, and historical degradation are some of the factors that significantly affect the citizens' quality of life (Pankaj, 2018). Initiatives for regeneration, such as historical preservation in Jaipur, slum rehabilitation in Kolkata, and core area management in Delhi, are influenced by regional settings (Onkar *et al.*, 2008). Depending on the characteristics of a city, regeneration involves either at macro-level of the inner core or micro-level such as traffic operation plans, historic building conservation, and service upgrading (Onkar *et al.*, 2008). Several schemes were started in India, including the Jawaharlal Nehru National Urban Renewal Mission (JNNURM), which was introduced in 2005 to improve urban development, infrastructure, and services.

Basic Services to the Urban Poor (BSUP), Urban Infrastructure Development Scheme for Small and Medium Towns (UIDSSMT), and Integrated Housing and Slum Development Programme (IHSDP) were among the sub-submissions that addressed urban poverty and inadequate infrastructure (Narkhede & Bura, 2022). Also, the Ministry of Housing and Urban Affairs has made significant progress, neighborhood-level policies that address environmental sustainability, social and economic progression, and failing infrastructure are necessary to revitalize urban areas (Narkhede & Bura, 2022).

1.2 Concepts in urban regeneration

Urban regeneration focuses on the concept of revitalizing outdated buildings, ancient structures, and neighborhoods. Redevelopment of brownfield sites and the revitalization of ancient structures are issues in global cities (Bratuskins *et al.*, 2020). In addition, the revitalization promotes the provision of diverse dwelling plans (Shawabkeh, 2018). It aims to address the growing needs of communities resulting from urbanization and population increase (Shawabkeh, 2018). Sustainable development is another important concept. The Sustainable Development Goals (SDGs) have a significant emphasis on social sustainability (Marta & Giulia, 2020). Socially sustainable urban regeneration focuses on economic, environmental, and

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social issues, thus it is in line with SDGs that aim to achieve well-being (SDG 3), reduce inequalities (SDG 10), build resilient, inclusive cities (SDG 11), and develop peaceful societies (SDG 16) (Marta & Giulia, 2020). Studies on social sustainability are still few, even though their significance has grown recently (Marta & Giulia, 2020). The revitalization of communities and neighborhoods is necessary to accomplish sustainable cities (Romanelli *et al.*, 2022). Urban regeneration enhances quality of life, fosters participation, and promotes sustainable development. Moreover, it can facilitate inter-organizational relationships between public and private organizations and facilitate urbanization (Romanelli *et al.*, 2022).

The focus on urban communities is another essential component of urban regeneration (Li *et al.*, 2024). Sustainable urban community regeneration uses sustainable methods to address issues like excessive consumption of energy and poor space quality, significantly contributing to urban growth. This approach, which focused on urban regeneration through improved maintenance methods, initially appeared in rich countries including the US, UK, and Japan (Li *et al.*, 2024). Adaptive preservation of cultural heritage sites' structures is another connected issue. Reusing heritage sites rather than destroying them is the goal of adaptive preservation. Since the majority of traditional settlements in India have lost their true value, this is a challenge (Vidyullatha *et al.*, 2023).

One of the most important policies for restoring ancient buildings and transforming cities is urban regeneration (Romanelli *et al.*, 2022). Adaptive use of old or historic structures can enhance the ecology, landscape, cultural identity, and local resources (Vidyullatha *et al.*, 2023). Although community involvement is essential for successful urban regeneration, its impact has not yet been investigated, and there is a lack of research that can clearly relate socioeconomic factors to outcomes (Chahardowli *et al.*, 2020). Secondly, the limited study on comprehensive research that brings capacity building together with community service delivery to vulnerable communities indicates the existence of an under-researched area that must be investigated (Cahantimur & Beceren, 2023).

This also suggests that the complexity of urban regeneration may not be adequately addressed by the existing study, which places a smaller focus on long-term sustainability and participatory techniques (Chahardowli *et al.*, 2020). The gaps need to be addressed to develop more effective and sustainable strategies (Vidyullatha *et al.*, 2023).

1.3 Purpose, aim and objectives

There has been significant research on urban regeneration, but this knowledge gap persists in the practical application of such frameworks in a particular context, particularly in small and mid-sized cities in India (Neves *et al.*, 2024). Despite having limited exposure, numerous authors continue to focus on large, large cities with advanced infrastructural and economic foundation (Said & Dindar, 2024). Successful intervention examples in recent years, such as the regeneration of ancient city cores, have provided cities the chance to improve their urban character and attract in investment (Chahardowli *et al.*, 2020).

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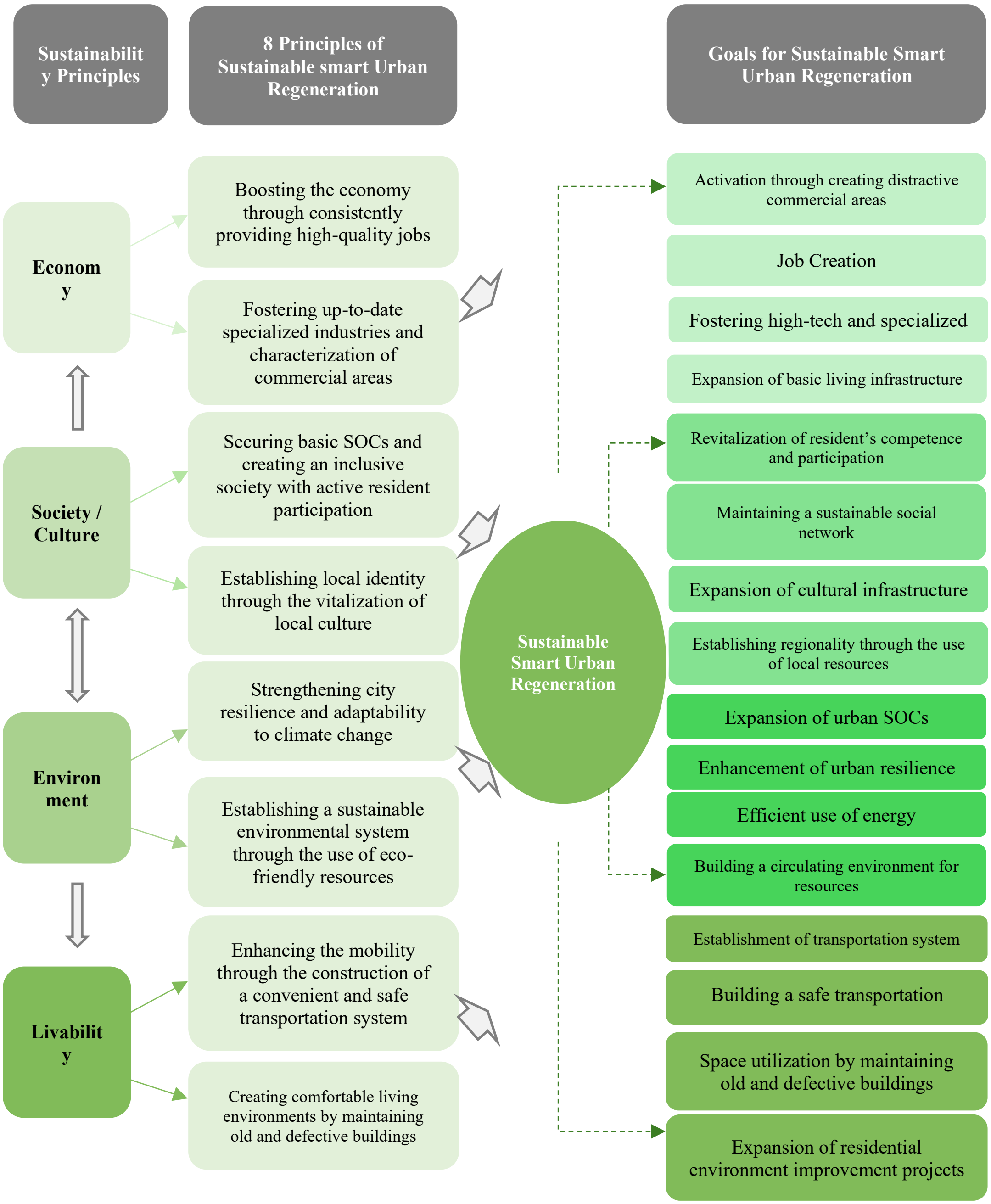
Figure 2: Principles of Urban Regeneration



Source: Enhancing Sustainable Urban Regeneration through Smart Technologies: An Assessment of Local Urban Regeneration Strategic Plans in Korea -Hyun Woo Kim

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Additionally, the Port of Rimini regeneration project's use of virtual reality to engage the community indicates that regeneration contributes to improvements in public space and quality of life (Belaroussi, 2023). This aspect of urban revitalization encourages resilience, livability, and sustainable development on a global scale, which eventually results in communities that are healthier and more vibrant (Romanelli *et al.*, 2022).

This study addresses the urban regeneration gap in smaller cities with socio-economic and infrastructure issues, with an emphasis on Yavatmal City, India. (Neves *et al.*, 2024). Yavatmal's urban landscape is defined by economic decline, poor infrastructure, and social issues that impede growth. To promote livability and community well-being, a comprehensive approach that incorporates affordable housing, green spaces, and smart infrastructure is needed (Chahardowli *et al.*, 2020). The city's reliance on agriculture has led to economic stagnation and outdated infrastructure, contributing to the issue. According to (Neves *et al.*, 2024) socioeconomic inequality and informal settlements are examples of unequal restoration.

Research that is especially focused on Yavatmal's needs would be required because there aren't many practical case studies of comparable situations. As demonstrated by the successful urban regeneration frameworks, it is essential to involve communities in the regeneration process to foster trust and enhance outcomes (Cahantimur & Beceren, 2023). Further, to improve urban resilience, environmental sustainability and socioeconomic revival must be integrated (Neves *et al.*, 2024). This research seeks to highlight some of the most pressing regeneration challenges, put forward new, innovative approaches in urban planning, and formulate standards to evaluate regeneration in terms of quality of life and socio-economic growth (Vidyullatha *et al.*, 2023). Challenges specific to Yavatmal make this case study the ideal opportunity to evolve step-by-step, feasible interventions in smaller Indian cities for their regeneration. The aim of this study is to formulate integrated urban regeneration strategies that would be based on socio-economic revival, environmental sustainability, infrastructure improvement, and cultural heritage preservation to make the Yavatmal livable, resilient, and conducive to community well-being.

The following research questions will be examined in order to achieve this aim:

- What are the key socio-economic and infrastructural problems facing Yavatmal, and how do these problems influence its development?
- How could GIS be applied to analyze the challenges and determine the effects of urban regeneration on Yavatmal's development?
- How can those frameworks from national and international contexts be adapted to achieve the specific needs of Yavatmal?
- To maximize sustainable urban regeneration in Yavatmal, how may MCDM approaches be applied to prioritize regeneration choices while taking stakeholder and community input into consideration?
- What new urban planning strategies, accompanied by smart infrastructure, green spaces, and affordable housing, can be used for regenerating Yavatmal?

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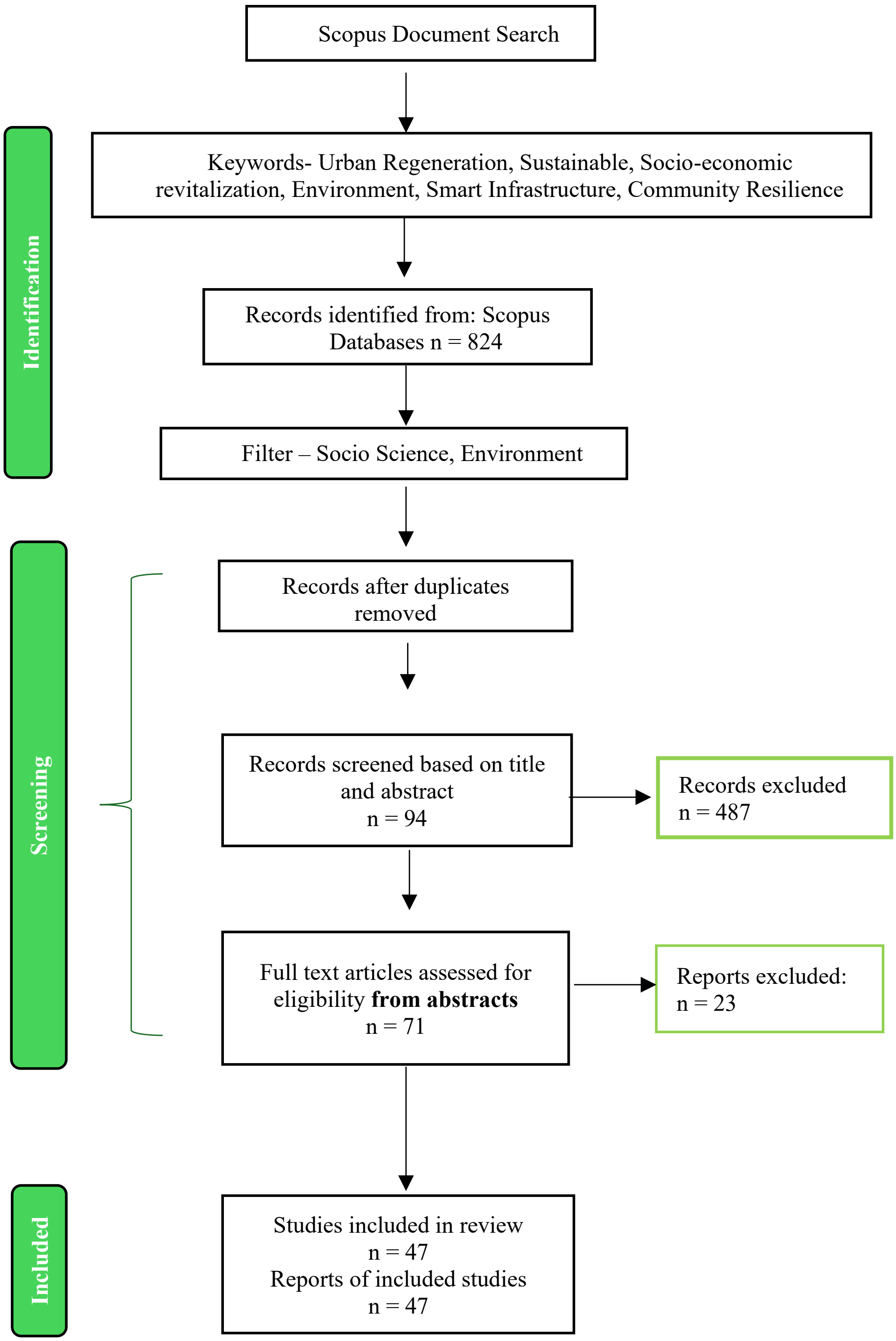
Figure 3: Literature Review Methodology



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This research uses GIS and Multi-Criteria Decision-Making (MCDM) techniques, it examines whether regeneration efforts may provide Yavatmal with an innovative perspective on the social, economic, and environmental aspects of life. By combining socio-technical viewpoints, the MCDM framework tackles the problem of prioritizing urban renewal criteria and enables the identification of the most feasible and well-rounded regeneration solutions (Manupati *et al.*, 2018). It ensures sustainable development that is economically feasible, environmentally responsible, and socially inclusive.

2.0 Methodology

2.1 Literature methodology

The literature review used the systematic approach by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards. To get a deeper understanding of a study issue, a strategy like this ensures a strict and transparent procedure in determining the appropriate research.

First, a search for keywords was conducted in the Scopus database. These included "Urban Regeneration, Sustainable, Socio-economic Revitalization, Environment, Smart Infrastructure, and Community Resilience". A total of 824 documents were found using the keyword search. Later, filters were used to make sure the research paper that was discovered would be relevant to the study's aim; specifically, the article was classified under the "Social Science" and "Environment" sections. Following the application of the filter, 581 papers were considered relevant and subjected to additional study, while 243 papers were eliminated. After then, the abstracts of those 581 publications were examined in order to determine which ones were relevant to the research. As a result, 94 publications that were in alignment were found.

To ensure their eligibility for consideration in the research, the complete texts of 71 publications were examined from the list based on 94 records that were chosen. As a result, 23 records were removed from the pool of eligible records. After a thorough screening and evaluation of eligibility, 47 studies made it into the final review. These studies served as the foundation for determining the main ideas and patterns in literature, which in turn provided light on the crucial elements of community resilience, sustainability, and urban renewal. This systematic approach allowed 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.

2.2 Research methodology

The research methodology for this study follows a structured and systematic approach in addressing the identified research problem and achieving the objectives of the study (Shawabkeh, 2018). This study uses a mixed-methods research strategy, combining qualitative and quantitative techniques to provide an in-depth analysis of Yavatmal's regeneration process.

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While the quantitative method makes use of geographical analysis using GIS and Multi-Criteria Decision-Making (MCDM) tools, the qualitative approach concentrates on understanding socioeconomic and environmental concerns. Identifying the research problem is the fundamental stage in the research approach.

Next, the aim and objectives that determine the research's scope and direction are defined. A comprehensive literature review is conducted to analyze existing studies, reports, and research papers, thereby allowing the identification of research gaps, the need for innovation, and the novelty of this study. Yavatmal City's socioeconomic and environmental characteristics will be the primary focus of the research. This will act as an opportunity for concentrated regeneration initiatives.

The study combines primary and secondary research methods to ensure a comprehensive understanding of urban regeneration for environmental and socioeconomic revival, with a particular emphasis on Yavatmal. Primary data was gathered via structured questionnaires, and stakeholder perspectives were recorded. Secondly, data was gathered from reports, online websites, newspaper magazines, government officers and literature.

The study collects data using two methods primary Data and secondary data. The primary data is based on structured questionnaires that are used to directly gather both quantitative and qualitative data from stakeholders, such as citizens, government officials, and urban planners. Whereas, in secondary data the In-depth literature reviews will be an important source from previous studies, reports, and statistical data. Available geographic and demographic datasets, satellite imagery, land use maps, and policy documents will be procured from official government websites and the town planning departments.

The collected data will be analyzed to make relevant conclusions and will be analyzed as quantitative and qualitative data. The quantitative analysis helps to find trends, patterns, and correlations, numerical data from surveys will be processed. Survey data will be examined to find patterns and connections between urban issues and socioeconomic variables. Additionally, the distribution of public spaces, infrastructure problems, and land-use patterns will be mapped using GIS techniques. Whereas, the qualitative analysis helps to assess stakeholder perspectives and contextual elements, non-numerical insights from secondary sources and interviews are studied. Determine Yavatmal's advantages, disadvantages, possibilities, and risks about urban regeneration. The study identified urban regeneration alternatives for Yavatmal using a combination of GIS and MCDM approaches.

On the basis of land use, population density, infrastructure deficits, and environmental challenges, critical places are emphasized on GIS thematic maps. MCDM further prioritized options considering economic viability, sustainability, and stakeholder involvement. In order to solve socioeconomic and environmental issues, the research created focused, sustainable strategies that were in line with local development objectives. The findings offer a route to sustainable urban change by offering practical suggestions for urban regeneration.

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Figure 4: Research Design for Developing Urban Regeneration Strategies for Yavatmal

Identification of research problem

↓

Title of the Study

↓

Aim and Objectives

↓

Literature review and Preliminary Analysis
Review existing analysis, research papers, reports, journals and articles

↓

Defining Research Gap, Need and Novelty

↓

Methodology

↓

Site Selection and Site Analysis
Identification of a site and analysis of Yavatmalsems current conditions

↓

Data collection
Both primary and secindary data collection

↓

Data analysis
Using analysis tools GIS and MCDM techniques

↓

Findings

↓

Developed implementation strategies
(Discussion and Inferences)

↓

Reporting and Conclusion

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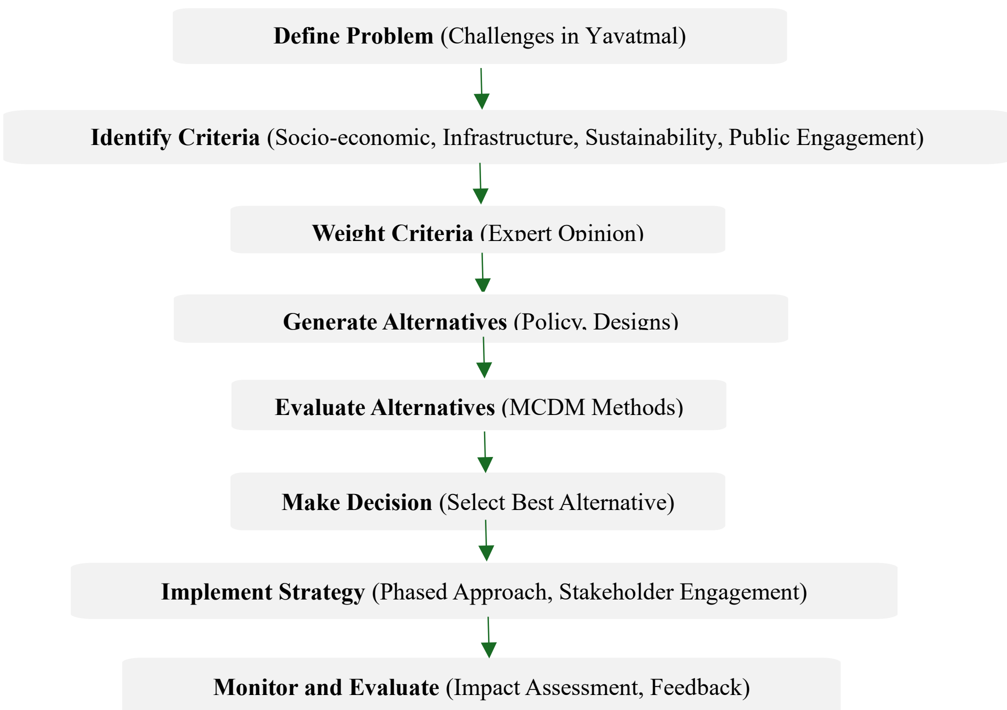
3.0 Tools and Techniques

Multi-Criteria Decision-Making (MCDM) and Geographic Information Systems (GIS) are two techniques that are combined in this study in order to develop a solid framework for addressing the needs of the development-centric urban regeneration of the Yavatmal. This approach would support the study's investigation of the feasibility of Yavatmal's regeneration strategy. By using these techniques, the study will help in the creation of initiatives that balance social, environmental, and socioeconomic issues in the Yavatmal.

3.1 MCDM framework

The MCDM method integrates each of these criteria, which include social inclusion, environmental sustainability, and economic feasibility, to achieve multiple objectives and make it easier to examine regeneration, alternatives.

Figure 5: MCDM Framework



The approach seeks to take into account the opinions of the numerous stakeholders, and as a result, the different techniques that have been selected and are relevant to the research study's objective are combined and also helping with addressing community needs. This

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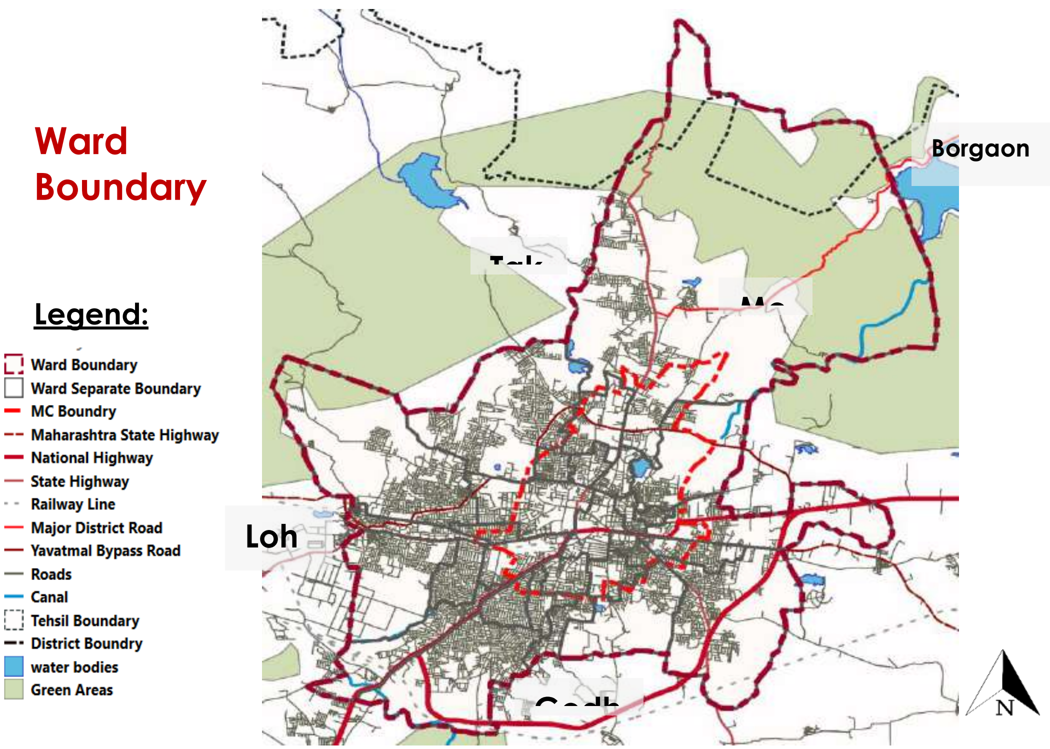
approach therefore encourages balancing the planned interventions. Urban regeneration in Yavatmal adopts an MCDM approach to tackle socioeconomic stagnation, environmental problems, and challenges related to insufficient and dormant infrastructure. The issues that have been brought forward are first identified, followed by recognition of the criteria for evaluation such as sustainability and socioeconomic impact, after which the weights are distributed according to the opinions. The MCDM technique rates potential solutions such as community-based projects and policy reforms. And in order to accomplish the long-term objectives of the selected plan, this approach first actively involves all stakeholders before continuing to support the monitoring and development of planning techniques.

This approach makes use of GIS tools, which are also employed in the identification of underdeveloped areas and the creation of green spaces and corridors to optimize the enhancement of transportation networks while simultaneously increasing community resilience. In order to achieve socio-economic renewal and support environmental preservation, the GIS framework and the MCDM are used in combination to provide sustainable urban redevelopment that is tailored to the requirements of the Yavatmal community.

Figure 6: Ward Boundary Map of Yavatmal



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4.0 Study Area

Yavatmal is a city and municipal municipality located in the eastern Indian state of Maharashtra. Yavatmal serves as the district's administrative center. The city is located about at latitude 20.3893° N and longitude 78.1303° E on the Deccan plateau area. Other districts are connected by the city. Amravati and Wardha districts border Yavatmal to the north, Chandrapur district borders it to the east, Telangana state and Nanded district border it to the south, and Washim and Hingoli districts border it to the west.

The Wardha-Painganga-Wainganga plains, which are characterized by hills, valleys, plateaus, and other characteristics, are one of the many geographical features of the Yavatmal. With a total size of around 13,582 square kilometers, Yavatmal district makes up 4.41% of Maharashtra state. The Yavatmal district's geography is separated into six distinct geographical zones. The Yavatmal Plateau, which covers the majority of the tehsils of Kalamb, Kalamb, Kelapur, and Ghatanji; the Bembla Basin, which is located in the northern parts of Ner and Babulgaon tehsils; the Pusad Hills, which are located in Pusad, Mahagaon, and Umarkhed tehsils; the Wardha Plain, which is located along the Wardha River in Kalamb, Ralegaon, Maregaon, and Wani tehsils; and the Penganga Valley, which is located along the southern district boundary.

Because of these geographical features and their characteristics, the Yavatmal region is distinct in terms of its varied terrain, development, and surroundings. The city of Yavatmal has 5585 households spread over 40 wards. Over the next few decades, both the population and urbanization will continue to rise due to the expansion and improvement of infrastructure. This represents the potential for both urbanization and economic growth characteristics. The district has a population of 2077144 and constitutes 2.63% of the state's total population. The population density is 153 persons per km2, which is much less than the overall population density of the state at 257 persons per km2.

Yavatmal district ranks 19th in terms of population and sixth in terms of area out of the 30 districts in the state of Maharashtra. With a decadal growth rate of 12.78%, the population of Yavatmal district increased from 1,822,942 in 1981 to 2,458,271 in 2001 and 2,772,348 in 2011. Yavatmal districts are mostly rural. The main source of income and livelihood for the local population is agriculture, which is also the main industry supporting the district's economy. Approximately 21.58% of its people live in towns. According to the 2011 census, Yavatmal City is home to 116,551 individuals. This figure will keep rising annually. It will be projected to reach 167,000 by 2025.

The demographics of Yavatmal are diverse and require significant improvement. Sex Ratio is slightly above the national average with 952 females per every 1,000 males. However, the sex ratio of children aged 0–6 is 922 girls for every 1,000 boys, suggesting that gender parity has to be improved. The overall average literacy rate in the district of Yavatmal is 82.82%, which is quite acceptable. The literacy percentage for women is 75.93%, whereas the rate for

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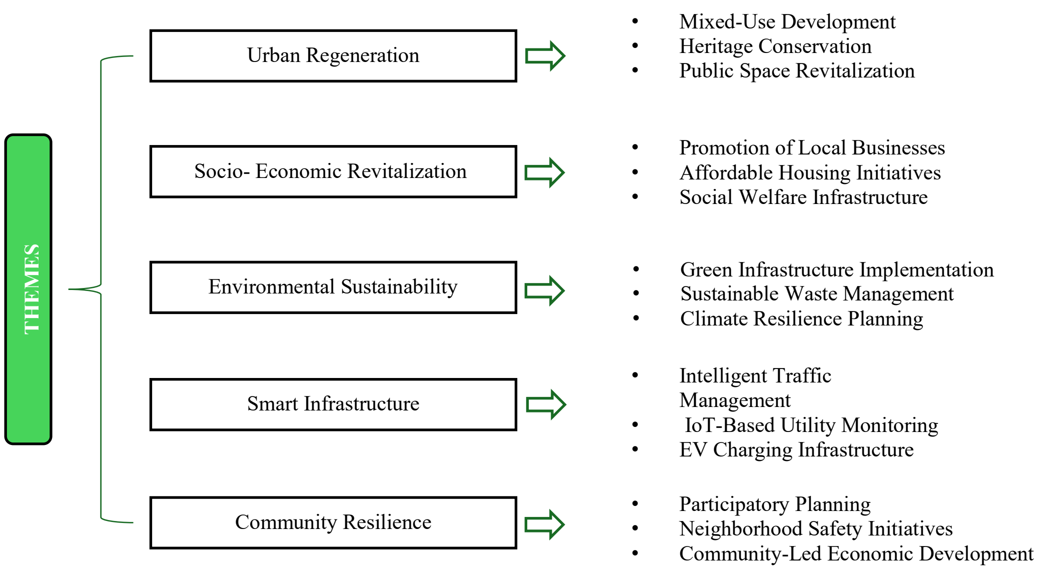
men is 89.41%. The fact that the literacy rate in rural regions is 80.47% while it is 91.24% in urban areas indicates that educational measures are necessary in the urban areas. With around 17% of the people belonging to scheduled castes and 5.61% to scheduled tribes, Yavatmal boasts a diverse social fabric. Diversity is beneficial for the district's cultural richness, but it also determines whether inclusive development and resource allocation are required.

The Yavatmal district's economy is still mostly based on agriculture, with cotton serving as the major product and economic activity. As a result, worker participation is significantly lower than in other districts. Yavatmal district is the area in Maharashtra where the most cotton is grown. In Yavatmal, agriculture employs more than half of the people. According to the 2011 census, Yavatmal Municipal Council employed 39,237 people. Of them, 93% were employed in major jobs, which is defined as employment that lasts more than six months per year, while the remaining 7% were employed in marginal work. Of these, 1,222 were cultivators, 457 were agricultural laborers, 734 were employed in home industries, and 34,087 were employed in other activities. As a result, there has been a steady shift in urban areas toward industrial and service-oriented occupations, indicating socioeconomic development.

Figure 7: Identifies Themes from Literature Review



Trade and trade are essential to the district's economy since Yavatmal is a cotton city and a major exporter of cotton, teak wood, nylon, limestone, and charcoal. Yavatmal offers a robust transit system that facilitates both travel and commerce. Cotton and jowar are two of the district's main crops. The Yavatmal region is extremely well connected by road, with several towns passing along state and national routes. Hence, the district imports all necessary goods

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from places like Nagpur, Pune, and Mumbai, including cement, food grains, machines, and medicines. Yavatmal, Pusad, Wani, Digras, and Pandharkawada are important commerce hubs. The significant roads that facilitate access are the Amravati-Chandrapur State Highway and the Nagpur-Hyderabad National Highway. Yavatmal lies on the Nagpur-Tuljapur State Highway. Rail connectivity is restricted to narrow-gauge lines, including the Yavatmal-Darwha segment, which is mostly utilized for the movement of commodities. This means that to serve the district's expanding urban and industrial demands, rail and road connectivity must be improved.

Due to the city's reliance on agriculture, the problem has resulted in both economic stagnation and outdated infrastructure. The Yavatmal offers a distinct set of opportunities and challenges, mostly due to its socioeconomic and geographical characteristics. Being the rapidly growing city, Yavatmal faces critical issues including infrastructural shortages, environmental deterioration, and a slowdown in its socio-economic development that make it suitable for the cause of development-centered urban regeneration. This inclusive planning may help in balancing the city's economic expansion.

5.0 Results

Through literature analysis, five major themes are urban regeneration, community resilience, socio-economic regeneration, environmental sustainability, and smart infrastructure. have emerged to determine the challenges with infrastructure physicality, economic decline, social problems, smart infrastructure and green space opportunities. While issues with physical infrastructure include outdated utilities and a lack of connectivity, economic decline is characterized by decreased industrial activity and unemployment. The problems urban regions confront are made worse by social concerns such as inequality and housing conditions. Growing green areas, promoting sustainability, and incorporating smart technology present opportunities.

The integration of sustainable practices within urban regeneration is crucial for enhancing the quality of life and fostering economic growth (Neves, 2024). The literature emphasizes the importance of participatory processes and stakeholder involvement in achieving successful regeneration outcomes (Chahardowli, 2020). The involvement of local communities in the planning process fosters a sense of ownership and responsibility, which is essential for the sustainability of regeneration efforts (Neves, 2024). Additionally, the implementation of renewable energy sources and energy-efficient systems in urban regeneration projects can significantly reduce the carbon footprint of urban areas (Cahantimur, 2023). The regeneration of historic city cores has been identified as a key strategy for enhancing urban identity and attracting investment (Chahardowli, 2020).

The study identifies the main urban problems in Yavatmal with regard to environmental deterioration, economic decline, and a lack of infrastructure. The study uses a Multi-Criteria Decision-Making (MCDM) approach to prioritize urban regeneration initiatives based on stakeholder input, economic viability, and sustainability. Unused land, infrastructural gaps, and

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redevelopment zones may all be spatially mapped with the use of geographic information systems (GIS). The findings indicate that high-density regions with underutilized transportation hubs, ecologically sensitive areas, and insufficient basic amenities are locations with potential for urban regeneration. According to the study, parks and green areas, intelligent infrastructure, affordable housing, and cultural preservation are important tactics for inclusive urban growth. The MCDM framework prioritizes regeneration by taking into account a number of factors, including economic possibilities, environmental considerations, and human well-being. GIS-based thematic mapping makes it easier to identify the locations where interventions should be concentrated, which is accomplished through resource-optimal urban planning.

6.0 Discussion

The findings are in the direction of data-driven decision-making in urban redevelopment, particularly for medium-sized communities like Yavatmal, where infrastructure development has been delayed by economic dependence on agriculture. The study follows global best practices for urban revitalization by identifying targeted intervention zones using GIS-based spatial analysis. One important takeaway is that community-led and sustainable revitalization initiatives require stakeholder involvement. Global experience shows that sustainable land-use planning regulations, economic diversity, and collaborative governance are the keys to urban revitalization. The study supports resilient, inclusive urbanization, which is one of the Sustainable Development Goals (SDGs 11 and 8). Despite the unique socioeconomic and infrastructure issues in Yavatmal, other communities dealing with urban deterioration can use the MCDM-GIS hybrid model as a model. Long-term growth of sustainable urban ecosystems may be achieved by the integration of economic hubs, ecological protection, and smart infrastructure.

7.0 Conclusion

This study emphasizes the value of integrated urban regeneration strategies in the revitalization of metropolitan areas affected by environmental and socioeconomic problems. The study offers a methodical way to find, assess, and implement regeneration initiatives in Yavatmal by using MCDM for ranking and GIS for geographical analysis. The proposed approach promotes long-term economic sustainability and social engagement in addition to addressing immediate infrastructure deficiencies. Research suggests that urban resilience may be enhanced by a phased implementation strategy that incorporates green spaces, smart infrastructure, and economic diversity. In order to evaluate the long-term efficacy of municipal regeneration initiatives, future study would incorporate longitudinal impact studies. Furthermore, in order to ensure that city regeneration is always responsive to evolving municipal needs, policy guidelines must include citizen involvement and adaptive planning. In

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order to create a sustainable and just future, communities like Yavatmal may transform unused assets into vibrant urban areas by using a deliberate, evidence-based, and participative strategy.

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CHAPTER 55

Diagrid Structure in High-Rise Building: A BIM Implementation, Risk Assessment and Safety Measures

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ABSTRACT

The evolving demand for innovative, efficient, and sustainable construction practices has led to the use of diagrid structures in high-rise buildings. Known by their diagonal grid patterns that eliminate the need for vertical columns, diagrids have major benefits in structural efficiency, material optimisation, cost-effectiveness and visual appeal. This study addresses the potential of diagrid structures in high-rise construction, highlighting their implementation using Building Information Modelling (BIM) tools. The performance of diagrid structures and traditional column-beam systems will be compared in this study. In order to provide useful insights for the adoption of diagrid structures in the Indian construction industry, this study aims to create a Project Management Framework (PMF) specifically designed for their lifecycle management by utilising BIM tools and sophisticated analysis techniques. In order to assess performance under a variety of load conditions, such as wind, seismic and gravity loads, the methodology involves using Autodesk Revit to create detailed 3D models of diarid and conventional structures, followed by structural analysis in ETABS. A comparison of energy consumption is made possible by Autodesk Insight's energy simulations, which are based on variables like location, material characteristics and orientation. Additionally, 5D analysis incorporates cost data for resource and expense management, while Navisworks 4D simulations show the construction timeline. By providing adaptable recommendations and a solid framework, this study contributes to the growing adoption of diagrid structures, promoting innovation, sustainability and efficiency in high-rise construction in India and beyond.

Keywords: Diagrid structures; High-rise buildings; Building Information Modelling (BIM) tools; Project Management Framework (PMF).

1.0 Introduction

Diagrid structures are becoming more and more popular as high-rise building demand creative and efficient structural systems rises.

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Triangulated in nature, diagrids improve lateral stability, maximise material use, and provide more design freedom. These buildings provide structural efficiency as well as aesthetic appeal, so removing the need for traditional vertical columns. Engineers and architects search for answers that strike a compromise between strength, material efficiency, and sustainability as urbanisation keeps buildings higher. Among the major benefits of diagrid buildings are better lateral stability, less material consumption, and alignment with environmentally friendly building techniques. High-rise buildings choose them since their geometric structure improves resistance against dynamic forces. In the Indian construction industry, the adoption of diagrid structures is gaining momentum, particularly with the integration of Building Information Modeling (BIM). BIM facilitates precise structural modeling, risk assessment, and project management, streamlining the construction process. Autodesk Revit, widely used in structural design, plays a crucial role in modeling and analyzing diagrid structures, allowing for better planning and execution.

Optimizing high-rise building designs for the Indian construction industry tends to become better in terms of efficiency and sustainability at a lower base cost. Traditional structural systems often lack integrated approaches that combine structural design with advanced project management tools, leading to inefficiencies. This study aims to resolve these problems, where BIM tools are used to study diagrid structures for energy efficiency, sequencing (4D analysis) and cost estimation (5D analysis)

Thus, this study intent to evaluate the feasibility and effectiveness of diagrid structures in high-rise construction, emphasizing their practical implementation through BIM. It explores their structural integrity, safety performance and efficiency in comparison to conventional structures. Additionally, the research investigates the integration of 4D and 5D BIM methodologies with energy performance analysis to enhance project scheduling, cost estimation and operational efficiency. By addressing these aspects, this study seeks to develop a structured framework for the design, analysis and practical application of diagrid structures, contributing to advancements in high-rise construction technology. Leveraging BIM tools such as Autodesk Revit and Navisworks, this research provides a comprehensive approach to optimizing diagrid adoption in modern construction.

The structure of this paper first explores diagrid structures by analyzing their performance and integration with BIM technologies. The literature review identifies key advancements in diagrid systems while highlighting existing research gaps in their practical implementation. The methodology involves a detailed workflow-3D modeling in Autodesk Revit, structural analysis in ETABS, and 4D & 5D BIM analysis in Navisworks to evaluate the constructability, scheduling efficiency and cost implications. By developing a structured project management framework (PMF), this study aims to provide practical guidelines for optimizing diagrid adoption in high-rise construction. The findings contribute to enhancing efficiency, reducing material waste and promoting sustainable design practices in modern construction projects.

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2.0 Literature Review

The evolution of structural systems in high-rise buildings has led to the adoption of diagrid structures as an alternative to traditional frameworks. Ali & Moon (2007) highlighted the benefits of diagrid systems, including enhanced lateral stiffness and reduced material usage. Their study demonstrated how diagrids, through their diagonally interconnected members, eliminate the need for conventional vertical columns, leading to both aesthetic and functional advantages. Moon *et al.* (2007) introduced a methodology for preliminary diagrid design, showing that diagrid angles between 60° and 70° optimize lateral resistance, reducing bending moments and improving overall structural efficiency.

Jani & Patel (2013) further analyzed the design and efficiency of diagrid structures in high-rise steel buildings using ETABS modeling. Their study concluded that diagrid systems can reduce material consumption by up to 20% while significantly improving lateral stiffness, reinforcing their economic and structural feasibility. Sustainability and energy efficiency are also significant considerations in diagrid system adoption. Asadi & Adeli (2017) explored the role of diagrids in sustainable high-rise buildings, demonstrating their ability to enhance energy efficiency by improving daylight penetration and natural ventilation, which in turn reduces operational costs. Rahila & Narayanan (2021) conducted an optimization study on multi-storey diagrid buildings using ETABS software to analyze different configurations. Their findings confirmed that shorter diagrid modules improve lateral stiffness, while longer modules enhance material efficiency, striking a balance between performance and cost. However, while these studies presented strong arguments for the structural and economic viability of diagrids, they often failed to integrate seismic performance considerations with sustainability aspects, creating a gap in understanding their full lifecycle impact.

In terms of seismic resilience, Kiran & Yogesh (2022) compared diagrid and conventional structures, concluding that diagrid frameworks experience 20-30% lower storey displacement under lateral loads, making them structurally superior in high-rise applications. Asadi *et al.* (2018) conducted a nonlinear time-history analysis to assess seismic performance and loss estimation in steel diagrid structures. Their study found that while diagrids offer superior resilience, they may experience higher floor accelerations, necessitating damping systems for improved performance. Vhanmane & Bhanuse (2020) examined material efficiency in diagrid buildings, showing that diagrid systems use significantly less steel while maintaining high structural stability, making them a cost-effective choice for high-rise construction. However, while these studies confirm the structural resilience of diagrid systems, most do not provide a comprehensive analysis of their performance in different seismic zones or compare their long-term behavior under dynamic loading conditions.

BIM has revolutionized construction management, yet its integration with diagrid systems remains underexplored. Azhar (2011) reviewed the trends, benefits, risks, and challenges of BIM adoption in the AEC industry, finding that BIM enhances design

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coordination, cost estimation, and project efficiency while reducing construction errors and rework. Criminale & Langar (2017) analyzed challenges in BIM implementation, identifying cost, interoperability, and training as the major barriers to adoption. Akkoyunlu (2018) explored parametric BIM façade module development for twisted diagrid structures, demonstrating that automated BIM workflows improve constructability and material efficiency.

Shahabian & Fadai (2019) developed an intelligent parametric BIM solution for diagrid structures, proving that algorithm-driven BIM modeling reduces material wastage by 15-20% and enhances structural efficiency. Misal *et al.* (2022) examined BIM integration in G+20 residential towers, confirming that 5D BIM analysis improves cost forecasting and scheduling efficiency, leading to better project management outcomes. Despite these findings, there is a lack of specific studies on the integration of 4D and 5D BIM with diagrid structures to optimize scheduling and cost estimation. Monteiro & Martins (2020) studied BIM-based quantity take-off methodologies, emphasizing that modeling guidelines improve material estimation accuracy and reduce procurement costs. Najid *et al.* (2024) proposed a framework for optimizing construction projects, finding that integrating BIM and data-driven scheduling techniques significantly enhances workflow efficiency. Leung & Tam (2015) demonstrated that extending daily working hours by two hours can lead to a 37.2% reduction in construction time, improving project delivery efficiency. However, research on the direct impact of BIM-driven scheduling and cost estimation on diagrid construction efficiency remains limited. Abanda *et al.* (2020) explored the use of a 4D/5D BIM-based framework for construction project scheduling risk management, emphasizing that current risk management techniques in construction suffer from fragmentation and lack of real-time assessment.

While studies have examined various aspects of diagrid structures, several critical gaps remain. Research on their dynamic and seismic performance often overlooks extreme conditions and long-term sustainability under seismic forces. Though diagrid systems are recognized for material efficiency, real-world assessments of their lifecycle sustainability and cost benefits are lacking. Despite BIM's potential for design accuracy, constructability, and safety management, its application in diagrid projects remains underexplored. Additionally, most studies focus on either structural performance or energy efficiency, failing to integrate structural, energy, and safety analyses into a comprehensive framework. Comparisons with conventional structures primarily assess isolated factors like material savings and load distribution rather than a holistic performance, safety, and sustainability comparison. Furthermore, there is a lack of research on 4D and 5D BIM applications for managing diagrid project timelines and budgets. Finally, standardized BIM-integrated project management frameworks tailored for diagrid structures are missing, despite their unique fabrication, transportation and assembly challenges.

3.0 Methodology

This study follows a structured stepwise approach to model, analyze and evaluate diagrid and conventional structures.

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- *Step 1:* Diagrid structures are designed for structural efficiency and material optimization. Steel ISLB beams are selected for their high strength-to-weight ratio, ensuring stability in tall buildings. The diagonal beam configuration eliminates vertical columns, optimizing space utilization and load transfer efficiency. A central core is incorporated to balance gravity loads and accommodate building services such as elevators and staircases.
- *Step 2:* Autodesk Revit is used to create 3D models for both diagrid and conventional structures, leveraging its BIM capabilities for accurate geometric representation.
- *Step 3:* 3D models are exported to ETABS, a software specialized in analyzing storey displacement, storey drift and structural performance under wind, seismic, and gravity loads.
- *Step 4:* Energy performance analysis is conducted using illuminance analysis and daylighting factors ensuring improved natural light penetration and reduced dependency on artificial lighting.
- *Step 5:* 4D and 5D BIM Simulations in Navisworks 4D and 5D BIM simulations are conducted in Autodesk Navisworks to enhance project planning and cost management. 4D analysis integrates construction scheduling with the 3D model, providing a visual timeline to detect conflicts before execution. 5D analysis incorporates cost estimation, improving budget tracking and resource allocation.
- *Step 6:* A Project Management Framework (PMF) is developed using PMBOK (Project Management Body of Knowledge) principles to effectively handle scheduling, resource allocation, and risk management for diagrid structures. This framework ensures that key project aspects such as scope, time, cost, and risks are well-coordinated. BIM tools play a crucial role in this process, with 4D BIM helping in project sequencing and coordination, while 5D BIM supports budgeting and cost control. By applying this approach, the framework provides a practical and efficient way to implement diagrid structures in high-rise construction, ensuring better planning, cost-effectiveness and sustainability.

This methodology combines BIM-based modeling, advanced structural analysis and project management techniques, ensuring diagrid structures are optimized for efficiency, safety and sustainability.

4.0 Data Analysis and Findings

This section provides a comprehensive evaluation of the comparative performance of diagrid and conventional structural systems in high-rise buildings. The analysis covers structural performance, energy efficiency, construction scheduling, and cost estimation. Advanced software tools, including Revit, ETABS and Navisworks, were utilized to evaluate different aspects of the structures. This study focuses on the design and analysis of a G+25 diagrid high-rise structure for mixed-use development, incorporating office and retail spaces. The project is located in Mumbai, India, which falls under Seismic Zone III, requiring a structural system that

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ensures adequate lateral stability and resilience against seismic forces. The building spans a total floor area of 150,000 sq. ft., designed to maximize functional efficiency while maintaining structural integrity.

Figure 1: Diagrid Model in Revit

Figure 2: Conventional Model in Revit

Table 1: Common Building Configuration

Plan dimension	24 m X 24 m (G + 25)
Height of typical storey	3 m
Slab thickness	150 mm
Column size	500 mm X 500 mm
Beam size	500 mm X 300 mm
Live load	3 KN/m2
Earthquake data	IS 1893 (part 1) – 2002
Type of soil	Medium soil
Safety factor	1.5
Response reduction factor	5
Type of structural systems	1) Rigid frame structural system 2) Shear wall structural system
Seismic Zone Factor	0.36

4.1 Structural analysis of diagrid and conventional structure in ETABS

The structural models were analyzed in ETABS to assess their performance under lateral and vertical loads. Both the diagrid and conventional structures were designed with

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identical floor plans and dimensions for a precise comparison. The diagrid structure consists of 25 storeys, each 3 meters high, with ISLB 600 sections used for diagonal members. A Revit model (Figure 1) was developed to visualize its framework and load distribution before exporting it to ETABS for analysis. Similarly, a conventional framed structure model (Figure 2) was created to study its column-beam arrangement and evaluate its structural efficiency against the diagrid system. The specifications of both structures are detailed in Table 1.

4.2 Storey displacement and storey drift analysis

Storey displacement and drift analyses were conducted to evaluate the lateral stability of both structural systems. Figure 3 presents the maximum storey displacement, with the X-axis representing storey levels and the Y-axis indicating lateral displacement (mm). The results show that the diagrid structure experiences 30-40% lower displacement than the conventional framed structure due to its efficient lateral load transfer mechanism. The displacement values highlight the superior lateral stiffness of the diagrid system, minimizing excessive movement and improving overall stability. Similarly, Figure 4 illustrates storey drift with storey levels on the X-axis and storey drift (unitless) on the Y-axis. The diagrid structure demonstrates significantly lower storey drift compared to the conventional system, ensuring better structural integrity under seismic and wind loads. Lower inter-storey drift reduces structural damage and enhances occupant safety.

Figure 3: Maximum Storey Displacement Graph for G+25 Buildings

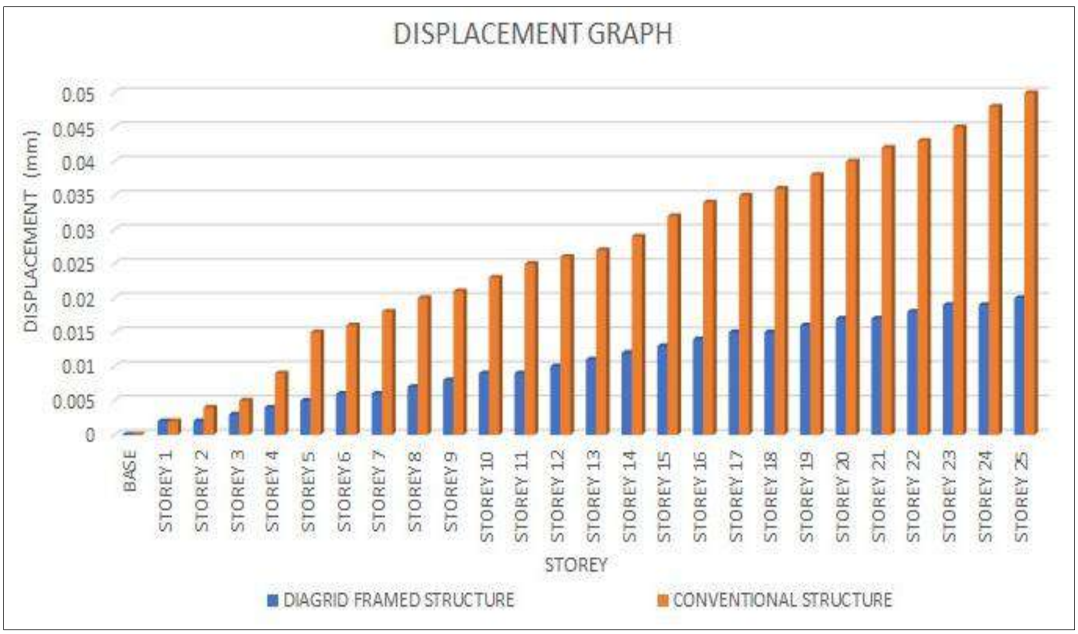
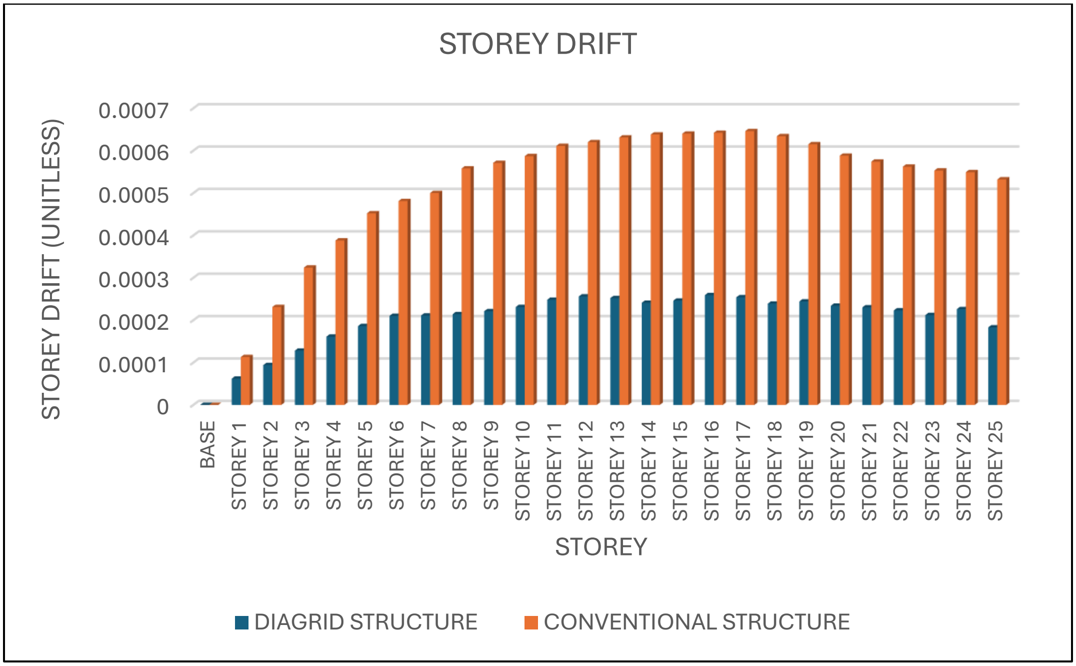


Figure 4: Maximum Storey Drift Graph for G+25 Buildings



As observed from the graph and confirmed by previous studies (Moon, 2011), effectively control lateral deformations due to their diagonally interconnected members, which enhance stiffness and load distribution. However, this study further validates these findings by conducting simulations under specific conditions relevant to high-rise construction in the Indian context, considering material properties, seismic factors, and construction methodologies unique to the region. By doing so, it provides additional insights into the practical applicability of diagrid systems beyond theoretical studies.

4.3 Energy analysis

High-rise buildings require substantial energy for lighting, cooling, and ventilation, making energy efficiency a crucial factor in sustainable design. This study evaluates the illuminance and daylight factor performance of diagrid and conventional structures using Revit Insight, focusing on natural light distribution, artificial lighting demand, and glare control. Figures 5 and 6 illustrate the illuminance analysis, measuring the amount of light reaching a surface. At 9:00 AM, the diagrid structure achieves 60% daylight coverage, reducing artificial lighting needs, while the conventional structure provides sufficient daylight in only 39% of the space. By 3:00 PM, the conventional structure attains 48% daylight exposure, surpassing the diagrid's 36%, but at the cost of higher glare levels.

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Figure 5: Illuminance Analysis Results for Diagrid Structure

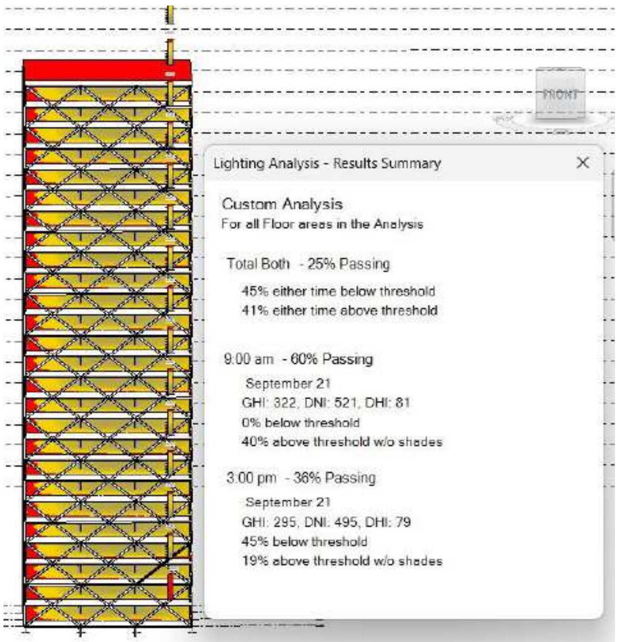

Figure 6: Illuminance Analysis Results for Conventional Structure

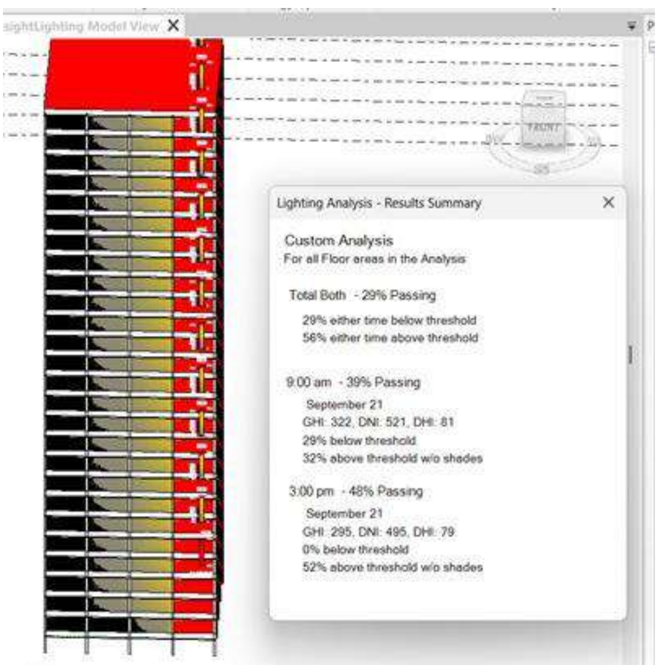

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Figure 7: Daylight Factor Results for Diagrid Structure

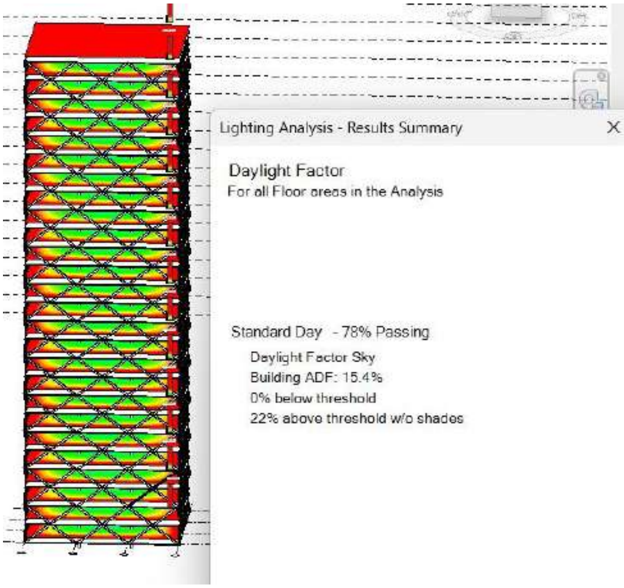
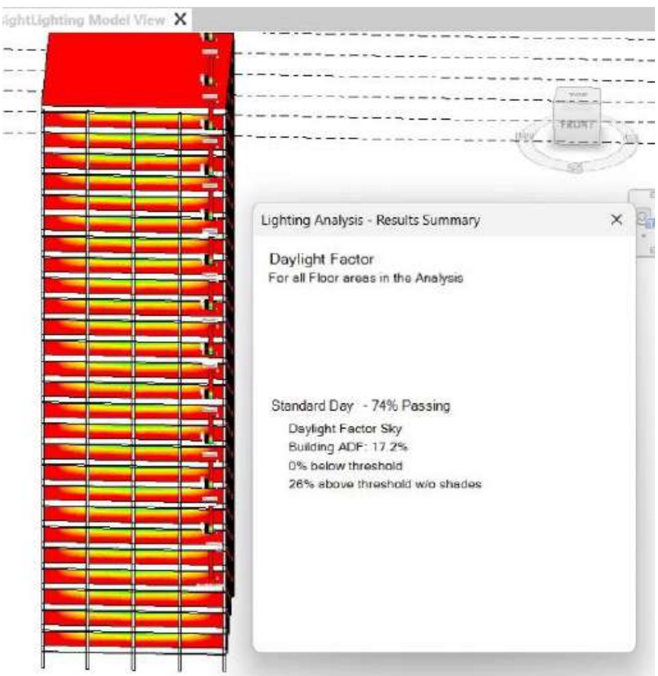


Figure 8: Daylight Factor Results for Conventional Structure



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Figures 7 and 8 compare daylight factor (ADF%), showing the conventional structure with 17.2% ADF, allowing more natural light but causing uneven distribution and glare issues, whereas the diagrid structure maintains 15.4% ADF, ensuring better light uniformity and occupant comfort. Table 2 summarizes the results, confirming the diagrid system's efficiency in space utilization, daylight uniformity, and glare reduction, while the conventional structure offers higher daylight penetration with increased glare concerns.

4.4 Scheduling and cost analysis

This study integrates Primavera P6 for advanced schedule planning and Navisworks for cost analysis and timeliner simulation to systematically evaluate the performance of diagrid structural systems against conventional column-beam frameworks.

4.4.1 4D BIM analysis (construction scheduling)

The diagrid system enables completion in approximately 2.2 years, whereas the conventional structure takes around 2.8 years. This reduction in construction time is primarily attributed to prefabrication techniques, modular assembly, and optimized structural design, which minimize on-site construction activities. Conversely, the conventional structure follows a sequential construction approach, leading to longer durations due to extensive formwork, reinforcement, and curing requirements.

Table 2: Energy Efficiency Comparison: Diagrid vs. Conventional Structures

Parameter	Conventional Structure	Diagrid Structure	Comparison
Floor Space Utilization	Less (more internal columns)	More (fewer internal columns)	Diagrid is better – More open space and flexibility in interior design.
Daylight Utilization	Higher daylight penetration but uneven	Balanced daylight distribution	Diagrid is better – More uniform daylight exposure.
Artificial Lighting Need	Higher due to glare in some areas	Lower due to controlled lighting	Diagrid is better – Requires fewer artificial lights.
Glare & Over-illumination (%)	56%	41%	Diagrid is better – Less glare, improving occupant comfort.
Morning Performance (9:00 AM)	39% Passing	60% Passing	Diagrid is better – Better light distribution in the morning.
Afternoon Performance (3:00 PM)	48% Passing	36% Passing	Conventional is better – More light exposure in the afternoon.
Daylight Factor (ADF%)	17.2%	15.4%	Conventional is better – More daylight but causes glare.
Energy Efficiency	Higher lighting energy demand	Lower lighting energy demand	Diagrid is better – Saves more energy.

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4.4.2 5D BIM analysis (cost estimation)

The Cost estimation analysis, conducted through Navisworks, combines material, labor and equipment costs with scheduling data. Findings based on the CPWD Schedule of Rates 2023 (Mumbai Region) and 2024 market rates indicate that while diagrid structures involve higher upfront costs due to prefabrication and specialized steel sections, their long-term financial benefits outweigh these expenses. Lower material wastage, reduced labor costs, and enhanced construction efficiency contribute to overall budget optimization. The cost breakdown comparison is presented in Table 3, emphasizing a total savings of ₹12 Cr in diagrid structures.

Table 3: Cost Breakdown Comparison

Cost Type	Diagrid Structure (₹ Cr)	Conventional Structure (₹ Cr)
Material Cost	33.99	27
Labor Cost	24	16.5
Equipment Cost	17.25	8.5
Total Cost	₹75.25 Cr	₹52 Cr

4.4.3 Material consumption and cost savings

The quantity take-off analysis using Navisworks reveals a 17.5% reduction in steel consumption for diagrid structures, primarily due to optimized load distribution and efficient lateral force transfer. As shown in Table 4, column steel usage is reduced by 88.5%, while beam steel consumption decreases by 80%, significantly lowering material costs. Additionally, prefabrication reduces on-site labor and installation expenses, while the simplified structural framework minimizes formwork, reinforcement, and welding costs. A 6-month shorter construction time further decreases labor, equipment, and site management costs. These factors collectively result in substantial cost savings, making the diagrid system a more economical and efficient alternative to conventional structures. Research by Moon *et al.* (2007) supports this, stating that diagrid systems reduce material usage by 15 to 20% compared to conventional structures.

Table 4: Steel Consumption Comparison between Diagrid and Conventional Structure

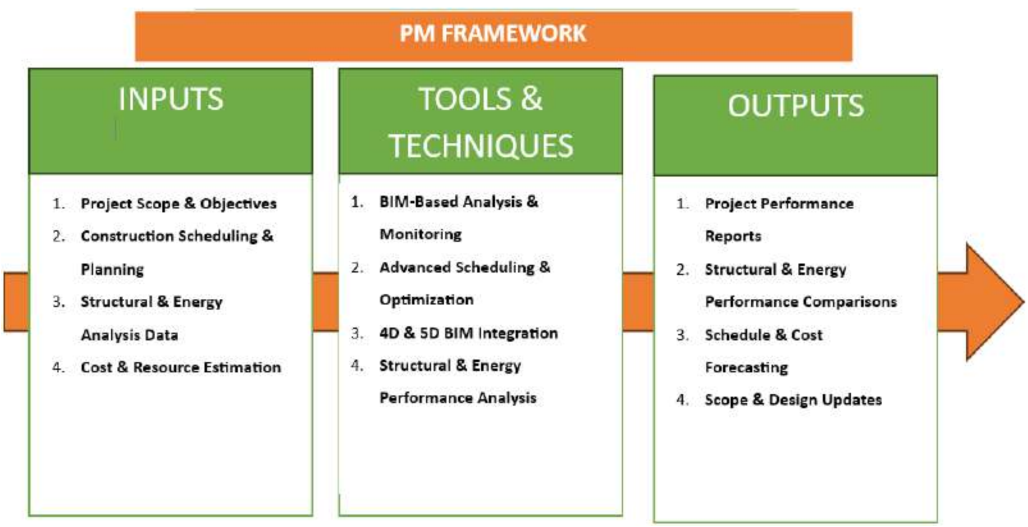
Structural Component	Conventional Steel Usage (tons)	Diagrid Steel Usage (tons)	Reduction (%)
Column Steel	98.4	11.25	**88.5%**
Beam Steel	108	21.6	**80%**
Total Structural Steel	1646.4	1357.64	**17.5%**

4.5 Project management framework

The Project Management Framework (PMF) developed in this study is inspired by the PMBOK Project Management Framework, which provides a structured approach to project governance, risk management and execution. This framework is designed to address the unique challenges associated with high-rise diagrid structures by integrating structural analysis, cost estimation and scheduling to optimize efficiency, minimize risks and enhance overall project performance. Unlike conventional buildings, diagrid structures require intricate load distribution analysis due to their unique geometry. Cost estimation becomes more complex due to prefabricated components, reduced material consumption, and variations in labor costs, while scheduling is equally challenging as the prefabricated nature of diagrid elements influences sequencing and logistics. To overcome these challenges, a structured approach is necessary, leading to the introduction of the PMF, which systematically integrates Building Information Modeling (BIM) tools like Revit and Navisworks, scheduling tools like Primavera P6, and structural analysis software like ETABS in this study.

This framework is developed based on best practices from previous studies (Abanda *et al.*, 2020), BIM-based project controls and compliance with safety regulations such as IS 1893:2016 for seismic considerations. It incorporates key input parameters essential for project execution, including project scope and objectives, construction scheduling and planning, structural and energy analysis data, and cost and resource estimation. Project scope and objectives focus on lateral stability, load distribution and energy efficiency to ensure optimal structural performance.

Figure 9: Project Management Framework (PMF)



Construction scheduling and planning are carried out using Primavera P6, employing the Critical Path Method (CPM) to effectively sequence activities and prevent delays. Structural analysis data are gathered through ETABS, which assesses lateral stability, storey drift, and

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seismic resilience, while Energy analysis data through Autodesk Insight plugin from revit software is used for illuminance and daylight performance analysis to ensure energy efficiency. Cost and resource estimation are performed using 5D BIM integration, allowing precise breakdowns of materials, labor, and equipment costs. The PMF utilizes advanced digital tools for execution, including BIM-based analysis and monitoring, advanced scheduling and optimization, 4D and 5D BIM integration, structural analysis and energy performances. BIM-based analysis and monitoring in this study are conducted using Revit, which is used for 3D modeling, parametric design and seamless integration with structural analysis tools. It helps in analysing precise material specification and detailed visualization of structural components, ensuring better coordination before construction begins. Navisworks is used for 4D and 5D BIM simulations, where 4D BIM links the construction schedule with the 3D model, allowing for better sequencing and visualization of project timelines. 5D BIM integration enables cost estimation, budget tracking, and resource allocation, helping to improve financial planning and reduce project risks. Primavera P6 is used for detailed project scheduling and optimization, ensuring that all construction activities are well-coordinated and executed efficiently. The following Figure 9 illustrates the Project Management Framework (PMF), outlining its components and workflow.

5.0 Conclusions

This study highlights the structural and economic advantages of diagrid systems in high-rise construction. The findings confirm that diagrid structures offer superior lateral stability, seismic resilience and material efficiency compared to conventional structures. Their unique geometric configuration enhances load distribution, minimizing structural deformations under lateral forces. Additionally, energy performance analysis indicates that optimized daylight penetration in diagrid buildings reduces dependence on artificial lighting, contributing to overall energy efficiency.

A key aspect of this work was the integration of 4D and 5D BIM methodologies. The 4D BIM analysis shows that prefabrication in diagrid construction significantly reduces project duration, cutting approximately six months from the overall timeline. This efficiency minimizes labor dependency and accelerates project completion. Meanwhile, the 5D BIM cost assessment indicates that while the initial cost of diagrid structures is higher (₹75.25 Cr compared to ₹52 Cr for conventional systems), long-term savings in labor costs, reduced material wastage (17.5% of reduced steel usage) and operational efficiency overcome this investment. Over the building's lifecycle, these advantages make diagrid structures a cost-effective and high-performance solution for high-rise developments.

Beyond the direct structural benefits, diagrid systems contribute to the broader objectives of sustainable and resilient urban development. Their material optimization aligns with sustainable construction practices and promoting resource efficiency. These insights

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provide a valuable foundation for architects, engineers and project managers aiming to implement innovative structural solutions in high-rise construction.

5.1 Recommendations

While this study establishes the advantages of diagrid structures, future research should explore their potential through advanced technologies. Digital twin technology can be integrated to enable real-time monitoring, predictive maintenance, and performance analysis, ensuring enhanced building efficiency and longevity. Additionally, BIM-based energy simulations should be expanded to support the development of net-zero energy buildings, reinforcing the role of diagrid structures in sustainable construction. Automation and robotics in construction present another promising avenue for improving the implementation of diagrid structures. Advanced fabrication methods, such as automated welding and modular assembly, can enhance precision and reduce onsite labor requirements. Furthermore, integrating a comprehensive risk assessment framework within BIM can improve uncertainty management, allowing for better decision-making during design and construction implementation.

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CHAPTER 56

Digital Marketing Strategies in Real Estate for Pune City

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ABSTRACT

This study looks at how digital marketing methods affect real estate sales and marketing in Pune. The research looks at how real estate developers in Pune respond to a competitive market driven by increased demand for contemporary residential homes. It focusses on how digital change has transformed buyer interaction via virtual tours, online advertising, and SEO. Furthermore, the study investigates how younger generations prioritise lifestyle amenities, which influences project designs and marketing methods. The research emphasises the necessity of a well-defined strategic approach to sales and marketing, namely the integration of digital marketing technologies to improve brand awareness, lead generation, and total income. The results indicate that using digital platforms, community interaction, and content production are essential for gaining a competitive advantage in Pune's burgeoning real estate business.

Keywords: Digital marketing; Real estate; Residential properties; Virtual tours; Online advertising; SEO; Lifestyle amenities; Competitive market.

1.0 Introduction

Pune, a fast-expanding city, offers several prospects for real estate developers in a competitive market. As individuals from many backgrounds seek higher living standards and investment possibilities, the city's real estate industry is experiencing tremendous transformation. Demand for residential properties in tier-1 cities such as Pune is on the rise, owing to the growing middle class and changing lifestyles. Younger generations place a higher value on lifestyle facilities like gyms, green spaces, and co-working spaces, which are influencing project design and marketing methods. Furthermore, digital transformation has altered how developers interact with prospective customers. Tools like virtual tours, internet ads, and SEO have become indispensable, enabling for seamless involvement and informed decisions. This changing environment emphasises the significance of a well-defined sales and marketing strategy that includes market research, establishing customer profiles, and developing appealing marketing mixes.

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Digital marketing has become indispensable, outperforming conventional approaches and providing significant advantages like brand awareness, lead creation, and greater income. Using social media, community interaction, and content production, developers may build a strong presence and attract new purchasers. Finally, internet marketing plays an important part in designing effective real estate plans, providing a competitive advantage in Pune's dynamic marketplace.

2.0 Objectives of the Study

- To increase brand awareness and visibility in the real estate sector of Pune city.
- To generate high-quality leads to real estate properties in Pune city.
- To enhance customer engagement and foster lasting relationships in Pune city.
- To improve the online presence and ranking of the real estate in Pune city.

3.0 Review of Literature

The real estate industry plays a significant role in the global economy, where effective marketing strategies are crucial for success. Bhadauria *et al.* (2024) explored the impact of digital marketing strategies on real estate sales, highlighting the effectiveness of various digital tools in improving sales performance. Their study adopted a mixed-methods approach, utilizing surveys, interviews, and case study analyses to assess the role of digital marketing in real estate. Similarly, Tomasik (2024) examined the efficiency of marketing tools used by real estate companies in Poland, emphasizing the growing importance of websites, social media, and visualization tools in marketing strategies. Her study also analyzed the incorporation of ESG principles, reflecting a shift towards environmentally conscious marketing practices, such as replacing traditional flyers with digital formats.

In line with these findings, Ammani (2019) highlighted how digital marketing has revolutionized the real estate industry, providing builders with tools to showcase properties online and gain a competitive edge. This sentiment was echoed by Atila (2022), who investigated the implementation of digital marketing strategies by PT Rizki Mandiri Barokah, revealing its significant impact on sales and customer reach. Munirah *et al.* (2022) focused on the resilience of the real estate market during the COVID-19 pandemic, demonstrating the effectiveness of internet platforms like Facebook in driving engagement and maximizing profits. Kaur (2019) discussed the transformative role of digital marketing in the real estate industry, highlighting its dual impact: enhancing service quality while challenging traditional intermediaries. Bansude *et al.* (2021) underscored the competitive nature of the real estate market and the critical role of digital marketing in promoting diverse property types, from single-family homes to luxury condos. The study emphasized how digital platforms help buyers make informed decisions, ensuring financial stability and market growth.

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Rehena *et al.* (2019) extended the discussion to urban planning, analyzing the smart city concept in Pune, which integrates digital tools for traffic management and citizen engagement. This aligns with the research by Waghulkar (2016), who explored the feasibility of online marketing for agricultural greenhouse products, illustrating the broader applicability of digital platforms across sectors. His study emphasized the Indian government's "Digital India" initiative, promoting technological adoption even in unorganized sectors like agriculture. Pawar (2020) provided insights into the real estate market in Pimpri-Chinchwad, Pune, focusing on customer preferences and the role of brokers in meeting diverse property needs. Together, these studies highlight the pervasive impact of digital marketing across industries, particularly in real estate, where technology has redefined customer engagement, sales strategies, and sustainability practices.

3.1 Research gap

While numerous studies have explored the role of digital marketing in the real estate sector both globally and within India, there is a limited focus on city-specific analyses, particularly for rapidly growing urban centers like Pune. Existing literature primarily addresses general trends, tools, and the broader impact of digital marketing strategies, but lacks in-depth investigation into how these strategies are tailored and implemented in the unique socio-economic and demographic context of Pune. There is also a noticeable gap in understanding the effectiveness of specific digital marketing tools and platforms in influencing buyer behavior and sales performance within the Pune real estate market. This study aims to bridge this gap by providing localized insights into the digital marketing practices of real estate firms operating in Pune City.

4.0 Methodology

The research methodology for the study titled "Digital Marketing Strategies in Real Estate for Pune City" employs a descriptive research design, focusing on primary data collection to analyze the effectiveness of digital marketing strategies. Data was gathered through structured questionnaires and semi-structured interviews with key personnel from 50 purposively selected real estate companies in Pune. The questionnaire covered company demographics, digital marketing practices, effectiveness, and challenges, while interviews provided in-depth insights into specific tools, strategies, and future plans. Quantitative data was analysed using statistical tools, and qualitative data was thematically examined to identify trends and patterns. Ethical considerations, including voluntary participation, informed consent, and confidentiality, were upheld throughout the study.

5.0 Statistical Data Analysis and Results Discussions

The data analysis for this study involves both reliability statistics and a one-sample t-test to ensure the validity and robustness of the findings. Reliability statistics, such as

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Cronbach's alpha, were employed to assess the internal consistency of the questionnaire responses. The one-sample t-test was conducted to evaluate the significance of digital marketing strategies' effectiveness against predefined benchmarks. This approach facilitated the identification of key trends and insights related to the impact of digital marketing in the real estate sector of Pune city.

Table 1: Reliability Statistics

Cronbach's Alpha	N of Items
.989	36

Table 2: T-Test (One-Sample Test)

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
How effectively do you think real estate companies in Pune promote their brand on social media platforms?	31.226	99	.000	3.70000	3.4649	3.9351
Real estate advertisements in Pune city are memorable and impactful.	33.368	99	.000	3.73000	3.5082	3.9518
The online campaigns of real estate companies in Pune provide clear and relevant information about their properties.	33.683	99	.000	3.80000	3.5762	4.0238
You frequently come across digital content from Pune real estate companies on various platforms.	30.864	99	.000	3.77000	3.5276	4.0124
How strongly do you agree that the current digital marketing efforts effectively increase brand awareness for real estate in Pune?	32.999	99	.000	3.79000	3.5621	4.0179
To what extent do you feel familiar with real estate brands in Pune due to their online campaigns?	28.824	99	.000	3.65000	3.3987	3.9013

The reliability analysis shows that Cronbach's Alpha value is 0.989, which indicates excellent internal consistency among the 36 items measured. This high value suggests that the items are highly correlated and reliable in assessing the construction being studied. With 100% of the cases being valid (100 out of 100), the dataset is fully complete, and no cases were excluded, ensuring the robustness of the analysis. Overall, the reliability statistics demonstrate that the scale used in this analysis is highly reliable for measuring the intended variables. The results of the one-sample t-tests indicate that participants strongly perceive the effectiveness of

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digital marketing efforts by real estate companies in Pune. For each of the five statements tested, the mean differences are significantly positive, with t-values ranging from 28.824 to 33.683 and p-values all less than 0.001, showing that these perceptions differ substantially from the test value of 0. The confidence intervals for the mean differences, ranging from 3.4649 to 4.0238, confirm that respondents consistently agree that Pune real estate companies effectively promote their brand on social media, provide clear information through online campaigns, and enhance brand awareness. These findings suggest that the online marketing strategies used by real estate firms in Pune are viewed as highly impactful, memorable, and familiarizing to the audience. The results indicate that digital marketing strategies employed by Pune-based real estate companies significantly enhance customer engagement, brand awareness, and lead generation. Strategies such as online advertising, social media presence, SEO, and personalized communication are highly effective in attracting serious buyers and fostering lasting customer relationships. The frequent use of well-designed websites, interactive social media, and responsive digital platforms further boosts visibility, trust, and customer satisfaction, contributing to long-term brand loyalty and recognition.

6.0 Conclusion

The study emphasizes the increasing importance of digital marketing in determining the success of the real estate sector in Pune. As competition grows and market conditions shift, real estate developers are strategically adopting digital tools and technologies to effectively attract and engage potential buyers. Innovative methods such as virtual property tours, targeted online advertising, social media marketing, and search engine optimization (SEO) have transformed the way properties are marketed, making the home-buying process more seamless and accessible for customers. A significant change in marketing strategy is the focus on lifestyle-oriented branding and the promotion of modern amenities. Real estate companies are no longer just selling properties; they are creating narratives around luxury, convenience, and community living.

This shift has resulted in a more personalized and customer-centric approach, where digital campaigns are customized to align with the preferences and aspirations of homebuyers. The research highlights the essential need for real estate firms to continually innovate and enhance their digital marketing strategies. By utilizing advanced data analytics, AI-driven recommendations, and immersive technologies like augmented reality (AR) and virtual reality (VR), businesses can maintain a competitive edge in Pune's evolving real estate market. Adopting these digital innovations will not only improve brand visibility and credibility but also boost sales and foster long-term customer engagement, ensuring sustained growth in an increasingly digital-first landscape.

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CHAPTER 57

Digitalization for Sustainable Construction Supply Chain Management

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ABSTRACT

The aim of this study is to research the potential impact of digitalization on improving sustainable construction supply chain management, while emphasizing the consolidation of sophisticated technology like Building Information Modeling (BIM), artificial intelligence (AI), and Internet of Things (IoT) technologies. Mixed methods are being used for conducting the study as it integrates surveys with quantitative aspects and qualitative data from key informants like material suppliers, construction companies, and policymakers. Based on the Technology Acceptance Model (TAM), the research analyzes the perceived usefulness and ease of use of digital technologies in enhancing sustainability results. Results indicate that digital technologies greatly support resource efficiency, decrease waste, and enhance supply chain transparency in construction. Nevertheless, impediments in the form of high costs of implementation, shortage of technical know-how, and regulatory issues limit extensive uptake. The research concludes that digitalization, when properly embedded, can catalyze sustainable practice but needs collective efforts from stakeholders, enabling policies, and cost-effective measures. This research adds to the existing body of knowledge on digital transformation in construction, providing applicable findings for practitioners in the industry and policymakers to close the gap between theoretical promise and practical application.

Keywords: Digitalization; Sustainable construction; Supply chain management; Building Information Modeling (BIM); Artificial Intelligence (AI).

1.0 Introduction

The building construction sector is also looking more and more towards digitalization to maximize sustainability in supply chain management, with the motive of efficiency, transparency, and environmental accountability. Building Information Modeling (BIM), blockchain, artificial intelligence (AI), and the Internet of Things (IoT) are being implemented to streamline logistics, minimize waste, and maintain adherence to environmental norms. BIM, especially, has been extensively researched in terms of enhancing project transparency, collaboration, and utilization of resources, with blockchain promoting transparency and traceability of material procurement.

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AI and IoT are also being increasingly adopted for predictive analysis and real-time monitoring, respectively, though additional empirical research remains necessary to determine their long-term payoffs and return on investment.

Although these digital technologies have a theoretical potential, their practical adoption is still in its infancy in the face of obstacles like capital-intensive expenditure, absence of pilot models, and differences in digital infrastructure, particularly in developing economies. The Technology Acceptance Model (TAM) offers an effective model in explaining the use of these technologies, focusing on perceived usefulness and ease of use. Yet, existing literature lacks empirical studies on the incorporation of digitalization into sustainability evaluation techniques such as Life Cycle Assessment (LCA) and the effect of stakeholder coordination, policymaking, and cost-effectiveness. This study tries to bridge such gaps by constructing a TAM-based model containing sustainability-related variables, providing not only theoretical insights but also actionable advice for construction companies.

1.1 Objectives

The research objectives are to identify and measure the role of digitalization and sustainability in construction supply chain management, evaluate the barriers and enablers of digital adoption, and assess the impact of technologies like BIM, AI, and IoT on resource efficiency and environmental compliance. This study aims to bridge the gap between theory and practice, providing insights into how digitalization can enhance sustainability in the construction industry.

2.0 Literature Review

Digitalization plays a pivotal role in enhancing sustainable construction supply chain management by integrating advanced technologies that improve efficiency, transparency, and overall performance. The adoption of digital tools such as Building Information Modeling (BIM), blockchain, and artificial intelligence (AI) facilitates better decision-making processes and fosters collaboration among stakeholders, ultimately leading to more sustainable practices in the construction industry. (Anna Lisa Junge *et al.* 2020) highlight the potential of digital transformation technologies (DTT) to enhance energy efficiency, optimize logistics resources, and reduce transport distances, positively impacting environmental and social sustainability.
Mudigonda *et al.* (2022) emphasize the construction industry's shift toward sustainability through green initiatives and supply chain management (SCM), noting that while suppliers believe they are making sufficient environmental efforts, consumers perceive these efforts as inadequate. The study also identifies high initial investments and a lack of proven models as barriers to sustainable practices. (Koctas-Cotur *et al.* 2024) explore the integration of Industry 4.0 into construction supply chains (CSCs), identifying client collaboration through ICT (BIM) as a critical factor during the design phase. (Frangopol *et al.* 2024) discuss the importance of

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resilience, risk, and sustainability in ensuring the functionality of structures under multiple hazards, emphasizing the need for probabilistic life-cycle frameworks and risk-based decision-making. (Maria Teresa Henriques Alves Ferreira *et al.* 2022) propose integrating sustainability analysis tools like Life Cycle Assessment (LCA) and Carbon Footprint with BIM to optimize building performance and reduce environmental impacts.

Androod *et al.* (2024) reviews the positive impact of digitalization on supply chain sustainability, noting enhanced transparency and real-time data exchange, while also identifying challenges and research gaps. (Lu *et al.* 2024) systematically reviews the application of digital technologies (DTs) like IoT and AI in construction sustainability, identifying key areas such as integration, optimization, and monitoring. (Stroumpoulis *et al.* 2024) highlights the strategic role of digital transformation and information systems in advancing sustainable supply chain management, emphasizing the need for comprehensive sustainability strategies powered by Industry 4.0 technologies. (Sundarakani *et al.* 2024) discuss the challenges and opportunities of digital transformation in supply chain management, particularly in the post-COVID-19 era, and propose a framework to support the logistics industry during disruptive technological changes. Collectively, these studies underscore the transformative potential of digitalization in achieving sustainable construction supply chain management while addressing challenges and identifying future research directions.

3.0 Research Methodology

The research methodology for this study employs a mixed-methods approach, combining quantitative and qualitative techniques to explore the role of digitalization in sustainable construction supply chain management. Primary data was collected through structured surveys targeting key stakeholders, including construction firms, material suppliers, and technology providers, while secondary data was gathered from existing literature and industry reports. A purposive sampling method was used to ensure responses from experts in the field, with a minimum sample size of 100. Quantitative data was analyzed using descriptive statistics and visualization tools like SPSS/Excel, while ethical considerations such as informed consent, anonymity, and data security were strictly adhered to. This approach ensures reliable and valid insights into the adoption and impact of digital technologies on sustainability in construction supply chains.

4.0 Data Analysis

The data analysis section examines the relationship between digitalization and sustainable construction supply chain management using statistical methods. It evaluates key variables such as technology adoption, sustainability performance, and supply chain efficiency to identify trends and insights.

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4.1 Factor analysis

Since values over 0.7 are regarded acceptable for Kaiser-Meyer-Olkin (KMO) sampling adequacy, the sample size is appropriate for factor analysis at 0.797. Bartlett's Test of Sphericity is significant (p =.000), with an estimated chi-square value of 547.288 and 120 degrees of freedom, indicating that the correlation matrix is not an identity matrix and that component analysis is possible. The findings support factor analysis of the data.

Table 1: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.797
Bartlett's Test of Sphericity	Approx. Chi-Square	547.288
	df	120
	Sig.	.000

Source: Compiled by authors

According to the "Total Variance Explained" table, the first four components have eigenvalues larger than one and explain 57.886% of the cumulative variance, which is regarded adequate for most social scientific research.

Table 2: Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.602	35.010	35.010	5.602	35.010	35.010	3.179	19.866	19.866
2	1.469	9.181	44.191	1.469	9.181	44.191	2.304	14.398	34.264
3	1.149	7.179	51.370	1.149	7.179	51.370	2.213	13.829	48.093
4	1.043	6.517	57.886	1.043	6.517	57.886	1.567	9.793	57.886
5	.996	6.222	64.109						
6	.876	5.477	69.585						
7	.756	4.722	74.308						
8	.704	4.399	78.707						
9	.673	4.207	82.914						
10	.568	3.549	86.463						
11	.498	3.114	89.576						
12	.490	3.060	92.637						
13	.388	2.422	95.059						
14	.360	2.247	97.306						
15	.226	1.414	98.720						
16	.205	1.280	100.000						

Source: Compiled by authors

The first eigenvalues reveal that Component 1 accounts for 35.010% of the variance, followed by Components 2, 3, and 4, which contribute 9.181%, 7.179%, and 6.517%,

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respectively. After extraction and rotation, the variation explained by each component is redistributed as follows: Component 1 accounts for 19.866%, Component 2 for 14.398%, Component 3 for 13.829%, and Component 4 for 9.793%. The rotation contributes to a simpler and more understandable structure by dispersing variation more equally throughout the components. Overall, the four components give a significant representation of the underlying structure of the data. Four factors representing different sustainability methods are shown in the Rotated Component Matrix. Component 1 is highly linked to sustainable product demand, government regulations, lifespan cost analysis, and waste management, suggesting regulatory and consumer-driven sustainability. Component 2 emphasises social and operational sustainability via community participation, worker health and safety, and post-occupancy assessment. Sustainability metrics, carbon footprint, and energy efficiency characterise Component 3, emphasising data-driven sustainability approaches. Finally, Component 4 emphasises environmental innovation in sustainability by linking renewable energy utilisation and sustainable material prioritisation. Varimax's rotation approach simplifies the structure, assuring interpretability and meaningful variable grouping. The report highlights four sustainability pillars: legislative and consumer- driven activities, social and operational standards, quantitative measures, and environmental innovation.

Table 3: Component Matrix[a]

	Component			
	1	2	3	4
@2Consumersareincreasinglydemandingsustainableproducts	.760			
@4Governmentregulationsshouldenforcetheuseofsustainable	.748			
@10Alifecyclecostanalysishasbeenconductedtoensurethe	.666			
@1Usingsustainablematerialscansignificantlyreduceenvironm	.657			.314
@9Acomprehensivewastemanagementplanisinplacethatinclud	.530			
@3Theconstructionindustryismakingsignificantprogresstowa	.523		.522	
@15DigitaltoolssuchasBuildingInformationModelingBIM	.453	.364		.379
@14Engagementwithlocalcommunitieshasoccurredtounderstand		.809		
@13Workerhealthandsafetymeasuresarestrictlyenforcedwit		.737	.334	
@16Apostoccupancyevaluationisplannedtomonitorthebuildi		.668		
@11EnergyefficienttechnologiessuchasLEDlightingandeffi	.321	.323	.300	
@5Ourorganizationusesspecificmetricstomeasuresustainabil			.822	
@6Sustainabilitymetricssuchascarbonfootprintandenergys			.717	
@12Localsuppliersareprioritizedtoreducetransportationemi			.541	.357
@7Renewableenergysourcessuchassolarorwindareutilized				.856
@8Theprojectprioritizessustainableorrecycledmaterialsin	.376			.461
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.				
a. Rotation converged in 6 iterations.				

Source: Compiled by authors

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5.0 Conclusion

This research identifies the revolutionary capability of digitalization in attaining sustainable construction supply chain management. Through the application of technologies like BIM, AI, and IoT, the construction sector can greatly enhance resource efficiency, lower environmental footprint, and increase transparency. Nevertheless, the implementation of these technologies is hindered by high costs, technical challenges, and regulatory loopholes. The results highlight the necessity of cooperation among stakeholders, friendly policy environments, and cost- efficient approaches to bypass these barriers. The study stresses the significance of integrating digital transformation with sustainable objectives, providing practical suggestions for industry professionals and policymakers alike. Through solving these issues, the construction industry can use digital technology to gain long-term sustainability, lower carbon emissions, and increase efficiency in operations, thus making a contribution towards world environmental and economic objectives.

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CHAPTER 58

Digitally Integrated Agile Project Management and Lean Construction

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ABSTRACT

Inefficiency, resource waste, and inability to adapt to changing project needs have long dogged the building industry. This paper addresses these issues using Lean Construction (LC) and Agile Project Management (APM) ideas coupled with digital technologies. Lean's focus on cutting waste and optimising resource use paired with agile methods marked by incremental development and responsiveness offer great promise to transform project delivery. This study is to identify enabling technologies and key enablers, evaluate their impact on important project outcomes like cost, schedule, and customer satisfaction, thereby facilitating the adoption of Agile and Lean ideals via web-based platforms. By combining IoT, Big Data Analytics, and ERP systems, the research seeks to close the differences in project management techniques in multi-project settings. The research uses a mixed-method approach, looking at qualitative results from industry practitioners in addition to quantitative results from construction practitioners, therefore developing an integrated framework. This system will improve management of employees, stakeholder communication, and flexibility of projects as well as ease administrative work with automation. The study places an emphasis on continuous feedback loops, real-time teaming technologies, and early stakeholder engagement in order to facilitate alignment and successful decision-making. The conclusions hope to offer concrete approaches towards utilizing hybrid Lean-Agile methods in networked digital building construction projects with the overall aim of achieving more sustainability, responsiveness, and project performance. The conclusions are hoping to advance the construction sector towards more efficient and competitive practices through embracing digital innovations.

Keywords: Agile Project Management (APM); Lean Construction (LC); Digital integration; Resource optimization; Stakeholder collaboration.

1.0 Introduction

Project management is meant to provide satisfaction to all stakeholders through efficient and effective project implementation. It calls for a balance between organizational and

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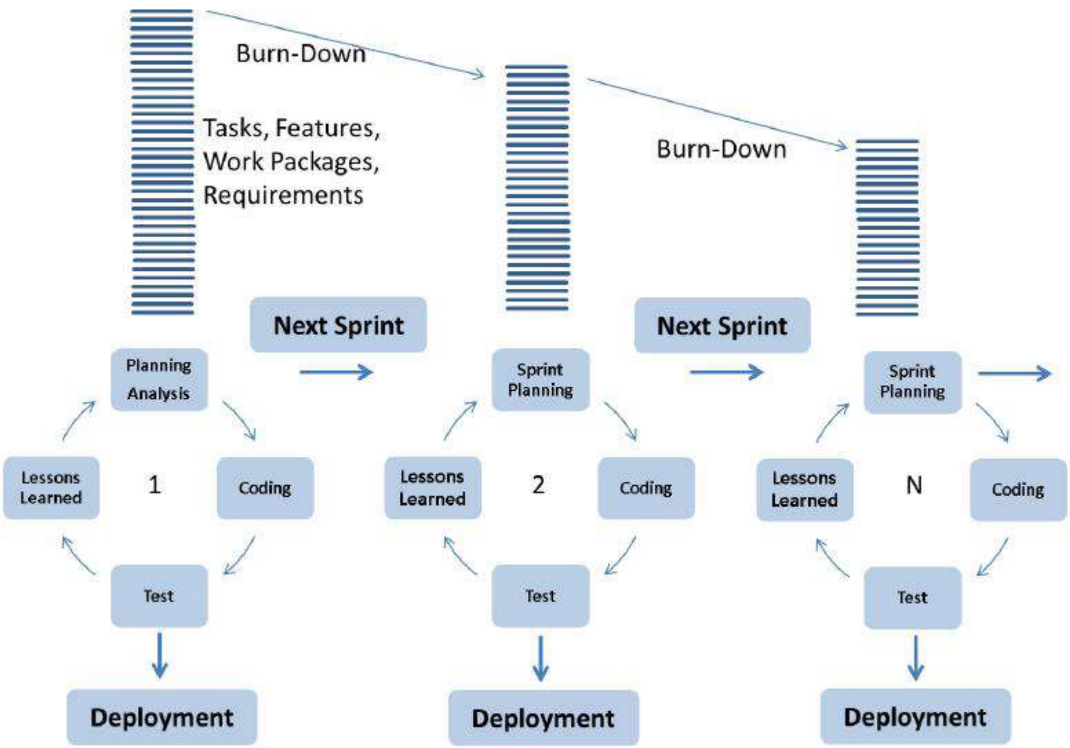
project-based outlooks, keeping bureaucracy to a minimum, and aligning management practices with the needs of projects. The strategy must be lean, agile, and target-oriented, with an emphasis on flexibility and communication. Agile construction is focused on continuous improvement, collaboration, and responsiveness through the division of big projects into small pieces, customer feedback-based prioritization. Agile applies iterative incremental sprints, whereby teams finish work, show progress, and respond quickly. It balances planning and documentation with flexibility, in line with Project Management Institute methodologies. Agile is ideally suited for continual product development and on-time project. Agile's iterative development cycle allows teams to adjust and respond to changing project demands quickly, fostering continuous collaboration and project optimization."

Figure 1: Iterative Nature of Agile



Lean is a quality improvement and waste reduction philosophy that began in manufacturing. It intends to improve the working environment by eliminating waste, which in turn improves quality, production time, and cost. Waste, in project management, includes excess documentation, planning, meetings, revisions, and multitasking, all of which Lean PM intends to minimize. While Agile aims to maximize software development, Lean is intended to enhance

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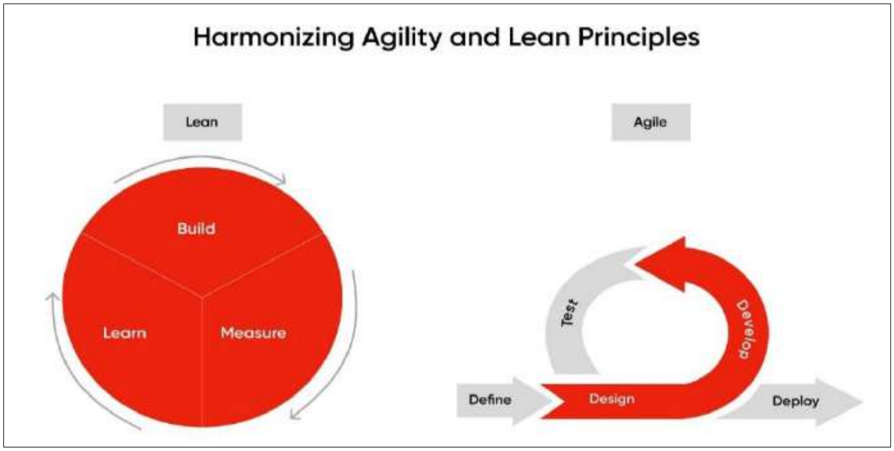
end-to-end manufacturing value streams. Lean tools such as Value Stream Mapping, A3 Thinking, and Kanban are used to manage and prioritize work.

History of lean construction: The roots of Lean principles date back to the early 20th century, as in the case of Henry Ford's Model T and the building of the Empire State Building, which was finished ahead of schedule and below budget. Post-WWII, Toyota developed Lean in manufacturing, and since then it has found usage in construction, for example, in the fast 15-day construction of the T-30 Hotel in China.

Integration of agile and lean: Combining Agile and Lean methods creates a robust project management framework that unites the flexibility of Agile with the focus on efficiency found in Lean. Agile's iterative development and feedback from customers complement Lean's principles of continuous improvement and elimination of waste. Such integration increases overall project productivity, simplifies process, and speeds up delivery. By integrating these approaches, teams can react faster to changing requirements and foster a culture of ongoing improvement, thus delivering projects on time and to client requirements.

Figure 2: Harmonizing Agility and Lean Principles



An integrated strategy combining Lean and Agile ideas would be more beneficial for project management. Agile's iterative methodology lowers the time to market, enables quick reaction to changing needs, and promotes better collaboration and communication by means of which changing needs are met. Lean concepts help to improve efficiency by cutting waste and streamlining processes. Two pairings increase project transparency, risk management, and stakeholder satisfaction. Simplified procedures, shortened lead times, and a culture of constant development help project managers to enable teams to produce high-quality products with more speed and responsiveness, thereby matching projects with project goals and beyond client expectations.

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This research explores the integration of Lean Construction (LC) and Agile Project Management (APM) with digital technologies to enhance project outcomes, such as cost, schedule adherence, and client satisfaction. By combining IoT, Big Data Analytics, and ERP systems, the study seeks to bridge gaps in traditional construction project management and optimize performance through hybrid methodologies. The study also develops an integrated framework for the adoption of these technologies, offering practical guidance for digital transformation in construction projects.

1.1 Research problem

While Agile and Lean methodologies have demonstrated efficiency in sectors like software development and manufacturing, their application in the construction industry remains under-explored, particularly in digital integration. Current research lacks a framework to integrate these methods effectively with digital tools, especially in multi-project construction settings. This study addresses these gaps by investigating the enablers and barriers to digital integration, the impact of digital tools on project performance, and the adoption challenges within the construction industry.

Classical project management approaches are often challenged to fit the dynamic needs and dangers connected with building projects in the modern changing and competitive corporate environment. Agile Project Management (APM) is preferred in different disciplines including software development because of its iterative character and flexibility. Such ideas have not been embraced by the building sector for very long. Likewise, Lean Construction (LC) ideas have shown promise for increasing project success generally, lowering waste, and driving efficiency. Still, there is much to learn about the construction sector adopting Agile in line with Lean ideas.

1.2 Objectives

- To quantify the impact of digital integration on project performance, specifically cost, time, and client satisfaction.
- To identify key digital tools that significantly improve project management outcomes in construction settings.
- To identify key digital tools and technologies that support the integration of Agile and Lean principles in construction projects.
- To evaluate the impact of digital integration on project performance outcomes, such as cost, time, and client satisfaction.

2.0 Literature Reviews

Over the last several years, Lean and Agile methods of building project management have attracted increasing attention. Different studies have looked at the reciprocal interactions of these strategies and their use to improve project effectiveness.

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Malla (2024) investigated the hybrid Lean–Agile system (HLAS) used in the building sector and proposed a conceptual model using Interpretive Structural Modelling (ISM). Project management tools, joint data platforms, and educational teams were among the most important facilitators of successful integration she came across. Especially in poorer nations, this paradigm provides a methodical approach that could help HLAS be implemented. Emphasising Last Planner System (LPS) and Scrum integration, Hamerski *et al.* (2024) also combined Lean Production and Agile Project Management within multi-project setups. Among the new techniques helping to close client-side project management with supplier-side manufacturing oversight gaps are integrated look-ahead planning sessions and Scrum for elimination of limitations.

Badran *et al.* (2024) investigated Lean and Agile project management in the building sector to see how each method influenced important performance criteria including time, money, quality, customer satisfaction, innovation, and responsiveness. Their results showed that whilst LPM enhanced quality, cost, and customer happiness, APM raised innovation and responsiveness at the price of cost performance. This acknowledges the complex use of many strategies based on the particular project objectives. Likewise, Pitagorsky (2006) argued on Agile and Lean project management concepts in support of flexible and expandable approaches addressing project-specific features and compliance standards. Raji *et al.* (2021) examined how Lean and Agile approaches may be more easily combined with digital technologies—especially in Industry 4.0 technologies. Their research utilising ISM revealed significant drivers of Lean and Agile approaches in contemporary building management as Cyber-Physical Systems, IoT, Cloud Computing, and Big Data Analytics. This link highlights how digital technologies increase the efficiency of Lean and Agile methods, therefore improving their use.

Sohi *et al.* (2016) also looked at Lean and Agile methods of complexity management in construction projects, finding that the approaches significantly assisted to lower project complexity, hence enhancing project performance in terms of time and cost saving. Cruz *et al.* (2020) methodically compiled the corpus of evidence in comparison of traditional, Lean, and Agile project management approaches. They concluded that Agile methods, despite Lean's well-known advantages, are more widely used; Lean still finds some challenges in acceptance. Research like those by Kashikar *et al.* (2016) and Chathuranga *et al.* (2023) has underlined in construction's adoption of Agile and Lean challenges like firmly rooted old procedures and a lack of training.

These challenges restrict the whole use of these approaches even if they may increase the delivery and efficiency of projects. Regarding project complexity, Sohi *et al.* (2016) also addressed the tight links between Lean and Agile approaches, therefore confirming both methods as successful tools for enhancing project outcomes.

Research such as that conducted by Lima *et al.* (2023) underlines the importance of socio-technical models and critical soft skills (CSSs) in applying Lean Project Management throughout the scenario of Industry 4.0, therefore suggesting a sustainable project management

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model. Conversely, Kineber *et al.* (2024) focused on the main success factors (CSFs) involved in the Agile Project Management (APM) deployment on residential construction projects across Nigeria and found dynamic project optimisation to have the greatest influence on APM adoption.

Additionally under consideration is Lean Thinking's spread to fields outside of construction. Focussing on waste reduction and project efficiency—as in construction—Rodrigues *et al.* (2023) proposed a conceptual framework for Lean Thinking adoption in IT project management. Dong *et al.* (2024) provided further analysis on Agile Project Management, which differs from traditional project management approaches and software-specific Agile methodology. Pasławski *et al.* (2021) investigated how Lean and Agile ideas may be used in ready-mix concrete supply in construction, therefore demonstrating that while somewhat different, both approaches can help to improve project performance by means of more flexibility and time savings. Finally, AbuKhamis *et al.* (2022) investigated Lean and Agile's potential to solve project management issues in non-profit organisations, suggesting that a blended strategy would improve monitoring and project objective alignment.

These studies taken together show Lean and Agile approaches' growing importance in raising construction project performance and efficiency. Effective implementation in different building environments depends on the changing confluence of digital technologies, the mapping of key enablers, and the need for properly tailored methods depending on project goals, notwithstanding some implementation hurdles.

Table 1: Comparative Table for Agile vs Lean

Criteria	Agile	Lean
Flexibility	High (iterative cycles and continuous feedback)	Moderate (focus on process optimization)
Waste Reduction	Moderate (focus on customer collaboration)	High (emphasis on waste elimination)
Client Satisfaction	High (adaptation to customer feedback)	High (efficiency leads to cost savings)
Time Management	Flexible (based on iterations)	Strict (focus on schedule adherence)

3.0 Methodology

Using a mixed-methods approach, the research looked at how digital technologies in the building industry combined with Agile Project Management and Lean Construction ideas. Beginning with exhaustive literature research to create the theoretical underpinnings and current use of Agile and Lean techniques within construction, the approach was divided into many tiers with a focus on digital inclusion. This step helped to identify important ideas, present models, and areas of study lacking. The next phase was qualitative data gathering via semi-structured interviews with project managers, building professionals, and digital platform specialists. These conversations provided understanding of the practical difficulties and benefits of combining lean

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and Agile ideas with digital technology. Furthermore, examined were in-depth case studies of building projects using online platforms that included these concepts to pinpoint best practices and lessons discovered. A sample size of 105 respondents was chosen to ensure a balanced representation across different roles and experience levels within the construction industry.

This size provides adequate statistical power for detecting meaningful differences in digital tool adoption and Agile-Lean integration. Semi-structured interviews were conducted with 15 construction project managers and digital technology experts. Each interview lasted approximately 45 minutes and was guided by a protocol focused on the challenges and benefits of integrating Lean and Agile methodologies with digital tools in construction. A survey form issued to 105 team members and construction project managers comprised the quantitative data collecting tool.

The poll gathered information on the acceptance, efficiency, and challenges of merging lean and Agile approaches with digital technologies. Data analysis using descriptive and inferential statistical techniques sought trends, correlations, and patterns. By means of a study of results from both quantitative and qualitative data, a direction for the use of digital technologies within Agile and Lean project management was derived.

The direction took the shape of optimal project execution techniques and rules to equip team members on digital platforms. Case studies were selected based on projects that had implemented Lean and Agile methodologies along with digital technologies, providing a diverse set of real-world examples to support the findings. Projects were chosen across different geographical locations and scales to ensure comprehensive coverage of the industry. Focus group talks with project managers and practitioners helped to validate the guideline so that it would be useful and relevant. Ethical standards were maintained throughout the study by means of informed permission from every participant, therefore ensuring anonymity and voluntary involvement.

4.0 Data Analysis

The chapter on data analysis assesses the research results of applying Agile Project Management and Lean Construction with modern digital technologies in the construction industry. Both quantitative and qualitative data were examined. Quantitative analysis employed SPSS software for descriptive statistics (mean, standard deviation, percentage) and inferential methods (correlation, regression, ANOVA) to establish trends and relationships. Qualitative data from interviews and case studies were analyzed thematically to identify prominent themes, issues, and best practices for digital integration. Such analyses give an insight into what drives the adoption and success of Agile and Lean approaches in construction and are used as the basis for the digital integration framework suggested.

The majority of respondents are aged 35-44 years (40%) and 45-54 years (39%), together making up 79% of the sample, indicating a focus on middle-aged participants. Smaller

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groups include those aged 25-34 years (13.3%), under 25 years (1.9%), and 55+ years (5.7%). The 36.2% of neutral responses indicate that a significant portion of respondents remain unsure about the effectiveness of digital tools in Lean and Agile implementation.

Figure 3: Age

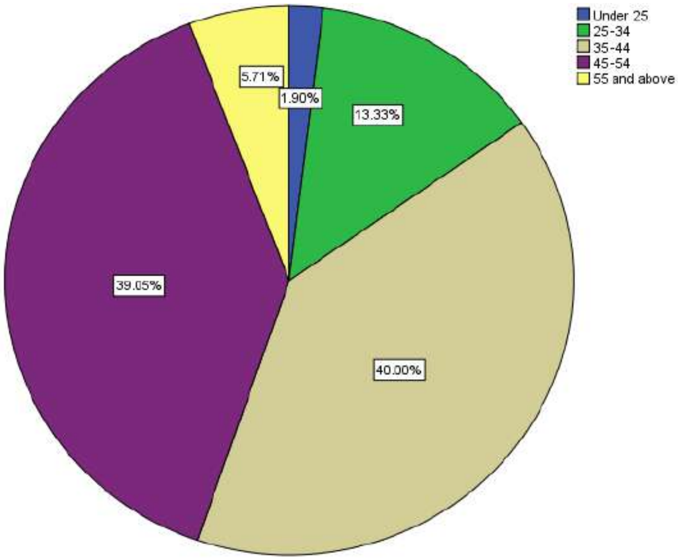
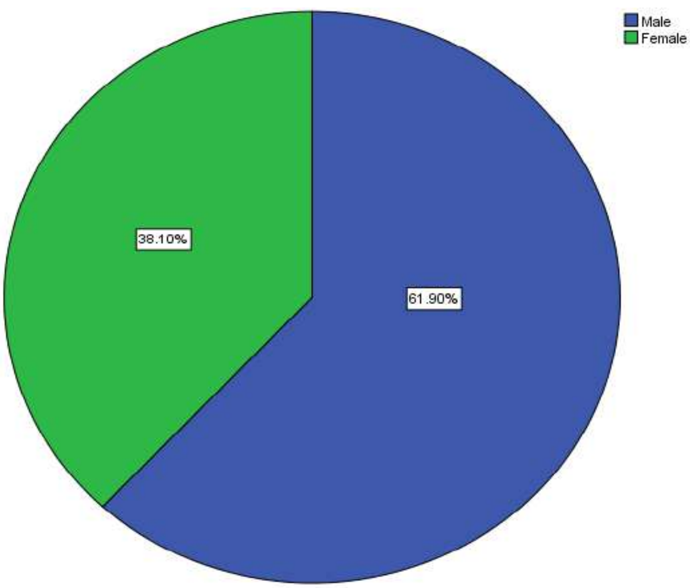


Figure 4: Gender



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This could be due to varying levels of experience with digital tools or differences in organizational readiness. Further investigation into this neutral response group may offer insights into the barriers hindering full adoption.This shows a concentration of respondents in mid-career stages, with limited representation from younger and older age groups. The gender distribution of respondents shows that males constitute the majority, representing 61.9% of the total sample, while females make up 38.1%. This indicates a notable gender imbalance in the study, with male participants being more prominent than females. The representation suggests that the research context or subject matter may involve higher participation or relevance for males, although a significant proportion of females are also included, ensuring some level of diversity in the perspectives gathered. Nearly half of the respondents (49.5%) have 4-6 years of experience, and 33.3% have 7-10 years, indicating a focus on mid-level experience. Smaller proportions have 1-3 years (10.5%), more than 10 years (5.7%), or less than 1 year (1.0%). This suggests the study captures insights primarily from those with moderate to significant experience. Most respondents work in semi-urban areas (36.2%), followed by rural (24.8%) and urban (21.0%) locations. A smaller proportion (18.1%) handle global projects. This shows a diverse sample with strong representation from semi-urban and rural areas, while also including insights from urban and international projects.

Figure 5: Years of Experience in Construction Industry

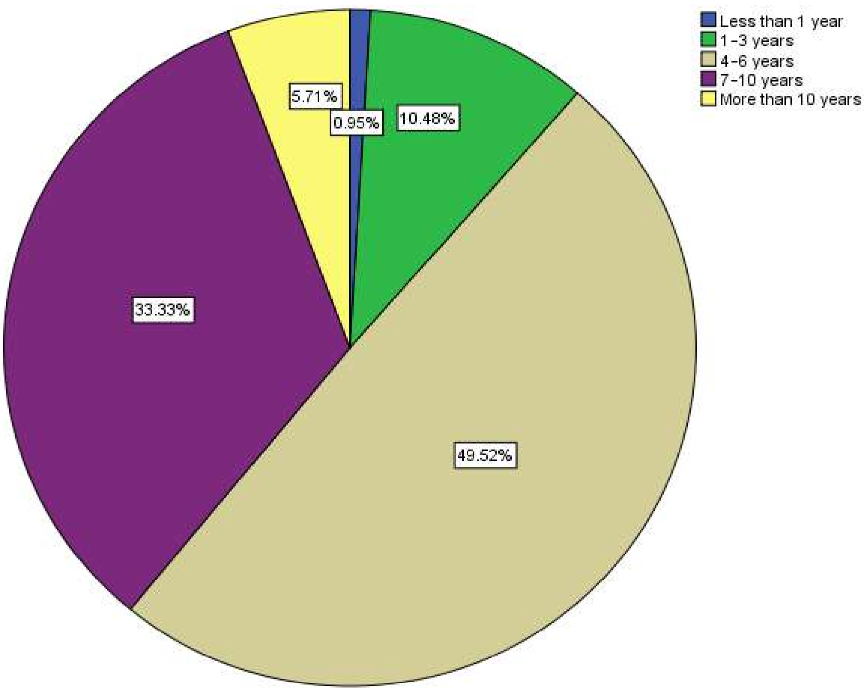

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Figure 6: Geographical Location of Projects

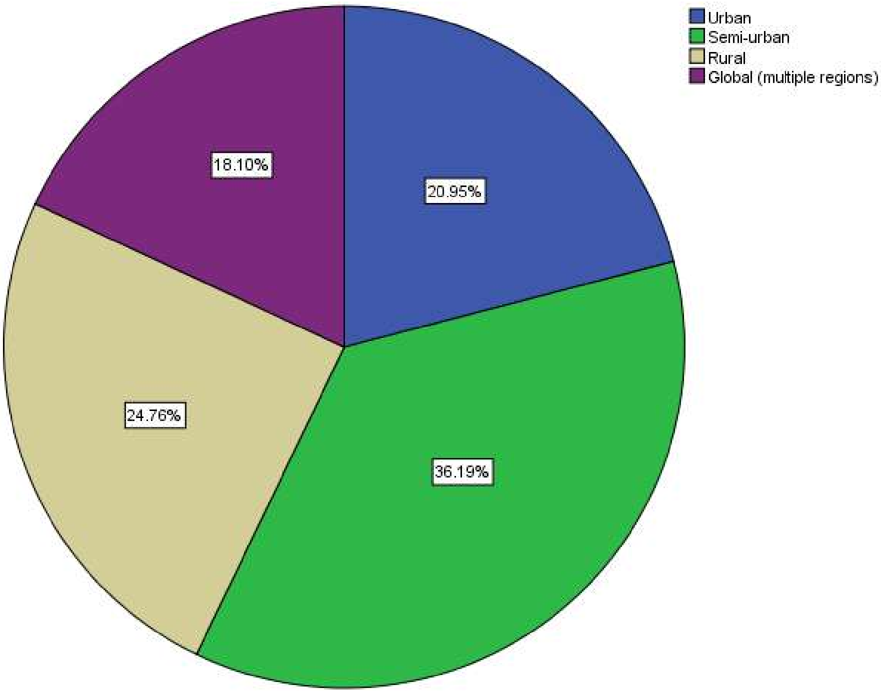

Table 2: Effectiveness of Digital Implementation in Agile and Lean Principles

Options	Frequency	Percent
Strongly Disagree	3	2.9
Disagree	4	3.8
Neutral	38	36.2
Agree	45	42.9
Strongly Agree	15	14.3
Total	105	100

Most participants have a positive view on the digital implementation of Agile and Lean principles, with 42.9% agreeing and 14.3% strongly agreeing. However, 36.2% remain neutral, and a small minority (6.7%) disagree, indicating some mixed perceptions or uncertainties. Overall, there is a favorable outlook, with potential for improvement or wider adoption.

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Figure 7: Effectiveness of Digital Implementation in Agile and Lean Principles

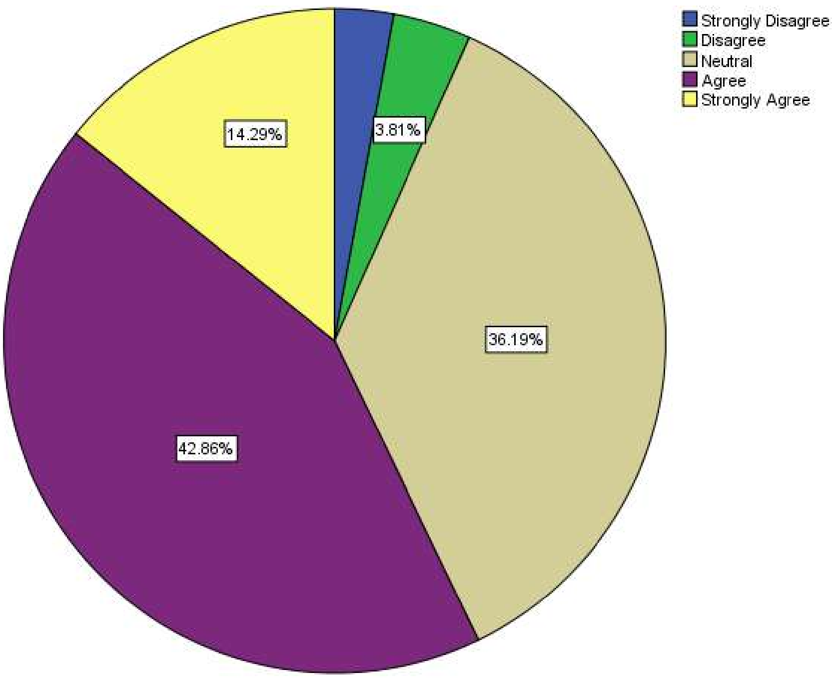

Table 3: Impact of Digital Tools on Simplifying Project Management Processes

Options	Frequency	Percent
Strongly Disagree	1	1
Disagree	4	3.8
Neutral	30	28.6
Agree	46	43.8
Strongly Agree	24	22.9
Total	105	100

The responses regarding the use of digital tools for Agile and Lean principles in simplifying project management processes show a generally positive outlook. A majority of respondents, 43.8%, agree, and 22.9% strongly agree that these tools have made project management processes easier. However, 28.6% remain neutral, indicating uncertainty or varying levels of experience with the tools' impact on project management. A small minority, 3.8%, disagree, and only 1.0% strongly disagree, suggesting that while most participants recognize the benefits of digital tools, there are a few who either haven't experienced the simplification or find the tools ineffective in their context

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Figure 8: Impact of Digital Tools on Simplifying Project Management Processes

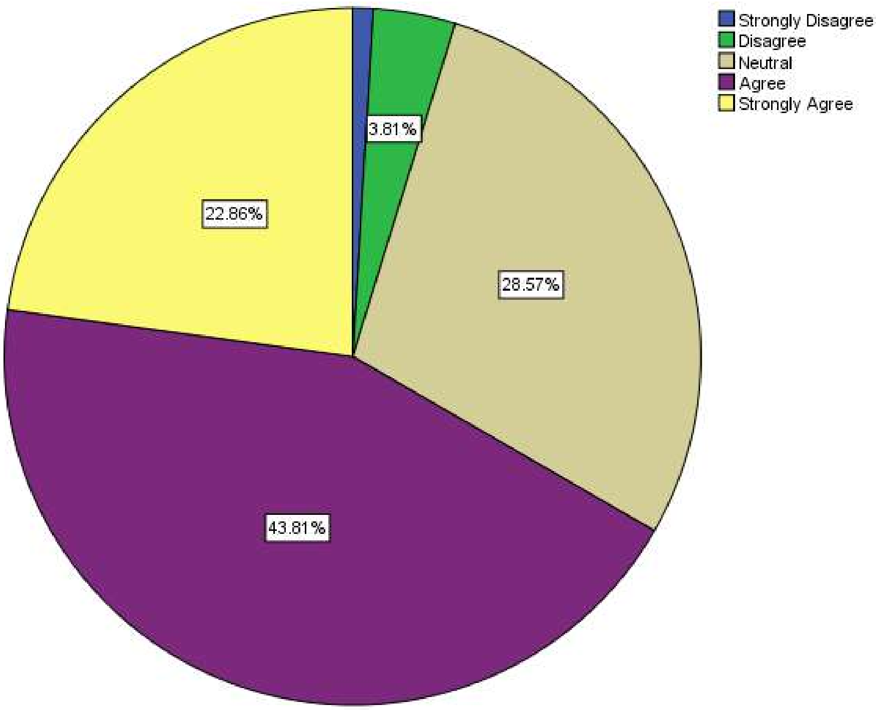

Table 4: Reliability Statistics

Cronbach's Alpha	N of Items
.745	26

The reliability statistics show that the Cronbach's Alpha value is 0.745, based on 26 items. This indicates a moderate level of internal consistency for the scale used in the study, as a Cronbach's Alpha value above 0.7 generally suggests that the items within the scale are reliably measuring the same underlying construct. The value of 0.745 is considered acceptable for research purposes, signaling that the items in the survey are sufficiently consistent to produce reliable results. The one-sample test results show that all the variables, including age, gender, educational qualification, role in the organization, years of experience, familiarity with Agile and Lean principles, level of digital competence, type of projects handled, organization size, and geographical location of projects, have statistically significant mean differences from zero. The t-values range from 20.10 for familiarity with Agile and Lean principles to 43.76 for years of experience in the construction industry, with all p-values being less than 0.001, indicating strong statistical significance.

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This suggests that the mean values for all these variables are significantly different from zero, confirming that the sample reflects meaningful data on each aspect. The 95% confidence intervals for each variable further support the reliability of these findings, as they show positive ranges for the mean differences, which indicates that the values are consistently above zero across the sample.

Table 5: One-Sample Test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
1. Age	40.133	104	.000	3.33333	3.1686	3.4980
2. Gender	29.000	104	.000	1.38095	1.2865	1.4754
3.Educational Qualification	42.865	104	.000	2.78095	2.6523	2.9096
4.Role in the Organization	32.033	104	.000	2.56190	2.4033	2.7205
5.Experience in Construction	43.763	104	.000	3.32381	3.1732	3.4744
6.Familiarity with Agile and Lean Principles	20.098	104	.000	2.52381	2.2748	2.7728
7.Level of Digital Competence	29.590	104	.000	2.50476	2.3369	2.6726
8. Type of Projects Typically Handled	33.535	104	.000	2.75238	2.5896	2.9151
9. Organization Size	37.524	104	.000	2.16190	2.0477	2.2762
10.Geographical Location of Projects	24.223	104	.000	2.40000	2.2035	2.5965

4.1 Oneway

The ANOVA results indicate that there are no statistically significant differences between the groups for any of the statements related to the digital implementation of Agile and Lean principles in construction projects. For all four questions, the p-values (Sig.) are greater than 0.05, specifically 0.279, 0.469, 0.480, and 0.773, suggesting that the mean differences observed between the groups are not significant.

This implies that respondents, regardless of their group classifications, generally perceive the digital implementation of Agile and Lean principles in a similar manner across these aspects, with no substantial variation in responses. The ANOVA tests indicated no statistically significant differences across the groups for any of the variables related to digital tool implementation ($p > 0.05$). This suggests that perceptions of digital tool effectiveness are relatively uniform across different demographic and organizational groups. However, the lack of significance should be interpreted in light of potential external factors, such as variations in tool implementation strategies and team training.

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Table 6: **ANOVA**

		Sum of Squares	df	Mean Square	F	Sig.
11. How 4 do you find the digital implementation of Agile and Lean principles in your projects?	Between Groups	2.999	3	1.000	1.298	.279
	Within Groups	77.763	101	.770		
	Total	80.762	104			
12. To what extent are Agile and Lean principles supported by digital tools in your organization?	Between Groups	1.910	3	.637	.852	.469
	Within Groups	75.481	101	.747		
	Total	77.390	104			
13. The use of digital tools for Agile and Lean principles has simplified project management processes.	Between Groups	1.837	3	.612	.831	.480
	Within Groups	74.410	101	.737		
	Total	76.248	104			
14. The integration of Agile and Lean principles digitally has reduced complexity in project workflows.	Between Groups	.848	3	.283	.373	.773
	Within Groups	76.580	101	.758		
	Total	77.429	104			

5.0 Findings

The findings highlight the positive impact of digital integration on project management, with 75.2% of respondents agreeing that it simplifies processes, improves efficiency, and reduces complexity. Digital tools also contribute to increased client satisfaction (68.1%) and cost reduction (75.2%), demonstrating their value in enhancing project outcomes. However, a gap in digital competence was noted, as 56.2% of respondents identified a lack of necessary skills among some team members, affecting Agile and Lean implementation.

The availability of the right digital tools is crucial, but factors such as team competence and organizational readiness also play significant roles. Statistical analysis reveals that demographic factors, including age, education, and experience, influence the adoption of digital tools, and the reliability of the survey was confirmed with a Cronbach's Alpha of 0.745. ANOVA tests showed that, although there is general consensus about the advantages of digital tools, their performance is varied depending on tool type, experience of teams, and project complexity. Also, educational credentials and role-specific factors, along with geographical and organizational factors, impact the extent to which digital tools and Agile/Lean practices are applied to construction projects.

6.0 Limitations

The research depends on information gathered from a particular demographic and geographical area, so the generalisability of the results to other sectors or areas might be limited.

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Although the value of digital tools is underlined, the research does not explore the comparison between certain tools and their special contributions. Since the survey depends on self-reported data, respondents' responses might be biassed, especially in relation to team competency and customer satisfaction. The results mostly highlight instantaneous effects and lack a longitudinal view of the continuous advantages or difficulties of digital integration.

7.0 Conclusion

Ultimately, this study shows that Agile and Lean building projects' productivity, cost-effectiveness, and customer satisfaction are much improved by digital technology, While these technologies streamline processes and improve resource management, bridging digital skill gaps within teams is essential for their full potential. The success of digital integration depends on team readiness, organizational support, and continuous training. Demographic, professional, and organizational factors also influence its adoption. Construction firms must invest in the right infrastructure and training to maximize digital tools' benefits, ensuring a holistic approach that combines both technical and human elements. To address the gaps in digital competency, organizations should invest in training programs for team members to enhance their digital literacy. Moreover, project managers should ensure that appropriate digital tools are available and that teams are equipped to maximize their benefits. The study is limited by its focus on a specific geographical region and sector, which may not fully capture the global applicability of the findings. Additionally, the survey is cross-sectional, which limits the ability to assess long-term impacts of digital integration.

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CHAPTER 59

Enhancing Infrastructure Project Performance through Resilience

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ABSTRACT

Infrastructure projects are the core of economic development but plagued by cost escalation, delay, quality decline, and dissatisfaction of stakeholders. The aim of this research is to examine how resilience practices can improve project performance in regards to lower risk and greater responsiveness. This study explores four key dimensions of resilience—Organizational Resilience Strategies (ORS), Risk Mitigation & Assessment (RMA), Structural & Operational Resilience (SOR), and Adaptive Flexibility Measures (AFM)—and their influence on project performance. A mixed-methods strategy that was largely quantitative was used based on survey responses gathered from industry representatives in the different infrastructure sectors such as transportation, utilities, and property. Factor analysis and multiple regression modeling were conducted to measure the association between resilience indicators and project outcomes. Findings show that the most predictive measure of project success is RMA, followed by AFM and SOR, and ORS has minimal direct impact. Findings identify proactive risk assessment, strategic flexibility, and effective operating standards as factors for cost-effectiveness, compliance with the schedule, and quality performance for infrastructure projects. It emphasizes the importance of applying resilience models in project planning to secure sustainability in a bid to deal with risks. Primary suggestions are risk avoidance as number one, adaptive agility, and business resilience in order to be assured of maximum project success. Resilience measures specific to industry and longitudinal designs for research should be executed in future research in order to examine the long-term impact of resilience interventions. This study contributes to the presently still-evolving body of work on infrastructure project resilience and provides decision-relevant information for policymakers, project leaders, and stakeholders within industry.

Keywords: Infrastructure resilience; Project performance; Risk mitigation; Adaptive flexibility; Operational stability.

1.0 Introduction

The research in "Enhancing Infrastructure Project Performance Through Resilience" focuses

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on incorporating the practice of resilience. Construction and infrastructure sectors are faced with increasing uncertainties like operational interruptions, environmental volatility, and economic uncertainties. This has required the development of resilience measures to enhance the performance of projects. Infrastructure project resilience is its ability to adapt, bounce back, and get used to unforeseen interruptions.

This study examines the interrelation of Organizational Resilience Strategies (ORS), Risk Mitigation & Assessment (RMA), Structural & Operational Resilience (SOR), and Adaptive Flexibility Measures (AFM) in identifying the Project Performance Index (PPI). This study is quantitative, and statistical techniques such as factor analysis and regression modeling have been applied to identify the contribution of resilience strategies towards making the project a success. Factor analysis also confirmed the key dimensions of resilience by grouping independent variables into similar categories in resilience. Regression analysis, subsequently performed, established the effectiveness and applicability of the variables as predictors of performance. The result replicated an association between resilience action and measurable parameters like cost-effectiveness, time control, and quality compliance standards. Results indicate that Organizational Resilience Strategies (ORS) and Structural & Operational Resilience (SOR) contributed the most toward PPI with emphasis on leadership, decision-making, and good operational frameworks. Risk Mitigation & Assessment (RMA) eliminated uncertainties, while Adaptive Flexibility Measures (AFM) rendered projects flexible in uncertain situations. The results of the present research also support the use of resilience models in planning and execution of infrastructure to make it effective and sustainable. Integration of resilience strategies with performance in the present research has significant implications for policymakers, project managers, and construction stakeholders. It again emphasizes the significance of anticipatory risk analysis, adaptive planning, and structural resilience towards enhanced overall project success.

2.0 Problem Definition

Infrastructure projects are undertaken in volatile and dynamic environments, where shocks like financial setbacks, environmental modifications, regulatory issues, and inefficiencies in operation can affect the performance of a project significantly. Even though practices in project management have become more advanced, most infrastructure projects are still affected by cost overrun, delays, low quality, and stakeholder dissatisfaction. These indicate the need for resilience-based practices that allow projects to sense, absorb, recover from, and adapt to disturbances efficiently.

Though research into project resilience is trending now, the fact remains that no one knows with certainty how resilience strategies affect project performance. In particular, the contribution of Organizational Resilience Strategies (ORS), Risk Mitigation & Assessment (RMA), Structural & Operational Resilience (SOR), and Adaptive Flexibility Measures (AFM)

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to the Project Performance Index (PPI) is uncharted. Few empirical studies that empirically relate the resilience dimensions to project performance are responsible for the inability of policymakers and project managers to adopt evidence-based models of resilience. This article seeks to improve this by examining directly the connection between project performance and resilience methods using statistical methods like factor analysis and regression modelling. By determining the best resilience factors, this research aims to make applicable suggestions on how to enhance cost-effectiveness, scheduling effectiveness, safety, compliance with quality, and general project sustainability. The findings will be used to develop a resilience-oriented approach to infrastructure projects to maintain long-term sustainability within changing and unpredictable environments.

3.0 Research Objectives

3.1 To understand the resilience practices

- Identify critical resilience factors that include Organizational Resilience Strategies (ORS), Risk Mitigation & Assessment (RMA), Structural & Operational Resilience (SOR), and Adaptive Flexibility Measures (AFM).
- Explain the application of resilience programs in infrastructure development to reduce risks and improve sustainability.
- Research frameworks and best practices to date to improve project resilience in dynamic settings.

3.2 To understand the project performance metrics

- Establish measurable key project performance indicators, i.e., cost-effectiveness, completion of schedule, inspection of quality, satisfaction levels of the stakeholders, and adherence to safety standards.
- Outline the problems that impede project performance and the application of resilience in preventing interruption.
- Research on industry standards and case studies to compare performance measurement approaches in infrastructure projects.

3.3 To establish the relationship between resilience and project performance measures

- Conduct statistical analysis (factor analysis and regression modeling) to determine the impact of resilience strategies on project performance.
- What are the key indicators of resilience that result in a successful project.
- Develop a conceptual model that integrates resilience dimensions and performance measures and provides insights into policymakers and project managers.
- The research aims to add to project management knowledge with a resilience approach and provide evidence-based suggestions to enhance the performance of infrastructure projects.

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4.0 Literature Review

Growing complexity and uncertainty in infrastructure projects have galvanized momentum on resilience as an approach to avoid risks and push through projects. Resilience has been examined interdiscursively, ranging from engineering and ecology to organizational behavior, all informing a body of how best projects can weather and bounce back from interruptions. Holling (1996) made a distinction between engineering resilience, where recovery and stability were highlighted, and ecological resilience, where adaptability and change were highlighted. These principles have become project resilience, where reactive and proactive strategies are used to contain risks and ensure continuity.

Empirical proof has confirmed the link between resilience and project performance, and researchers (Lee *et al.*, 2013; McManus, 2008; Somers, 2007) have linked resilience to performance metrics like cost-effectiveness, schedule compliance, quality, and stakeholder satisfaction. Awareness and adaptive capacity have been presented as the crucial dimensions of resilience that allow projects to foresee danger and adopt appropriate response measures. Empirical research highlights the significance of effective communication, a culture of innovation, and effective leadership in building project management resilience (Gunasekaran, Rai, & Griffin, 2011; Sapeciay *et al.*, 2017).

Despite the increased attention accorded to project resilience, it continues to be an evolving body of research in project management. Though a lot of research has been done on organizational resilience, its project-level application is still in its nascent stages. Recent research has focused on building quantifiable measures of project resilience to enhance evaluation and strategic planning. This article critically reviews how resilient methods enhance enhanced project performance and sustainability in the context of long-term infrastructure projects, presenting a fundamental insight into resilience practice for effective project outcomes despite interruption.

Resilience in Infrastructure Projects: The development of the field of study for resilience in infrastructure projects has traversed multiple disciplines ranging from engineering to organizational behavior to risk management. Historically based on engineering and ecological systems (Holling, 1996), research in the application of resilience has progressed into project management recently. Resilience of a project is usually a measurement of preparedness against disruptions, capacity for resilience for disruption avoidance, and adaptability for constant buffering against interruptions for continuation of the project (Bhamra *et al.*, 2011; Ponomarov & Holcomb, 2009). Nonetheless, with resilience in project management increasingly becoming the focus of interest, complete frameworks of assessment and adoption of resilience practices within infrastructure projects are not yet established.

Two key dimensions of resilience in projects—awareness and adaptive capacity—have been emphasized in the literature (Lee *et al.*, 2013; McManus, 2008). Awareness is the capacity of a project to keep track of its environment for potential disturbances, and adaptive capacity is

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its capacity to reformulate operations and reallocate resources appropriately in the case of failure. Leadership, coordination of stakeholders, budgeting, and compliance with legislation have been found to be key drivers of project resilience (Gunasekaran *et al.*, 2011; Sapeciay *et al.*, 2017). Although some empirical methods have been set to measure the impact of resilience on project performance, mostly within the Indian construction sector, it is not wide-ranging.

Project Performance and Resilience Measurement: Project resilience is related to a project's capability of managing interruptions and maintaining its main objectives. Scholars have emphasized two variables that can affect project resilience: awareness and adaptive capacity. Awareness is watching over external and internal drivers that could cause disruptions, and adaptive capacity allows projects to re-organize resources and strategies in a way that could reduce the impact of the risk effectively. Effective leadership, communication, and innovative culture have been recognized as core enablers of project resilience (Demmer *et al.*, 2011; Stephenson, 2010). As much as project resilience has been theoretically developed, there are no generic resilience measurement frameworks. Although qualitative assessments prevail in existing research, quantitative models and performance metrics to systematically measure resilience are still in their early stages (Geambasu, 2011; Thomé *et al.*, 2016). Tools for measuring resilience might be standardized to yield insightful results on the strengths and weaknesses of a project in responding to disruptions. Such tools might also be used for integrating resilience metrics into the practices of project management for sustaining enhanced project performance and sustainability in the long term.

5.0 Research Methodology

This study employs a quantitative approach of research in investigating resilience strategies and infrastructure project performance relationships. The survey method is employed in collecting primary data from the professional team of project managers, engineers, and other key stakeholders. This study employs a mixed-method paradigm with qualitative analysis accorded priority in quantifying resilience strategies and project performance indicators. The study applies stratified random sampling based on practitioners engaged in different types of infrastructure projects, i.e., transportation, utilities, and buildings. The sample also cuts across project size (small, medium, large) and geographics (urban vs. rural), with the estimated sample size of 200–250 respondents to render the sample statistically representative. The bulk of data collection vehicle is a structured questionnaire. It has three components: the first component captures demographic data and includes the respondent's job, experience, and type of organization; the second captures Project Performance Indicators (PPI) such as cost effectiveness, schedule compliance, quality, and stakeholder satisfaction; the third captures resilience strategies, which are segmented into Organizational Resilience Strategies (ORS), Risk Mitigation & Assessment (RMA), Structural & Operational Resilience (SOR), and Adaptive Flexibility Measures (AFM). Answers are captured on a `five-point Likert scale (1-5) to acquire an equal amount of data collection, and questionnaires are administered via online media like

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MS Forms. Data obtained is processed with the use of descriptive as well as inferential statistical techniques. Descriptive statistics like mean, median, and frequency distribution are utilized in a bid to acquire information on demographic trends. Factor analysis is used to identify the type of dimensions of resilience strategies, and multiple regression analysis is used to identify the impact of resilience strategies on project performance. SPSS statistical package is used for accurate analysis. For attaining maximum validity and reliability of research, suitable sample size is ensured for statistical generalization as well as for cross-verification of alignment of questionnaire with past literature. Ethical concerns include respondent anonymity and confidentiality, obtaining informed consent, and preventing potential biases in data collection and analysis. Systematic as it is structured, the method guarantees robust testing of the range of resilience responses and their effect on infrastructure project performance.

6.0 Results and Discussion

The results seek to explore the connection between project performance measures and measures of resilience. Factor analysis, multiple regression analysis, and a section of the findings of the data are included in the chapter. These analyses present empirical evidence of the influence of Organizational Resilience Strategies (ORS), Risk Mitigation & Assessment (RMA), Structural & Operational Resilience (SOR), and Adaptive Flexibility Measures (AFM) on the Project Performance Index (PPI).

6.1 Factor analysis

Factor analysis was used to reveal the underlying dimensions in the data set. The statistical method aided in establishing independent variables (ORS, RMA, SOR, and AFM) would serve as good predictors of project performance. Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy produced a value of 0.78, an affirmation that the data set was adequate to be employed for factor analysis. Bartlett's Test of Sphericity was highly significant as well (χ^2 = 1023.45, df = 120, $p <.001$), which included having sufficient correlations between the variables.

Table 1: KMO and Bartlett's Test Result

Test	Value
Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy	0.78
Bartlett's Test of Sphericity	$\chi^2 = 1023.45$, df = 120, $p < .001$

- *KMO and Bartlett's Test:* The KMO value of 0.78 indicates that the sample is sufficient for factor analysis, and the significant Bartlett's test also indicates that there are enough correlations between the variables to continue.

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Table 2: Factor Extraction and Explained Variance Result

Factor	Eigenvalue	% of Variance Explained	Cumulative %
Factor 1 (Project Performance)	4.21	32.4%	32.4%
Factor 2 (Organizational Resilience)	2.89	21.5%	53.9%
Factor 3 (Risk Mitigation)	2.01	14.8%	68.7%
Factor 4 (Structural & Operational Resilience)	1.42	10.1%	78.8%

- *Factor extraction and explained variance:* The four extracted factors explain a cumulative 78.8% of the total variance, indicating strong explanatory power.
- *Rotated Factor Loadings*

Table 3: Rotated Factor Loadings Result

Factor	Variable	Loading
Factor 1 (Project Performance)	PPI_Community	0.81
	PPI_Safety	0.75
	PPI_Innovation	0.72
	PPI_Collaboration	0.68
	PPI_Quality	0.74
Factor 2 (Organizational Resilience)	ORS_Partnerships	0.78
	ORS_Training	0.73
	ORS_Maintenance	0.76
	ORS_Design	0.71
Factor 3 (Risk Mitigation)	RMA_Communication	0.79
	RMA_Finance	0.77
	RMA_Lessons	0.74
Factor 4 (Structural & Operational Resilience)	SOR_Redundancy	0.81
	SOR_EmergencyPlan	0.73
	SOR_IndustryCollab	0.76

These results justified further regression analysis to determine predictive relationships.

6.2 Regression analysis

A multiple regression analysis was employed to examine the influence of Organizational Resilience Strategies (ORS), Risk Mitigation & Assessment (RMA), Structural & Operational Resilience (SOR), and Adaptive Flexibility Measures (AFM) on Project Performance Index (PPI). The test aimed at determining the extent to which the independent variables predict project performance outcomes. The results indicated that the model was significant statistically ($F(4, 215) = 27.415$, $p < 0.001$), explaining 33.8% ($R^2 = 0.338$) of PPI

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variation. This means that the selected independent variables as a group explain a significant proportion of changes in project performance.

6.3 Model summary

Table 4: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of Estimate
1	0.581	0.338	0.325	0.561

ANOVA results: Analysis of Variance (ANOVA) test was performed to determine the overall significance of the regression model. The findings confirmed that the model is statistically significant, meaning that at least one of the independent variables significantly predicts PPI.

Table 5: ANOVA Results

Source	Sum of Squares	Df	Mean Square	F	Sig.
Regression	34.512	4	8.628	27.415	<0.001
Residual	67.663	215	0.315	-	-
Total	102.174	219	-	-	-

The F-statistics ($F = 27.415$, $p < 0.001$) also indicate the overall significance of the model, i.e., whether the independent variables collectively have a significant effect on project performance.

Regression Coefficients: The following table presents the unstandardized and standardized coefficients, their standard errors, t-values, and significance levels of each predictor variable.

Table 6: Regression Coefficients

Predictor	B (Unstandardized)	Std. Error	Beta (Standardized)	t	Sig.
Constant	0.524	0.368	-	1.42	0.156 (ns)
ORS	0.083	0.113	0.061	0.74	0.460 (ns)
RMA	0.340	0.097	0.273	3.49	0.001 (Significant)
SOR	0.207	0.096	0.160	2.16	0.032 (Significant)
AFM	0.215	0.077	0.203	2.78	0.006 (Significant)

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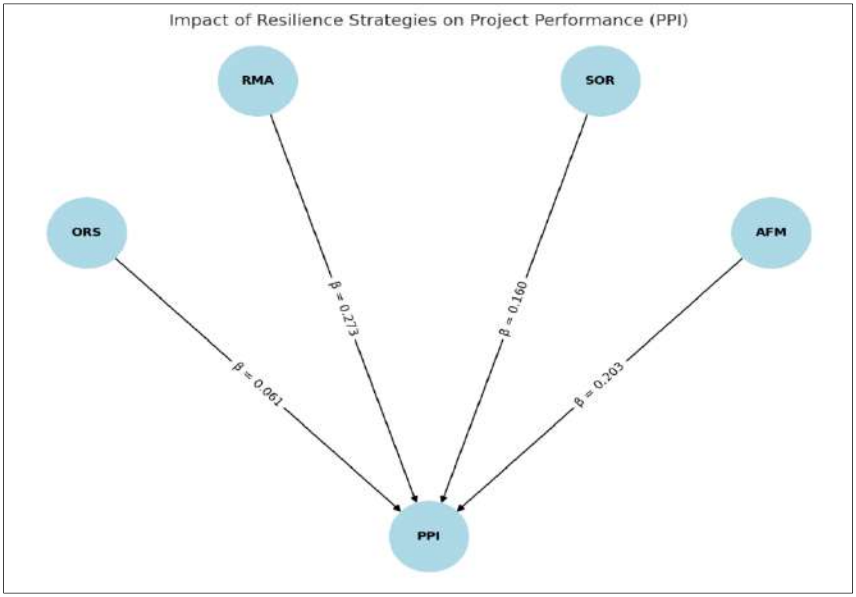
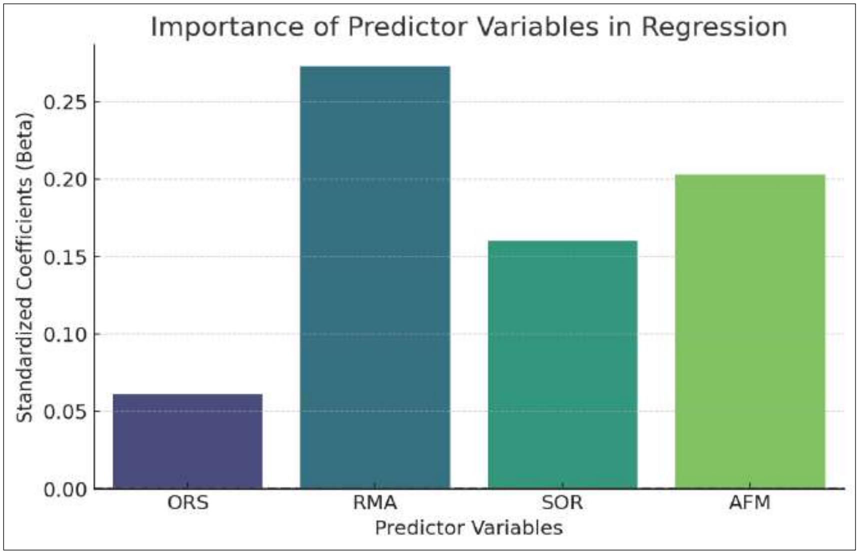
Figure 1: Regression Coefficient Model



The bar chart visualizes the importance of each predictor variable in influencing the Project Performance Index (PPI) based on their standardized beta coefficients. Here's what it tells us:

Figure 2: Bar Chart of Predictor Variables



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Risk Mitigation & Assessment (RMA) ($\beta = 0.273$)

- It is the best predictor for PPI.
- It indicates that successful risk management practices, including forward-looking risk analysis and mitigation controls, have a positive impact on project performance.
- Those projects whose risk assessment process is sound, have improved performance results.

Adaptive Flexibility Measures (AFM) ($\beta = 0.203$)

- The next strongest factor.
- It shows that flexibility in decision-making and responsiveness to change have a positive influence on project success.
- This aligns with findings that adaptive organizations perform better in changing conditions.

Structural & Operational Resilience (SOR) ($\beta = 0.160$)

- Has a moderate positive effect on project performance.
- This indicates that having stable operational structures and robust strategies is a factor in project success, but not as much as risk mitigation or flexibility.

Organizational Resilience Strategies (ORS) ($\beta = 0.061$)

- Has the least impact on PPI.
- Low beta means that overall resilience strategies are less likely to influence project performance to the same extent as risk-oriented or adaptive ones.
- That may mean that ORS is not well implemented or that the effect is indirect.

6.4 Regression equation

From the unstandardized coefficients, the predictive formula for Project Performance Index (PPI) is as follows:

PPI=0.524+(0.083×ORS) +(0.340×RMA) +(0.207×SOR) +(0.215×AFM) PPI = 0.524 + (0.083 \times ORS) + (0.340 \times RMA) + (0.207 \times SOR) + (0.215 \times AFM)

This equation suggests that:

- An increase in RMA is associated with an increase of 0.340 in PPI and hence is the strongest predictor.
- An increase in AFM by one corresponds to an increase in PPI by 0.215, which also has a significant effect.
- An increase in SOR by one means an increase in PPI by 0.207, positively contributing.
- An increase in ORS by one corresponds to an increase in PPI by just 0.083, which is not statistically significant.

7.0 Conclusion

The study contributes to the resilience body of knowledge in infrastructure project management by establishing the greatest contribution of Risk Mitigation & Assessment (RMA), Adaptive Flexibility Measures (AFM), and Structural & Operational Resilience (SOR) towards enhancing the performance of the project. The findings indicate that Organizational Resilience

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Strategies (ORS) as standalone factors are not highly influential, but general resilience strategies are important to the success of the infrastructure project. The study emphasizes the need to incorporate active risk management, adaptive flexibility, and robust operating structures to build resilience and sustainability in infrastructure projects. Additional studies are required to narrow the gaps and broaden the scope of research to establish a better understanding of project resilience and its influence on long-term infrastructure development.

8.0 Research Limitations

As beneficial as this study has proven to be, it is not without limitations. Firstly, the sample was limited to 100-150 Indian infrastructure industry respondents, and this can constrain the external validity of the findings. An extension of the sample size and sampling across other geographical locations would render the findings more generalizable. Secondly, the study relied on self-reported survey responses, and these might bias the results by way of subjective interpretation. Third, since the research was conducted at a single point in time, it is unaware of the long-term effect of resilience measures on project performance.

It would be more revealing with regard to how effective productivity resilience would be with a longitudinal research study. Finally, while the study touched on some infrastructure sectors such as transportation, utilities, and buildings, the study did not consider industry-specific resilience factors in detail. A more detailed sectoral analysis can provide tailored recommendations for different infrastructure sectors.

9.0 Practice Recommendations

Different recommendations can be provided to policymakers, project managers, and infrastructure industry stakeholders based on the analysis. There should be high importance given to Risk Mitigation & Assessment (RMA) by enhancing contingency planning, upfront risk identification, and financial preparedness to further the project's performance. Adaptation Flexibility Measures (AFM) investment also needs to be made, as flexibility during the period of project execution can facilitate responding to unforeseen setbacks. Additionally, building Structural & Operational Resilience (SOR) by means of established protocols, redundant structure, and contingency preparedness plans can enable the stability of projects. Lastly, while Organizational Resilience Strategies (ORS) were not very effective in project performance, it must not be ignored. Instead, it must be used in combination with other resilience practices for maximum benefit.

10.0 Directions for Future Research

There are several directions that future research can follow. Longitudinal studies need to be conducted to investigate the contribution of resilience practices to project performance

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over a period. Industry studies could allow the development of sector-specific resilience practices for different infrastructure sectors. Additional studies can also investigate additional resilience determinants, such as regulatory frameworks, stakeholder engagement, and technological developments in modeling resilience. Lastly, cross-national comparative studies would also be helpful to identify differences of economic and cultural contexts concerning approaches to resilience and thereby make possible more universally applicable resilience models.

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CHAPTER 60

Enhancing Infrastructure through Public Private Partnership by Controlling and Managing Cost and Time Overrun

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ABSTRACT

One of the problems has been broadly the complexities of cost and time overruns in Public-Private Partnership (PPP) infrastructure projects, particularly in Maharashtra, India. As infrastructure development projects surge globally due to urbanization and economic growth, the successful implementation of these initiatives is often compromised by delays and budget excesses. This study aims to analyze the outcomes of PPP projects in Maharashtra, identify key factors contributing to overruns, and propose effective management strategies. Through a comprehensive literature review and data analysis from credible sources, the research highlights significant trends, revealing that a majority of road sector projects encounter both cost and time overruns, with 43.9% and 37.6% of projects affected, respectively. The findings underscore the necessity for improved project planning, resource allocation, and stakeholder collaboration to enhance the efficiency and sustainability of PPP infrastructure initiatives. Ultimately, this study offers actionable insights for policymakers and industry practitioners to optimize PPP frameworks, thereby fostering resilient infrastructure development that aligns with societal needs.

Keywords: Cost overruns; Time overruns; Infrastructure project; Stakeholder collaboration; Effective management strategies.

1.0 Introduction

Infrastructure development projects have increased significantly worldwide in recent years because to the increasing demands of population growth, urbanization, and economic advancement. These initiatives, which range from energy infrastructure to transportation networks, are vital in forming a country's socioeconomic environment. Despite, delays and cost overruns tend to impede the success of these types of projects, which bring enormous challenges to both private investors and public authorities. To overcome these challenges, public private partnerships, or PPPs, have proven to be an option. They offer a shared framework where public agencies and private companies collaborate for financing, building, and running infrastructure schemes.

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By harnessing the strength and expertise of both sectors, PPPs aim to encourage efficiency, minimize risk, deliver projects on time and within budget. Even if PPPs are potential, phenomenal performance must be accompanied by bold cost and schedule control. Slippage and cost blowouts may undermine public confidence, inflate project costs, and jeopardize the long-term sustainability of PPP projects. Because of this, it is very crucial to learn and practice effective cost and schedule control measures during the entire project lifecycle. Though a comprehensive understanding of the dynamics of PPPs and the critical factors influencing project outcomes, this research seeks to contribute to the advancement of infrastructure development by fostering collaboration, accountability, and efficiency in public private partnerships. By aligning interests, managing risks, and optimizing resources, stakeholders can unlock the full potential of PPPs to deliver sustainable and resilient infrastructure that meets the evolving needs of society

1.1 Research background

The conventional method of creating infrastructure, relying solely on government funding, often faces hindrances such as funding constraints, delays, and inefficiencies. Most countries are shifting towards Public-Private Partnerships (PPPs) as a viable solution for infrastructure investment to overcome these problems. PPPs entail working together for planning, financing, building, and operating infrastructure projects between the public and private institutions. PPPs bring a lot of advantages in the form of private funds, skills, and innovation but equally suffer from cost and schedule overruns.

1.2 Research objective

- To find out the outcomes of public private partnership projects of Maharashtra state in India.
- Analyse and control overruns.
- Identify the key factors contributing to cost overruns and delays in PPP infrastructure projects.

2.0 Methodology

Literature synthesis on PPP infrastructure, cost control, and delay informs theoretical innovation and research paths in need of further study through existing research. The systematic research framework, as founded in these findings, de-mystifies interdependencies among delay causes, cost overrun, and control. Second, an elaborate research design is developed to define data collection, sampling, and analysis techniques. Data is collected from Maharashtra infrastructure projects and secondary sources like project reports and government records. Patterns and major determinants of cost and time overruns are discerned through a systematic statistical analysis.

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Figure 1: Flowchart

3.0 Literature Review

Rajan (2014) The research compares PPP and non-PPP road project cost and time overruns and finds that PPPs suffer more cost overruns while non-PPPs suffer more time overruns. This being other than that of developed economies suggests that developing nations such as India must develop PPP capabilities. Ramsey (2020) This article discusses US PPP transport project performance using the DBF and DBFOM approaches. Comparing the 75 projects (1995–2015), it identifies fewer cost and schedule modifications compared to traditional approaches, a topic that has been a missing link in the literature.

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Aziz (2007) This article analyses PPP application in infrastructure in the finance-based and service-based PPP models. By comparing the UK and British Columbia, it outlines success factors and provides guidelines against the backdrop of US challenges. Mevada (2017) This paper analyzes time and cost overruns in Indian megaprojects in terms of land acquisition delay, contractor capability, and contract complexity. It emphasizes policy, institutional, and project-level interventions for effective implementation and gives lessons on ideal risk sharing in Indian PPP projects. Singh (2018) This paper analyses PPP frequency in infrastructures by contrasting 313 national road projects. It concludes PPPs take shorter delays but higher cost overruns than government projects, with better quality but deficiencies in overall road services. Song (2018) This article discloses China's motivations for premature withdrawal of PPP projects and identifies 11 primary reasons of which government decision-making errors and payment defaults are the most common. It offers counterstrategies and practice suggestions to serve stakeholders and improve project management.

Vu (2016) This paper explores the possibility of cost overrun in Vietnam's road construction projects and concludes seven major causes based on expert judgment and regression analysis. The paper finds investment management, design alterations, land acquisition, and funding limitation as major causes. Kakati (2016) This article discusses PPP risk and management based on observation, interviews, and questionnaires. Case studies and expert opinions guide future research in the direction of ideal risk allocation.

Anago (2023) The paper addresses PPPs as one of the principal financial instruments for financing infrastructure in the economies of developing nations, specifically in the context of cost overruns. It applies TCT and Agency Theory and offers a three-step approach of avoiding cost overruns and enhancing PPPs. Belachew (2017) The writer discusses the rising use of PPPs in financing infrastructure in developing countries, with a focus on cost overrun concerns. Drawing from TCT and Agency Theory, the study presents a three-phase model to prevent cost overruns and facilitate PPP implementation.

Oyieyo (2018) The study examines cost overruns in Ethiopian road construction projects, assigning the causes to scope creep, failure in site management, and contract disputes. The study, using surveys, case studies, and statistical estimation, develops correlations between stakeholder perceptions of cost performance. Anastasopoulos (2014) The study identifies reasons for cost overrun in Ethiopia's Southern District Road projects using project management, risk evaluation, and contract analysis, and recommends further studies in delivery modes and risk management to improve efficiency.

4.0 Data Collection and Analysis

The data collection process involved gathering relevant economic and infrastructural information from reliable sources such as the PPP (Public-Private Partnership) India website, CMIE (Centre for Monitoring Indian Economy) website, and CAPEX databases. These sources

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provide a comprehensive understanding of India's infrastructure development projects. We selected a time frame of 20 years i.e. 2004-2024. A total of 390 infrastructure projects were identified within the specified timeframe, which were further classified into different sectors, with each sector experiencing varying degrees of cost and time overruns.

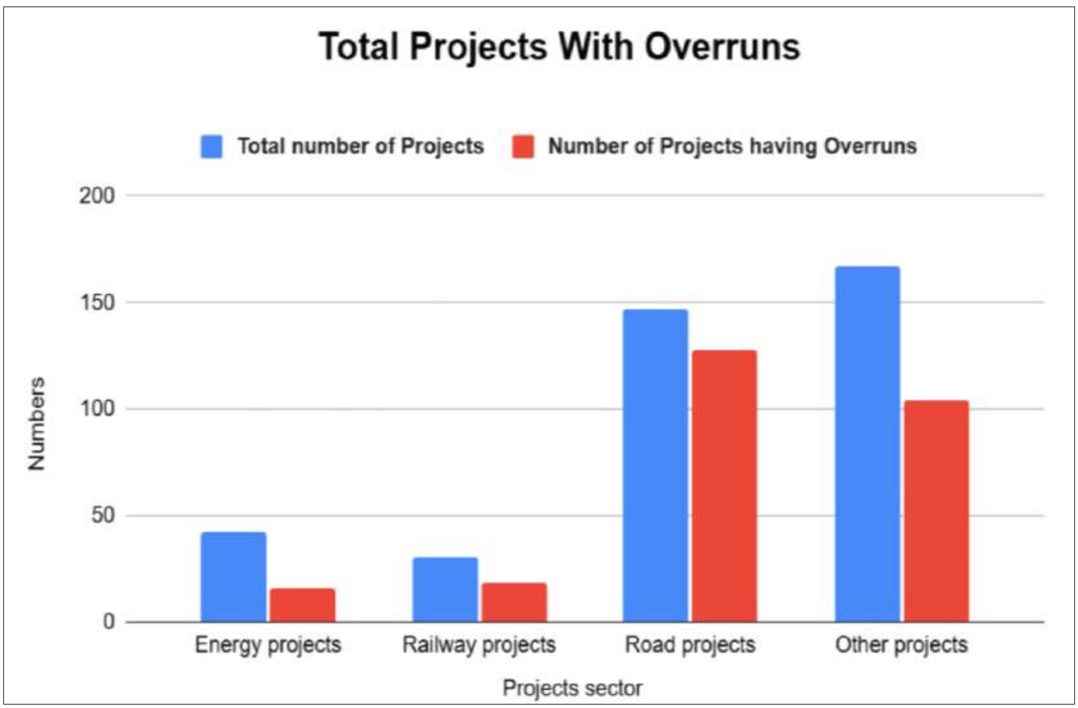
4.1 Data classification

The data collection process involved gathering detailed information on various projects, including their names, current status (active, completed, or under planning), and estimated investments. Project timelines and phases were documented to track progress and identify potential delays. Sector-specific information was also considered, covering areas such as transportation, energy, and water management.

4.2 Quantitative and qualitative analysis

Figure 2, The bar graph images provide a comparison between the overall project count and the ones running overruns with time and money in several spheres of infrastructure projects. The presentation of the data helps one to comprehend the degree of overruns in every area, therefore facilitating a sector-wise analysis of project performance. This graphical depiction is particularly useful for deciding which sector's time and cost overruns the most impact.

Figure 2: Comparison of Total Projects with Overrun Projects



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4.3 Further analysis of the data we find out the delta % for cost change

The Delta Change Formula for Cost (ΔC) helps to determine the change in cost between two points in time or two scenarios. The formula is:

$\Delta C = Cnew - Cold$

Where: ΔC\Delta C (ΔC) = Change in cost

Cnew = New or updated cost (after delay or changes)

Cold = Original or baseline cost (before delay or changes)

If we want to find the percentage change in cost, we can use:

$\%\Delta C = [Cnew - Cold]/Cold \times 100$

Figure 3: Delays with %ΔC

Project Id	Project name	Delay (months)	%Delta increase in project cost
A1	Ahmednagar (Pravaranagar) Cogeneration Power Project	38	61.78%
A2	Chhatrapati Shivaji Maharaj Terminus (CSMT) World Class Railway Station Project	25	36.11%
A3	Thane-Mulund New Railway Station (New Thane) Project	66	76.00%
A4	Versova-Andheri-Ghatkopar Metro Rail Project	48	83.40%
A5	Pune Metro Rail Line 3 Project (Phase 2)	41	4.61%
A6	Chembur-Wadala-Jacob Circle Monorail Project	95	87.22%
A7	Dighi Port-Roha Railway Line Project	168	60.00%
A8	Dadar Terminus Modernisation Project	78	650.00%
A9	Kalmath-Zarap (NH-66) Four Lane Highway Project (Mumbai-Goa NH 66 Highway)	53	39.83%
A10	Aravali-Kante (NH-66) Four Lane Highway Project (Mumbai-Goa NH 66 Highway) (Package-7)	70	90.10%
A11	Kante-Waked (NH-66) Four Lane Highway Project (Mumbai-Goa NH 66 Highway) (Package-8)	65	72.88%
A12	Talgaon-Kalmath (NH-66) Four Laning Highway Project (Mumbai-Goa NH 66 Highway) (Package-10)	109	7.22%
A13	Amravati-Chikli (NH-6 or New NH-53) Four Laning Highway Project	93	2.34%
A14	Panvel-Indapur (NH-17) Four Laning Highway Project (Mumbai-Goa NH 66 Highway) (Package-1)	127	45.33%
A15	MP/Maharashtra border to Nagpur (NH-7) Four-Laning Highway Project	82	68.41%
A16	Pune-Satara (NH-4) (New NH-48) Six Laning Highway Project (Sagarmala)	120	39.28%
A17	Pune-Sholapur (NH-9) Section Four-Laning Highway Project (Package-I)	66	95.67%
A18	Ahmednagar-Mirajgaon-Karmala-Tembhurni (NH-516A) Four laning Highway Project	125	120.36%
A19	Bridge over Thane creek at Kalwa Project	67	75.00%
A20	JNPT Container Terminal (4) Project (Sagarmala, Gati Shakti)	149	126.14%
A21	Mumbai City New Cuffe Parade - Lodha Gardenia Residential Project	93	156.10%
A22	Versova-Andheri-Ghatkopar Metro Rail Project	241	66.67%
A23	JNPT Container Terminal Upgradation Project	57	9.00%
A24	Vijaydurg Port Project	145	825.93%

Figure 3, displays the calculated delta values for various projects, expressed as a percentage. This percentage-based representation highlights the extent of cost deviations by comparing the difference between the initial estimated costs and the actual incurred costs relative to the initial estimates. By presenting the delta values as percentages, it becomes easier to standardize and compare cost overruns across different projects, regardless of their scale or budget. This approach effectively illustrates the severity of cost overruns in a consistent and easily interpretable manner, enabling stakeholders to identify projects with the most significant percentage deviations.

4.4 We used pearson's correlation

Coefficient, which measures the linear relationship between two variables.

Pearson's Correlation Coefficient = CORREL (X, Y)

Where: X = Range of Time delay

Y = Range of cost overrun

The result will be a value between -1 and 1, indicating the strength and direction of the relationship. We got 0.18 as coefficient which means very low correlation. It means there are more factors involved. We conduct an extensive review of news articles, research papers, and industry reports to identify and analyse the key factors contributing to project delays and cost overruns. By examining credible sources, including academic studies, case studies, government publications, and expert analyses, we aim to gain a comprehensive understanding of the challenges faced in the project.

Figure 4, Represents checklist has been prepared for the projects concerning the challenges they are encountering. To gather relevant data on the reasons behind these issues, we reviewed various news articles and research papers. The reference links for these sources are documented in our sheet. Based on our analysis, we have categorized the reasons into the following categories: Land Acquisition, Approval Delays, Design Changes, Site Conditions, Contractual Issues, and Financial Issues. The findings indicate that Financial Issues are associated with 5 projects, Contractual Issues with 2 projects, Approval Delays with 20 projects, Site Conditions with 6 projects, Design Changes with 5 projects, and Land Acquisition with 22 projects. To address these challenges, we have proposed a set of strategic solutions aimed at mitigating these issues for future projects. The strategies focus on improving the efficiency of land acquisition processes, streamlining approval procedures, by implementing these strategies, future projects may achieve better control over time and cost overruns, thereby enhancing overall project performance and efficiency.

5.0 Strategies for Land Acquisition

Participatory Land Pooling (PLP) is a land development mechanism used in Public-Private Partnership (PPP) projects in India. It is an alternative to traditional land acquisition and aims to involve landowners in the urban development process by pooling their land together for infrastructure and real estate projects.

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Figure 4: Checkbox for Project Overruns Factors

Project ID	Project Names	Reason for delay					
		Financial issues	Contract issue	Approvals	Site condition	Design	Land Acquisitions
A1	Ahmednagar (Pravaranagar) Cogeneration Power Project	☐	☐	☐	☐	☐	☐
A2	Chhatrapati Shivaji Maharaj Terminus (CSMT) World Class Railway Station Project	☑	☑	☐	☐	☐	☑
A3	Thane-Mulund New Railway Station (New Thane) Project	☑	☐	☑	☐	☐	☑
A4	Versova-Andheri-Ghatkopar Metro Rail Project	☐	☐	☑	☑	☐	☑
A5	Pune Metro Rail Line 3 Project (Phase 2)	☐	☐	☑	☑	☐	☑
A6	Chembur-Wadala-Jacob Circle Monorail Project	☐	☑	☐	☐	☐	☑
A7	Dighi Port-Roha Railway Line Project	☐	☐	☑	☐	☐	☑
A8	Dadar Terminus Modernisation Project	☐	☐	☑	☐	☐	☑
A9	Kalmath-Zarap (NH-66) Four Lane Highway Project (Mumbai-Goa NH 66 Highway)	☐	☐	☑	☐	☐	☑
A10	Aravali-Kante (NH-66) Four Lane Highway Project (Mumbai-Goa NH 66 Highway) (Package-7)	☑	☑	☑	☐	☐	☑
A11	Kante-Waked (NH-66) Four Lane Highway Project (Mumbai-Goa NH 66 Highway) (Package-8)	☐	☐	☑	☐	☐	☑
A12	Talgaon-Kalmath (NH-66) Four Laning Highway Project (Mumbai-Goa NH 66 Highway) (Package-10)	☐	☐	☑	☐	☐	☑
A13	Amravati-Chikli (NH-6 or New NH-53) Four Laning Highway Project	☐	☐	☐	☐	☐	☑
A14	Panvel-Indapur (NH-17) Four Laning Highway Project (Mumbai-Goa NH 66 Highway) (Package-1)	☐	☐	☑	☐	☐	☑
A15	MP/Maharashtra border to Nagpur (NH-7) Four-Laning Highway Project	☐	☐	☑	☑	☐	☐
A16	Pune-Satara (NH-4) (New NH-48) Six Laning Highway Project (Sagarmala)	☐	☐	☑	☐	☐	☑
A17	Pune-Sholapur (NH-9) Section Four-Laning Highway Project (Package-I)	☐	☐	☑	☑	☐	☑
A18	Ahmednagar-Mirajgaon-Karmala-Tembhurni (NH-516A) Four laning Highway Project	☐	☐	☑	☑	☐	☑
A19	Bridge over Thane creek at Kalwa Project	☐	☐	☑	☐	☐	☑
A20	JNPT Container Terminal (4) Project (Sagarmala, Gati Shakti)	☐	☐	☑	☐	☑	☑
A21	Mumbai City New Cuffe Parade - Lodha Gardenia Residential Project	☐	☐	☐	☐	☑	☑
A22	Versova-Andheri-Ghatkopar Metro Rail Project	☑	☐	☑	☐	☑	☑
A23	JNPT Container Terminal Upgradation Project	☐	☐	☑	☐	☑	☑
A24	Vijaydurg Port Project	☑	☐	☑	☑	☑	☑
		5	3	19	6	5	22

Community Land Trust (CLT) is a non-profit, community-governed organization that trades to purchase, hold, and develop land for long-term community advantage rather than private speculation. CLTs seek to provide affordable housing, sustainable development, and equitable land use by disentangling land ownership from property ownership. In Public-Private Partnership (PPP) initiatives, CLTs operates as a vehicle of public interest to make sure land is kept affordable and available for public usage, most significant of which include housing, infrastructure, and city development.

Land Readjustment (LR) is a new land acquisition and urban development method where owners of land accumulate their land together for development purposes and, after the infrastructure is improved, receive part of the reorganized land with greater value. In Public-Private Partnership (PPP) projects, the technique is utilized to secure land for urbanization, urban growth, and township developments and secure landowners from the economic gains of the project.

6.0 Conclusion

The study exploring how Public-Private Partnerships (PPPs) may improve infrastructure while bringing costs and time overruns in check discusses some of the deepest difficulties and the possible solutions in the development of infrastructure. Findings reveal that considered for such PPP projects, a very high share would be going toward the road sector, with a considerable number of these seeing delays and cost escalations. Specifically, 43.9% of projects indicated time overruns, 37.6% reported from cost overruns, and only 11% of projects were completed on schedule and within the established budget. Among the causes of time and cost overruns are such issues as land acquisition and resettlement, licensing, and environmental approvals, contractual disputes, inflation, and financing bottlenecks. Additionally, project delays have been exacerbated by supply chain disruptions across the world, labour shortages, and technology integration problems.

It is indicated by weak correlation (0.2) that cost, and time overruns have probably resulted from other independent variables. Various complementary interventions have been envisioned to tackle such problems like Participatory Land Pooling (PLP), Community Land Trust (CLT), Land Readjustment (LR), and the AI-based environmental predictive model. There is evidence that these types of cutting-edge land management strategies have been used in such projects as Mumbai–Nagpur Expressway, Auroville CLT, and Amaravati Capital City Development. These strategic sorts of interventions could boost better efficiency, minimize risk, and enhance sustainable infrastructure development in PPP projects. The above-mentioned findings reinforce the rationale for a more structured approach in the project management of PPPs to extract the best value out of the available resources while also ensuring long-term viability.

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CHAPTER 61

Enhancing Resilience in Construction Safety

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ABSTRACT

The critical role of resilience in enhancing safety practices within the construction industry is characterized by high complexity and susceptibility to risks such as project delays, cost overruns, and safety incidents. Current related research mainly focuses on broader and traditional construction safety practices, but due to the advancement of technology in construction, it lacks a method to evaluate safety management. Therefore, this research identifies key elements that influence safety resilience on construction sites. Applying the 4M framework (Man, Machine, Media, Management) to identify critical indicators for enhancing safety resilience. Central to these findings are strategies such as money as an additional framework, and robust risk identification and assessment, which ensure potential hazards are effectively mitigated. Adaptive decision-making and clear communication channels further support dynamic responses to on-site changes and implementing real-time monitoring and feedback systems enables immediate identification and resolution of risks. The study adopts a multifaceted approach, including a systematic literature review, stakeholder interviews, and structured questionnaires, to identify and evaluate key factors influencing construction safety resilience. We expect the insights gained from this research to provide practical guidance for construction companies aiming to improve safety performance. By adopting resilience-focused measures, organizations can reduce the impact of accidents, enhance operation efficiency, and promote a safer, more sustainable work environment. This approach not only prioritizes worker well-being but also reinforces the construction industry's commitment to long-term safety and resilience.

Keywords: Resilience; Potential hazards; Safety performance; Sustainable work environment; Risk.

1.0 Introduction

The construction sector significantly contributes to global economic growth and job creation (Marsh, 2024). However, rapid expansion in this industry presents challenges related to resilience, safety, and risk management (Aidoo *et al.*, 2021).

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Common issues such as uncertainties in project scope, cost overruns, and schedule delays can adversely affect project success (Zhang *et al.*, 2022). Implementing strategic solutions, particularly resilience models, is crucial to mitigate these risks and enhance safety throughout construction projects (Schafer *et al.*, 2008). A resilience framework enables construction companies to anticipate potential risks, adapt to unforeseen challenges, and implement robust safety measures (Construction Business Brokers, 2024). By integrating resilience principles into project management processes, businesses can improve their ability to handle disruptions, ensuring operational continuity and efficiency (Marsh, 2024). This structured approach facilitates proactive risk assessment and the development of contingency plans, embedding adaptability and flexibility into construction management (Eynce, 2023).

The construction industry involves a diverse range of stakeholders, each with distinct expectations and concerns. As teams navigate various transitions, project complexity increases, necessitating flexibility while adhering to established strategies (Canadian Construction Association, 2021). Adapting to evolving client expectations, regulatory changes, and external pressures adds another layer of complexity (Wall Street Journal, 2024). A systematic approach that balances risk reduction with operational efficiency is essential to maintain safety in this context (Time, 2025). Applying resilience measures in construction safety promotes long-term sustainability, enhances productivity, and leads to better project outcomes (Zhang *et al.*, 2022). By establishing robust risk management procedures, organizations can better withstand challenges, ensuring project success and the well-being of their staff (Aidoo *et al.*, 2021). Integrating resilience-based techniques into safety procedures is vital for creating a safe, adaptable, and efficient construction industry (Schafer *et al.*, 2008).

2.0 Literature Review

2.1 Understanding construction safety resilience

Resilience can be widely defined by the system's ability (e.g., ecological, organizational, psychological, etc.) to be aware of its surroundings and to adapt to recover once faced with disruptions (Folke, 2006). In engineering and construction, resilience is the ability to absorb or avoid damage without suffering complete failure. It is an objective of design, maintenance, and restoration of buildings and infrastructure, as well as communities (Bruneau *et al.*, 2003). Resilience is the capacity to bounce back from hardship, regain some semblance of normalcy following a shock or stressful event, or adjust to a new situation (Holling, 1973).

Resilience also refers to the ability of communities and structures at all levels and degrees of development to continue to function as habitable environments in the face of worsening or even catastrophic situations (Cutter *et al.*, 2008). Resilience thinking can help projects maintain their performance through flexible, systemic, and context-specific approaches once faced with disruptive events (Walker & Salt, 2006).

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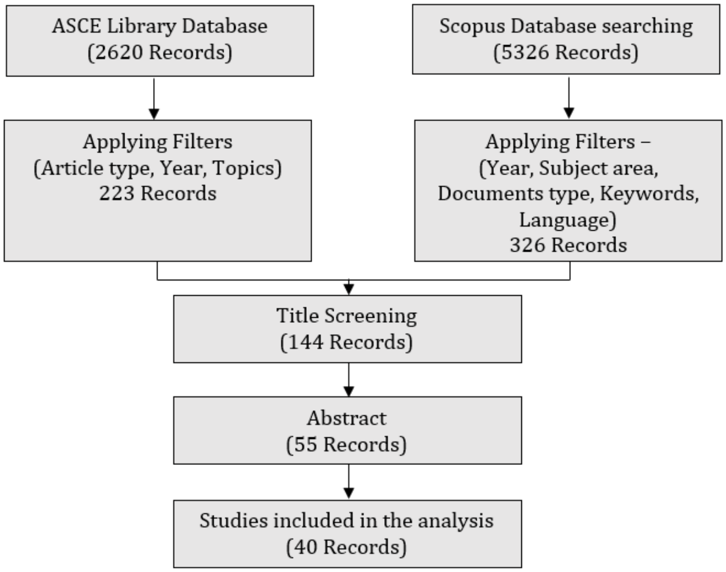
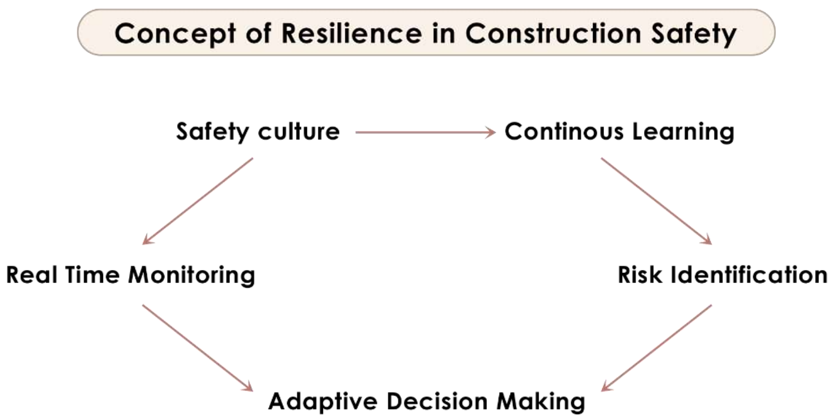
Figure 1: Systematic Literature Review



Source: Compiled by authors

Figure 2: Concept of Resilience in Construction Safety



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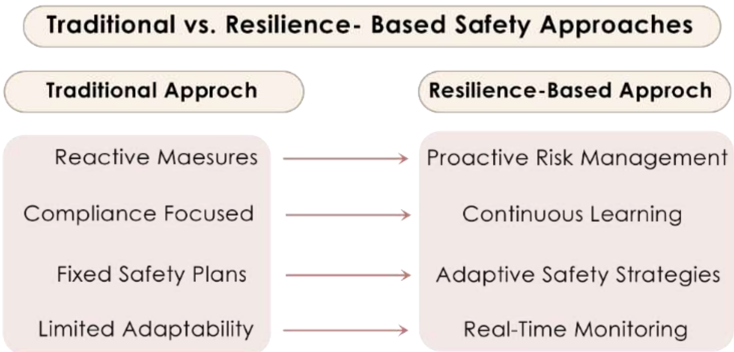
2.2 Resilience-based safety management approaches

Resilience-based safety management highlights proactive risk control, ongoing learning, adaptive safety measures, and real-time tracking to enhance safety on construction sites. In contrast to conventional strategies, this model prioritizes predicting risk, modifying responses to varying conditions, and reacting quickly to incidents. By incorporating real-time information and supporting adaptive decision-making, resilience-based approaches develop a more adaptable and resilient safety framework, which adds to overall project stability and the protection of workers. (Qian, 2023).

Figure 3: Traditional vs Resilience based Safety Approach



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3.0 Research Gap and Rationale

Sufficient financial resources are critical for increasing safety resilience on construction sites because they enable risk-reduction methods, training programs, and technology developments. Adequate financing allows access to high-quality personal protective equipment (PPE), innovative safety monitoring systems, and technical controls that reduce workplace dangers. It also promotes thorough safety training, which provides managers, supervisors, and employees with the ability to evaluate hazards, resolve crises, and make sound decisions. A well-funded safety framework encourages frequent site inspections, constant safety exercises, and the use of new technology like automated reporting and real-time danger detection systems to develop a proactive safety culture.

4.0 Research Methodology

4.1 Data collection

Once the survey instrument was finalized and the sample was selected, the data collection process began. Respondents were asked to complete the survey. The goal was to collect enough data to ensure meaningful analysis, with a focus on obtaining responses that reflected both the breadth and depth of project complexity.

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4.2 Data entry and management in SPSS

Data entry: Once the primary data (e.g., survey responses) was collected, it was entered into SPSS either manually or by importing files like Excel or CSV (Pallant, 2020). Each respondent's answers were entered as rows (cases), and variables (survey questions) were arranged as columns (Field, 2018).

Variable setup: For each survey question, variables were properly defined. In SPSS, variables were set up to reflect the type of data they represented (nominal, ordinal, interval, ratio) (Bryman & Cramer, 2011). Their properties, such as labels, values, and measurement levels, were defined accordingly (Tabachnick & Fidell, 2019).

Descriptive statistics: Descriptive statistics were used to summarize the basic features of the data and provide a straightforward overview of the sample (Hair *et al.*, 2020). In SPSS:

Frequencies: Frequency distributions were created to count how many times each response appeared in the data (Pallant, 2020). This helped identify trends in categorical data, such as the number of respondents who selected a particular answer (Field, 2018).

Measures of central tendency: SPSS computed mean, median, and mode to provide an understanding of the central point of the data, especially for Likert scale or numerical questions (Tabachnick & Fidell, 2019).

Measures of dispersion: SPSS computed standard deviation and variance, giving insights into the variability of the data (Hair *et al.*, 2020). For example, it showed how consistent or diverse the responses were regarding the complexity factors (Bryman & Cramer, 2011). SPSS was a robust tool that proved invaluable in the research on identifying and evaluating the key variables influencing the complexity of construction projects (Pallant, 2020). By using SPSS for tasks such as data entry, descriptive analysis, factor analysis, regression, and testing relationships between variables, reliable insights were obtained, and conclusions were drawn based on statistical evidence (Field, 2018). The software's ability to handle both quantitative and qualitative data made it an ideal choice for this study, providing a comprehensive analysis of the factors contributing to complexity in construction projects (Hair *et al.*, 2019).

5.0 Data Analysis and Findings

5.1 Relative Importance Indices (RII)

The Relative Importance Index (RII) is a widely used statistical tool for ranking and prioritizing various factors based on survey responses. It is extensively applied in fields such as construction management, project management, and social sciences to assess the relative significance of different parameters (Holt, 1998; Chan & Kumaraswamy, 2002). The formula for the Relative Importance Index (RII) is expressed as follows (Tam *et al.*, 2000; Assaf & Al-Hejji, 2006):

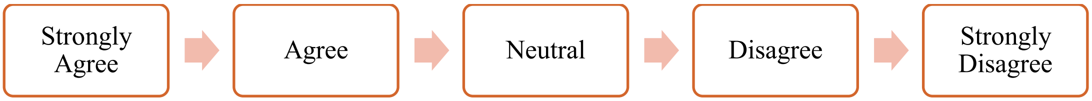
$$\text{Relative Importance Index(RII)} = \frac{\sum W}{A * N} = \frac{5n_5+4n_4+3n_3+2n_2+1n_1}{5 * N}$$

W: Weighting given to each factor by the respondent (e.g., 1 for strongly disagree to 5 or strongly agree)
A: the highest weight in the research (i.e. 5)
N: Total number of respondents

5.2 Questionnaire analysis (5 step approach)

- *Step 1:* We have listed the scale on a 1-5 scale by following-

Figure 4: Scale (Likert Scale)



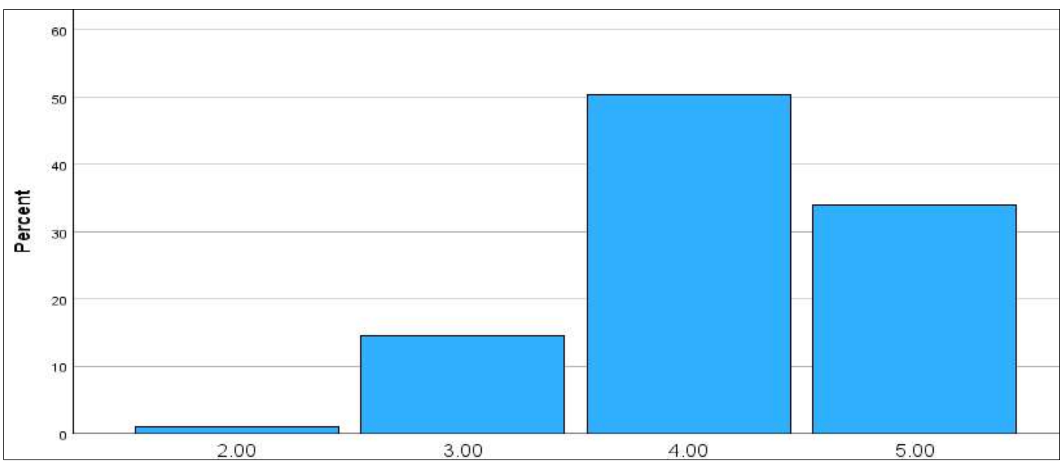
- *Step 2:* First, the data was converted to a numerical representation. With SPSS software, a frequency analysis was then carried out as part of the analysis. For example:

Table 1: Representation of Each Answer (in Percentage)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	1	1	1
	3	15	14.6	14.6	15.5
	4	52	50.5	50.5	66
	5	35	34	34	100
	Total	103	100	100	

Source: Compiled by authors

Figure 5: Representation of Each Answer (In Percentage Graph)



Source: Compiled by authors

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Table 2: Mean Score of Each Factor

Factors	Strongly Agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly Disagree (1)	No. of Responses
Man	38.2	46.6	16.4	1.6	0.2	103
Media	34.25	42.5	24.5	1.5	0.25	103
Machinery	30.2	47.2	16	9.2	0.4	103
Management	37.8	43.8	17.4	2.4	1.6	103
Money	41.6	46.8	10	4	0.6	103

Source: Compiled by authors

Table 3: Relative Importance Index

Factors	Strongly Agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly Disagree (1)	Total	Total No of responses (N)	A*N	RII
Man	191	186.4	49.2	3.2	0.2	430	103	515	0.834951
Media	171.25	170	73.5	3	0.25	418	103	515	0.81165
Machinery	151	188.8	48	18.4	0.4	406.6	103	515	0.789515
Management	189	175.2	52.2	4.8	1.6	422.8	103	515	0.820971
Money	208	187.2	30	8	0.6	433.8	103	515	0.84233

Source: Compiled by authors

- *Step 3:* For each factor, five core questions were identified. These questions were then categorized, and the mean score for each category was calculated accordingly.
- *Step 4:* We have applied the relative index formula (Figure 4)
- *Step 5:* The factors have been ranked in order of importance based on the collected Relative Importance Index (RII) data.

Table 4: RII Data and Ranking

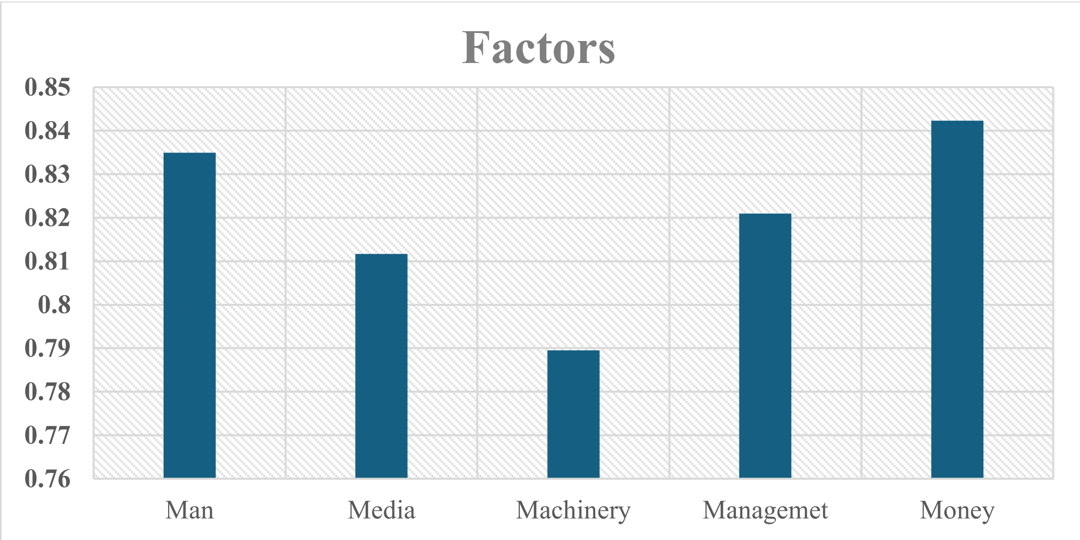
Factors	RII	Ranks
Money	0.84233	1
Man	0.834951	2
Management	0.820971	3
Media	0.81165	4
Machinery	0.789515	5

Source: Compiled by authors

5.3 Interview analysis

- *Step 1:* Data collection
- *Step 2:* Selection of best qualitative data analysis approach

Figure 6: Factors Ranking



Source: Compiled by authors

Table 5: Qualitative Approach

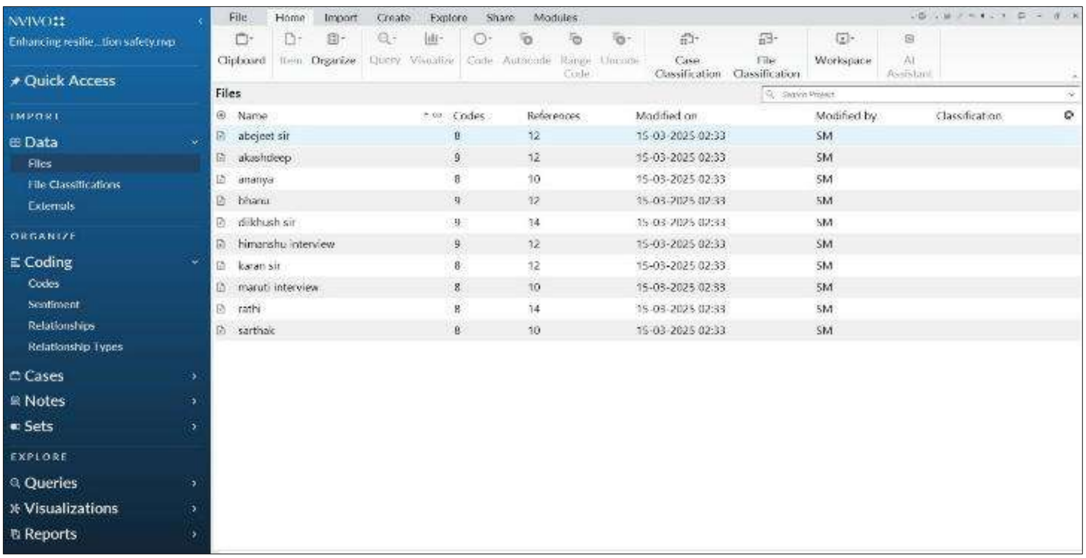
Responded	Experience (in years)	Domain	Designation
1	6 years site 20+in academia	Execution & Planning	Assistant prof.
2	8+ years	Real estate, Interior, Industrial projects	Quantity surveyor & techno commercial associate
3	2+	Infrastructure, Heritage & Building projects	Safety Engineer in Consultancy
4	3+ years	Infrastructure Metro projects	Site engineer under Consultancy
5	5+ years	Real estate and commercial projects	Site engineer under Contractor Party
6	12+ years	National Highway Infrastructure	Safety Engineer under Client party
7	5 years	Infra Metro Projects	Site Engineer under Client party
8	6 Years	Metro projects	Site Engineer under Contractor
9	31+ years	Real Estate, infra-highway projects	General Project Manager
10	12 years	Real Estate and commercial projects	Planning and costing engineer

Source: Compiled by authors

Thematic analysis is an agile and inclusive qualitative research method well suited for the identification of patterns and meanings in data. It provides a direct step-by-step procedure that guides researchers in investigating intricate experiences and social phenomena. It is a more precise and systematic way of analysis with the guarantee of coherence to pre-defined themes. It is also valuable in testing or developing already established theories and responding to targeted research questions, enriching the depth and applicability of findings. (Braun, V., & Clarke, V. 2006)

- *Step 3: NVIVO Software:* Reflexive Thematic Analysis (RTA) is a qualitative research approach that identifies, analyses, and interprets patterns (themes) in data. RTA, developed by Braun and Clarke (2006, 2019), is frequently utilized in several areas such as psychology, social sciences, and business research. It is a fluid, iterative technique that recognizes the researcher’s active participation in topic development, rather than taking an objective, detached posture. The reflexive thematic analysis process included the following steps in analysing +qualitative data:
- *Familiarization with the data:* In the first step of reflexive thematic analysis, the researcher familiarized with the data by transcribing the interview transcripts.

Figure 7: Importing the Interview Files (Contain the Whole Details of the Interview)



Source: Compiled by authors

- **Generating initial codes:** After familiarizing with the data, the second step of reflexive thematic analysis, is generating initial codes. The initial codes generated in Nvivo 15 are shown in the table below: developed by Braun and Clarke (2006, 2019)

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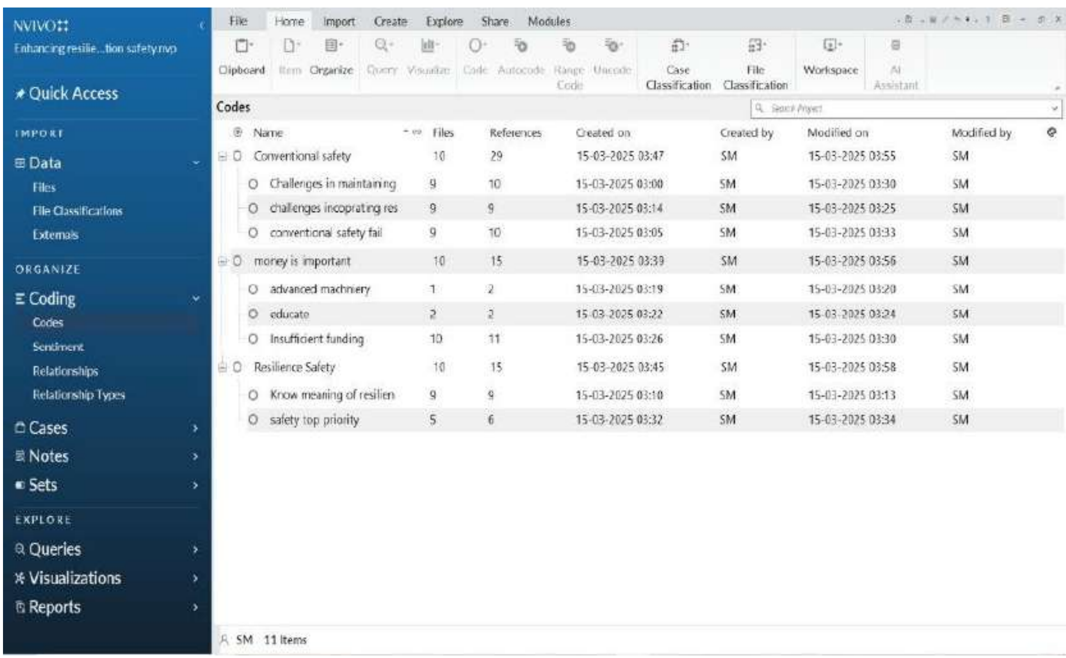
Table 6: Initial Coating

Name	Files	Reference
Challenges in maintaining	9	10
Challenges incorporating resilience	9	9
Conventional safety fail	9	10
Advanced Machinery	1	2
Educate	2	2
Insufficient funding	10	11
Knowing the meaning of resilience	9	10
Safety top priority	5	6

Source: Nvivo software

- **Generating theme**: After generating the initial codes, the review the identify patterns and relationships, grouping related codes into broader themes. These themes were then refined and revised to ensure they effectively addressed the study's research questions. Finally, each theme was given a name that aligned with the research objectives, providing a clear and structured framework for analysis. As shown in (Figure 9).

Figure 8: Generating Theme



Source: Nvivo software

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Table 7: Exported Code Book (NVIVO)

Conventional safety	This includes the challenges faced in maintaining and incorporating resilience, justification for failure of conventional practices	10	29
Challenges in maintaining safety on-site	Timeline, OSHA rules not followed, unpredictable activities, budget constraints, lack of awareness of safety	9	10
Challenges incorporating resilience in conventional	Mindset, continuous monitoring, limited data from previous projects, absence of contingency funds	9	9
Conventional safety fail	Ignored instructions, Limited funding, Unavailability of resources (machinery)	9	10
Money is important	Money plays an important role	10	15
Advanced Machinery	Modern cranes, feature advanced mechanisms, reduce operational risks	1	2
Educate	Incentives for safety protocols, Toolbox talk, Safety training workshops	2	2
Insufficient funding	Contractor excludes budget for safety, builders struggle to secure optimal pricing, and developers see safety funds as an expense	10	11
Resilience Safety	Proactive approach important in safety	10	15
Know meaning of resilience	Safety resilience is effective ,1/3 of accidents reduced, effective implementation of safety	9	9
Safety top priority	Strict safety practices, advanced safety mechanisms, Modern machinery	5	6

- *Producing the report:* The final stage of the reflexive thematic analysis process involved producing the report. The report represented the different codes and how they came together to form themes that answered the research questions posed in the study. The report also included excerpts representing the statements of different interviewed participants as evidence of different codes and themes. The table below shows the final codes and themes. (Braun and Clarke (2006, 2019)

6.0 Result and Conclusion

6.1 Interpretation of research findings

The data in this study was analyzed using the Relative Importance Index (RII) and a structured questionnaire to determine the essential aspects impacting resilience in construction safety. The study also used statistical tools like SPSS (Statistical Package for the Social Sciences) to process, evaluate, and draw relevant conclusions from the acquired data. The results of both methodologies give a full assessment of critical safety resilience elements and their implications for building projects.

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1. *Relative Importance Index (RII):* Analysis was employed to rank the factors affecting safety resilience based on their significance. The formula used for RII calculation is as follows in (Figure 7) The calculated RII values for each factor were ranked accordingly to determine their relative importance in (Table 4) The most important component was money (financial investment in safety measures), demonstrating that adequate financing is vital to achieving safety resilience. The second most significant component was human engagement (man), which emphasised the need of competent labour, training, and awareness in reducing construction dangers.
2. *Questionnaire Analysis:* A five-step questionnaire study was carried out to confirm the relevance of these elements.
   - *Step 1:* The poll employed a Likert scale (1 to 5) to assess respondents' views on safety resilience variables.
   - *Step 2:* The obtained data was transformed to numerical values and frequency analysis was performed using SPSS.
   - *Step 3:* Each factor's mean score was calculated to determine the amount of effect.
   - *Step 4:* The RII method was used to rank the components based on statistical data.
   - *Step 5:* A final ranking of criteria was calculated, as seen in Table 4.

     The questionnaire analysis results support the RII method's findings, reinforcing the idea that financial investment, human resource management, and effective leadership in safety programs all play an important role in building resilience.
3. *Interview Analysis (Qualitative Insights):* To supplement the quantitative study, structured interviews were undertaken with industry specialists (engineers, contractors, project managers, and safety officials) to acquire qualitative insights regarding construction safety resilience. The key conclusions from the interviews include: The importance of financial investment was emphasized by many experts, highlighting the need for major expenditure on safety measures, including equipment, training, and technology integration (Smith & Johnson, 2020; Patel *et al.*, 2021). Studies indicate that organizations that allocate sufficient financial resources for safety enhancements report fewer workplace incidents (Brown & Lee, 2019).

The need for trained labor was another crucial factor identified, as respondents stated that worker awareness and training programs significantly improve safety resilience. Poorly trained workers were found to be a significant risk factor in construction projects (Gonzalez *et al.*, 2018; Zhang & Kumar, 2022). Research suggests that continuous training and certification programs can enhance compliance with safety protocols and reduce accident rates (Williams & Turner, 2020). Additionally, management responsibility was highlighted as a critical component, with experts stressing that leadership plays a pivotal role in adopting effective safety measures and ensuring regulatory compliance (Davis & Clark, 2017).

Effective leadership fosters a culture of safety, where managers actively enforce protocols and encourage worker participation in safety initiatives (Robinson, 2021). These

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findings highlight the importance of a multimodal approach that combines financial resources, human experience, modern technology, and strong leadership to improve construction safety (Anderson *et al.*, 2019; Miller & Chen, 2023).

6.2 Summary of key findings

After analysing RII values, questionnaire responses, and interview insights, the following significant conclusions were reached.

- Financial investment (money) is the most important aspect in improving safety resilience since it dictates the ability to invest in technology, training, and processes.
- Human factors (Man) have an important role in construction safety, notably in skilled labor, danger awareness, and successful collaboration.
- Strong management (leadership) is required to guarantee compliance with safety requirements and the implementation of proactive safety policies.
- Communication (Media) enhances safety resilience by ensuring that safety regulations and danger warnings are delivered in real-time to all stakeholders.
- Machinery (automation and monitoring systems) helps to build resilience by decreasing manual mistakes and enhancing site safety through predictive analytics.

7.0 Recommendations

Integrating safety costs in initial rate analysis: During the initial rate analysis and budgeting phase of building projects, safety factors should be considered, and a separate budget allocation for safety measures should be made. Safety is a critical component of every construction project, and its expenditure should not be considered an accidental or supplementary expense. Instead, a distinct and well-defined budgetary allocation should be made to cover protective equipment, hazard prevention strategies, emergency response plans, and regulatory compliance. Organizations that incorporate safety expenditures from the start of a project can assure greater adherence to safety procedures, reduce cost escalations due to accidents or noncompliance, and improve overall project efficiency.

Shifting mindset and promoting a proactive safety culture: To build a proactive safety culture, construction professionals must first change their perspective and willingness to prioritize safety. Safety should not be considered as a simple statutory obligation, but as a critical operational characteristic that necessitates continual conversations and the execution of preventative actions. Encourage industry professionals, contractors, and workers to actively participate in safety-related discussions, which will result in increased awareness, accountability, and adherence to established safety measures. Organizations may drastically minimize worker accidents and increase construction project resilience by emphasizing the need for preventative measures, frequent safety exercises, and hazard awareness training.

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Improving safety compliance through policy reforms: To increase organizational motivation to apply complete safety measures, incentive-based safety standards should be implemented, comparable to the recognition mechanisms used in sustainable building. Green construction programs such as IGBC (Indian Green construction Council) accreditation reward buildings that follow sustainable principles with benefits such as improved Floor Area Ratio (FAR), brand recognition, and increased market value. A similar strategy may be taken for construction safety compliance, with businesses who strictly follow safety regulations receiving government incentives, policy advantages, or industry recognition. Establishing a structured incentive framework would motivate enterprises to prioritize safety, resulting in a more secure and resilient construction sector while also enhancing compliance with safety requirements.

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CHAPTER 62

Estimating Project Cost of Energy-Compliant Building

Shashwat Prajapati[1], Khanjan Gupta[2], Arpit Pandey[2] and Sourish Roy[2]

ABSTRACT

Energy-efficient buildings are structures specially designed to reduce energy consumption while sustaining or improving comfort and functionality. These buildings attain efficiency through various combinations of design, construction techniques, materials, and technologies that help minimize energy use for lighting, heating, cooling, and other operations. In the current scenario, energy-efficient buildings are essential for mitigating climate change by reducing greenhouse gas emissions and addressing rising energy costs through lower consumption. Energy conservation is therefore the need of the hour, for which energy-efficient buildings need to be encouraged, and stakeholders' concerns about heavy initial capital investment must be addressed with a justified and rational analysis. This research zeroes in on investments related to the initial cost of building envelopes and does a comparative analysis of different materials that can be used in energy-efficient buildings with those used in conventional buildings. The energy conservation building code (ECBC) is taken into consideration for designing building envelope and deriving costs associated with the materials and operation of the building taking special attention on HVAC (Heating, Ventilation and Air conditioning) systems. The research highlights using efficient materials to offset the additional expenditure for incorporating them. The findings of this research include an alternative analysis of conventional and energy-efficient building materials. It further examines the trade-off of choosing energy-efficient materials over conventional options.

Keywords: Energy-efficient buildings; Building envelopes; Building materials; HVAC.

1.0 Introduction

There has been a recent surge in interest in green buildings which is mainly driven by environmental concerns and a push for resource optimization that has sparked numerous research endeavours worldwide with an aim to increase understanding of the cost implications of sustainable construction. This study aims to estimate the project cost of an energy compliant building by studying a wide array of studies which will provide a holistic review of the economic landscape surrounding green buildings.

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This project aims to explore and address the critical aspects of energy-compliant buildings by focusing on energy compliance standards, the application of advanced tools and techniques, and the estimation of project costs. The economic aspect of green buildings is an important factor for employing sustainable practices. Research done by Lu *et al.* (2023) highlighted the role of Building Information Modeling (BIM) in cost reduction and an increased collaboration between multidisciplinary teams. The presence of a complex relationship between green building variables and property value was highlighted by Utomo *et al.* (2022), while Lee *et al.* (2023) showcased that energy-saving benefits can offset the initial construction costs of the Zero Energy Buildings (ZEBs).

Additionally, researchers have looked into the various methods to assess the green building economics and also introduced quantitative methodologies like regression models and a hybrid qualitative-quantitative method as Case Based Reasoning (CBR) (Alshamrani (2017); Leśniak *et al.* (2018). Others looked into administrative and engineering solutions that focused on strategies for cost optimization and validated the long-term savings associated with high-performance designs (Clark *et al.* (2000); Basten *et al.* (2018). Further studies identified the need for a holistic perspective regarding the assessment of green building projects throughout its lifecycle. Barathi *et al.* (2022) highlighted economic feasibility and Manjunath *et al.* (2021) research highlighted the environmental benefits of sustainable materials, while Gashaw *et al.* (2023) cemented the importance of the holistic evaluation models and Illankoon *et al.* (2017) highlighted a balanced consideration of economic, social, and environmental factors. Some studies also revealed the deterrents of sustainable construction practices such as the significant effect of policy interventions and technological advancements.

Dalirazar *et al.* (2023) by employing the PESTEL framework identified the barriers to adoption and proposed solutions, while Ashokkumar *et al.* (2020) emphasized a positive correlation between indicators of sustainability and certification levels. Furthermore, research by Saini *et al.* (2022) looked into combating climate change by making sustainable practices a necessity and Mohanta *et al.* (2022) highlighted the improvement of facility management. India has many topographic variations to understand its effect on sustainable construction practices and costs. Literature on regional variations and contextual factors influencing green building economics was referenced. A region- specific evaluation model for Ethiopian projects was developed by Gashaw *et al.* (2023) while Reddy *et al.* (2018) highlighted the importance of context-specific frameworks in India which involved local context, regional variations, and climatic conditions. The local certification patterns and regulatory interventions in Poland and Kolkata were studied by Plebankiewicz *et al.* (2019 and Kumar *et al.* (2021), respectively. Through this study we aim to understand the financial prospects associated with sustainable construction practices as well as calculating the costs of energy-compliant buildings in India, in accordance with the GRIHA (Green Rating for Integrated Habitat Assessment) and IGBC (Indian Green Building Council) certification which has been of the utmost importance in construction industry. GRIHA (Green Rating for Integrated Habitat Assessment) and IGBC

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(Indian Green Building Council) rating systems which promote sustainable building practices by assessing the building parameters centering on energy efficiency, water conservation, waste management, and indoor environmental quality are especially designed for the Indian conditions.

2.0 Research Objective

The research objective includes

- review and analyze numerous green building systems in the Indian context.
- investigate various tools and techniques applied in green building.
- compare cost packages of conventional building and energy-compliant building.

3.0 Review of Literature

This literature review highlights the approaches and various findings in the area of energy-compliant building design and cost analysis. Building Information Modeling (BIM) has played a key role in transparent valuation processes evidently that support AI models for life cycle cost analysis in green buildings and encourage multidisciplinary collaboration. Green buildings are found to be economically viable despite having greater construction costs on the trade-off of reduced operating costs. While evaluating green buildings, other techniques including Case-Based Reasoning (CBR),

Work Breakdown Structure (WBS), and Regression Models are helpful in identifying various cost components. Research indicates that implementing an initial cost prediction mode is essential to the project's economic viability. While it is confirmed that green building variables collectively influence property value rather than individually, it is not feasible to conduct a complete assessment of a project at this time.

Therefore, the project must be divided into work packages for better results. Research indicates that energy-compliant buildings can lead to substantial cost savings. Overall construction cost reduction is visible in the reports (up to 15.2% and 30%, respectively) by adopting sustainable materials and practices (Prajwal *et al.* (2021); Manjunath *et al.* (2021). This indicates the economic viability of energy-compliant designs. Reddy *et al.* (2018) gives us an in-depth understanding of sustainable building assessment tools, comparing LEED, GRIHA, IGBC, and BREEAM.

The study emphasizes the need for a new Sustainable Building Assessment Tool (SBAT) specially designed for India's unique climatic and regional conditions. It emphasizes the dire need of qualitative and quantitative methods for effective evaluation. Study of Plebankiewicz *et al.* (2019) gives us an analysis on the costs and benefits of green certification for office buildings in Poland, highlighting the need for integrated assessment systems. As mentioned above, India has three widely followed ratings systems for green buildings: LEED

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(Leadership in Energy and Environment Design), GRIHA (Green Rating for Integrated Habitat Assessment), and BEE (Bureau of Energy Efficiency) which are the key players in driving energy efficient by setting certain standards that makers need to comply. This helps ensure that buildings are affordable to build over the long term and acts as an important business case for governments considering new building codes, rating systems etc. Some of the tools and techniques include Life Cycle Cost (LCC) analysis, payback period Net Present Value (NPV), sensitivity analysis regression & life cycle cost analyses. Life cycle costing Blomberg *et al.* Case-Based Reasoning (CBR), Work Breakdown Structure (WBS), green construction, Critical Path Method Techniques (Wei *et al.*, 2013; Singh *et al.*, 2022).

The methods used are to identify major cost driver factors, predict maintainability performance (Mohanta *et al.*, 2022), and enable collaboration among stakeholders. Although the construction costs of a green building are higher, there is mounting evidence that they are financially justified given the significant savings in operating expenses and energy expenditure (Barathi *et al.*, 2022). Studies such as Prajwal *et al.* (2021) and Manjunath *et al.* show cost reductions of up to 15.2% and 30%, respectively, in sustainable materials & methods (2021). Accurate first-cost estimation models are critical for the success of projects (Gashaw *et al.*, 2023).

4.0 Research Methodology

In this study, a hypothetical commercial building model is created through BIM interface. Four different scenarios are evaluated doing variations in building envelopes and subsequent variation in civil, mechanical and electrical component cost. The layout for commercial building is shown in Figure 1. A 165-meter square floor area commercial office building has been taken in this study. Location of the building is assumed to be in Mumbai, India (Climatic zone- warm and humid). The analysis has been done to understand the cost variation between conventional and ECSBC building, their effect on HVAC requirements and building envelope selection. Autodesk Revit (BIM) software is used for the analysis of building models.

4.1 Comparison between conventional and energy efficient building

The present study is based on the standards for energy-efficient buildings that have been set by ECSBC and a comparison between envelope material for super ECSBC building and conventional building has been made. The building is considered for a hot and humid geographical area i.e. Mumbai, India. This study focuses majorly on the building envelope of energy-efficient and conventional buildings. The major concern is to cater to the building by minimizing the cooling load using different low U-value materials. The materials for conventional buildings are adopted from the general practice; for energy efficient buildings super ECSBC guidelines are being followed.

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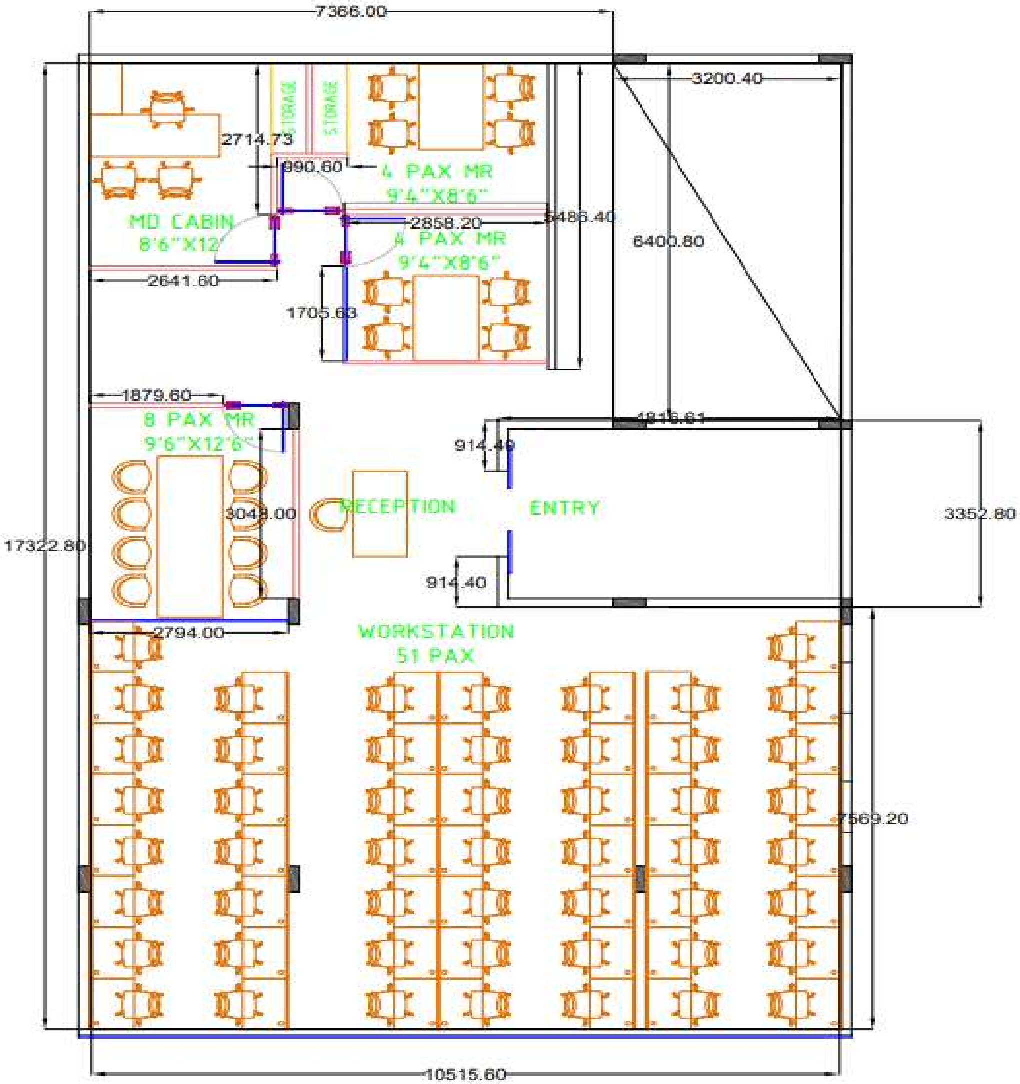
Figure 1: Building Layout



Source: Compiled by author

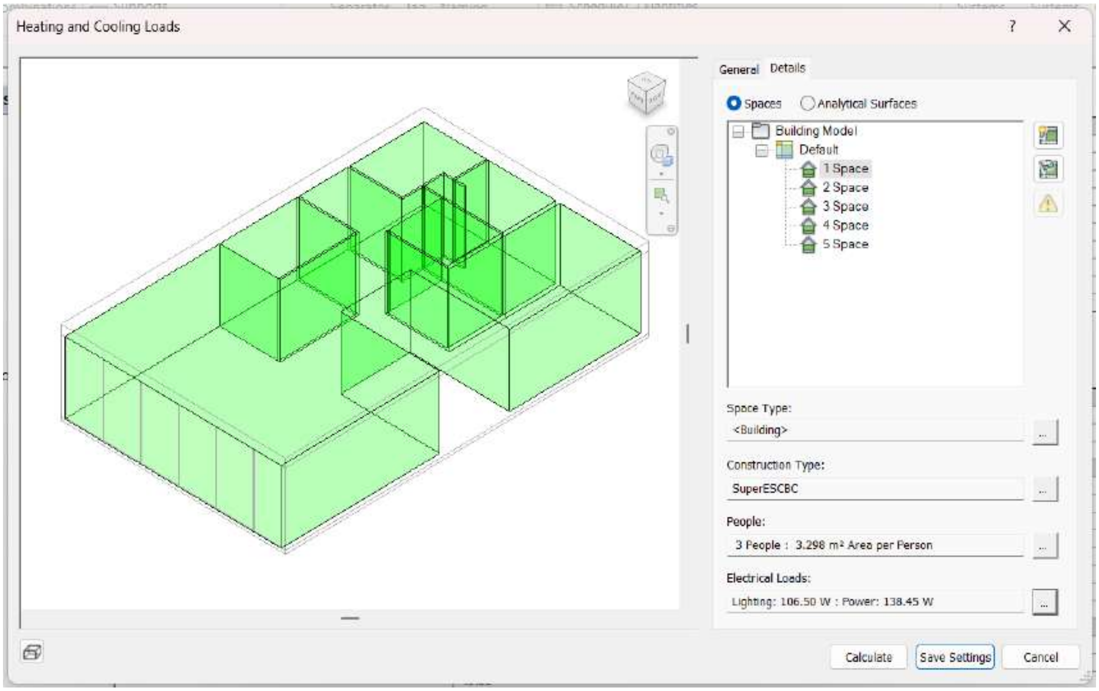
4.2 Load calculation

We utilized the appropriate software, Revit, and followed the necessary steps to perform the load calculation. Below are the materials that can be used for the envelope of both kinds of buildings and their respective U-values which will help to identify the best-suited material for the construction.

Table 1: Thermal Properties of Building Materials

Category	Conventional	Scenario1 (ECSBC)	Scenario2	Scenario3
Heat transfer coefficient value for roof, W/m^2K	2.54	0.17	0.17	0.17
Heat transfer coefficient value for wall, W/m^2K	2.08	0.18	0.4	0.7
Heat transfer coefficient value for glass, W/m^2K	3.76	1.4	1.4	1.4
Solar Heat Gain Coefficient for glass	0.86	0.26	0.26	0.26

Figure 2: Heating & Cooling Load Calculation Dialogue Box in Revit



Source: compiled by author

For the simulation of HVAC load in Revit, the materials with low U-value that ranges between Super ESCBC standards are selected for the energy-compliant building, and materials with higher U-values are selected for conventional buildings. The materials were selected based on the availability in the market and the software. Heat gain for a building depends on the material of the envelope. Lower U-value materials are advised to reduce the HVAC load. Using Autodesk Revit software building model is simulated to get a better understanding of variations in the HVAC load of conventional and energy-efficient buildings.

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Table 2: Load Calculation Assumption

Occupant	71
Sensible gain (W)	73.27
Latent gain (W)	58.61
Equipment load (W/m^2)	13.99
Lighting load (W/m^2)	10.76

5.0 Data Analysis and Findings

A single-story building located in Mumbai, India to analyze and compare the envelope costs of two building types: a conventional building and an energy-compliant building. The comparison will be conducted concerning their respective energy consumption profiles, that is, HVAC power requirements as well as initial construction costs.

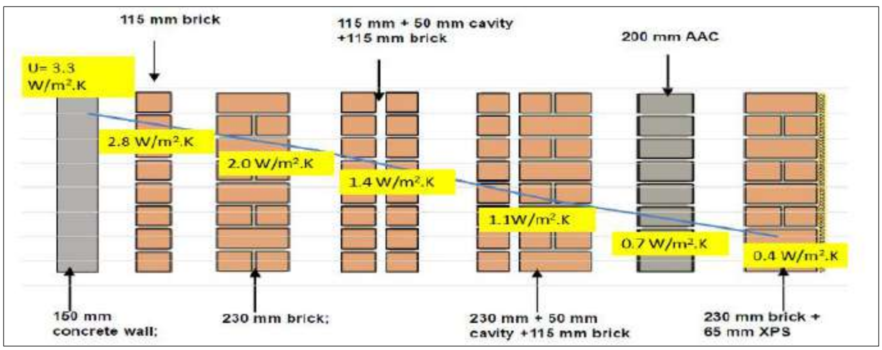
5.1 Conventional and energy-efficient building material u-value and BOQ comparison

Building Type: Office; Location: Mumbai, India; Area: 164 m^2; Volume: 550.93 m^3

Table 3: Comparison of load calculation

	Conventional Building	Energy Efficient Building Scenario 1(ACC Block with 50mm PIR insulation)	Energy Efficient Building Scenario 2(Conventional Brick with 65mm XPS)	Energy Efficient Building Scenario 3(ACC Block)
Total Load(W)	52,510	36,285	37,633	39,067
Sensible Load(W)	41,765	26,807	28,155	29,589
Latent Load(W)	10,745	9,478	9,478	9,478
Airflow(L/s)	3,004.50	1,808.80	1,910.70	2,019.10
Heating Load(W)	5,780	1,704	1,920	2,213
Heating Airflow(L/s)	317.6	217.6	217.6	217.6

Figure 3: U value of Building Materials used in Study



Source: https://beepindia.org

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5.2 Assumption

Unitary air conditioning cost = 35,118 INR per TR (as per Market Studies).

5.3 Comparison of building envelope cost

Major cost components are brickwork, concreting and insulation work.

Table 4: Comparison between the Cost of Building Envelopes for Different Scenario

Scenario	Conventional Building	Energy Efficient Building Scenario 1 (ACC Block with 50mm PIR insulation)	Energy Efficient Building Scenario 2 (Conventional Brick with 65mm XPS insulation)	Energy Efficient Building Scenario 3 (ACC Block)
Construction Cost (INR)	9,20,976	12,78,193	13,39,905	11,80,993

5.4 Comparison of AC cost

Table 5: Comparison of Cost of Air Conditioning

Scenario	Conventional Building	Energy Efficient Building Scenario 1(ACC Block with 50mm PIR insulation)	Energy Efficient Building Scenario 2 (Conventional Brick with 65mm XPS insulation)	Energy Efficient Building Scenario 3 (ACC Block)
AC Cost (INR)	5,24,312	3,62,067	3,75,763	3,90,108

5.5 Variation in initial and AC cost

Table 6: Variation in Cost for Different Scenario

Scenario	Energy Efficient Building Scenario 1(ACC Block with 50mm PIR insulation)	Energy Efficient Building Scenario 2 (Conventional Brick with 65mm XPS insulation)	Energy Efficient Building Scenario 3 (ACC Block)
Total Initial Cost (Conventional building) (INR)	14,45,288	14,45,288	14,45,288
Total Initial Cost (Energy Efficient building) (INR)	16,40,260	17,15,668	15,71,101
Percentage Variation	13.49% Higher	18.7% Higher	8.705% Higher

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6.0 Conclusion, Limitations and Recommendations

The key objectives associated with energy-compliant building are addressed by looking into the tools and techniques applied and estimating the project cost. The study emphasized the significance of following standards like the Energy Conservation and Sustainable Building Code (ECSBC) and Super ECSBC, which are essential for reducing energy consumption and encouraging sustainability. It pointed out the use of advanced tools such as Building Information Modeling (BIM) for simulating building performance and estimating life cycle costs, alongside methodologies like Case-Based Reasoning (CBR) and Work Breakdown Structure (WBS) for cost optimization. The cost analysis showed us that while energy-efficient buildings have higher initial construction costs, they provide long-term savings in operational and maintenance expenses, especially in HVAC systems. By using low U-value materials and advanced insulation, these buildings reduce cooling loads, showing economic viability over their lifecycle.

The research also highlighted the variation in initial and HVAC system costs, emphasizing the importance of choosing energy-efficient materials due to their lower HVAC operation and maintenance costs. It showed that energy-compliant buildings have reduced operational costs in the long run and that the comparative load between energy-compliant and conventional buildings increases with building area. The correct selection of energy-efficient materials was found to have a prominent impact on HVAC load. Moreover, the study tried to bridge the gap between BIM technology and end-users, providing insights that can facilitate more decision-making in sustainable construction projects. Overall, the research provides a compelling case for adopting energy-compliant building practices, offering a framework for sustainable and economically efficient construction projects.

6.1 Limitation

Challenges associated with the green building are as follows:

- The cost of energy-efficient buildings will be reduced with the availability of energy efficient materials locally.
- The amount of carpet area plays a significant role in total savings and this study have been conducted on a small carpet area.

6.2 Recommendations

Creation of Open-Source Modules to find the complete project cost for small to medium size projects which can be used by owners to make a preliminary decision. The use of locally found materials should be encouraged to reduce costs. The energy complaint building should be designed to fulfil the requirements of green building standards in order to attain its desired certification.

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CHAPTER 63

Evaluating Risk Management in Construction through Knowledge-Based Practices: A Spearman's Rank Correlation Analysis

Zoeb Younus Ali[1], Mandar Wadhonkar[1], Abhay Anand[1] and Shivam Padole[2]

ABSTRACT

Risk management is a critical aspect of construction projects due to their inherent complexity and uncertainty. This study explores the effectiveness of knowledge-based risk management (KBRM) practices in mitigating risks within the construction industry. Traditional risk management strategies often rely on reactive measures, which may not sufficiently address the dynamic nature of construction risks. This research investigates the role of knowledge-sharing, historical data utilization, and expert judgment in enhancing risk mitigation efforts. A structured survey was conducted among construction professionals, including project managers, engineers, and risk analysts, to assess their perception of KBRM practices. The study employs Spearman's Rank Correlation Analysis to establish the statistical relationship between the adoption of knowledge-based practices and risk reduction effectiveness. Findings indicate a positive correlation, highlighting the significance of structured knowledge management systems in identifying and mitigating project risks. The results suggest that integrating KBRM into existing risk frameworks improves decision-making, enhances risk prediction accuracy, and fosters a proactive risk management culture. The study provides valuable insights for construction firms and policymakers, advocating for the incorporation of knowledge-based strategies to enhance project resilience and sustainability.

Keywords: Risk management; Construction industry; Knowledge-based practices; Relative importance index; Spearman's rank correlation.

1.0 Introduction

The construction industry is characterized by high levels of uncertainty due to its complex nature, making risk management a critical aspect of ensuring project success. Effective risk management strategies help minimize financial losses, improve decision-making, and enhance overall project efficiency. more structured approach to mitigating risks by leveraging historical data, expert judgment, and collaborative strategies.

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Traditional risk management techniques primarily focus on reactive measures, often failing to address risks proactively. The incorporation of knowledge-based practices offers a This study employs Spearman's Rank Correlation Analysis to statistically analyze the relationship between the adoption of KBRM and its effectiveness in mitigating risks. The research investigates the extent to which structured knowledge-sharing, learning-based approaches, and data-driven decision-making contribute to improved risk management outcomes. The findings aim to provide construction firms with actionable insights for integrating knowledge-based strategies into their existing risk management frameworks. This research contributes to the existing body of knowledge by providing data-driven insights into the effectiveness of knowledge-based risk management in construction projects. By establishing a clear correlation between KBRM and improved risk mitigation outcomes, the study seeks to encourage broader adoption of structured knowledge-sharing practices within the industry. Ultimately, the research aims to enhance project resilience and sustainability by advocating for more systematic and proactive risk management approaches.

1.2 Research objectives

The primary objective of this research is to examine the impact of Knowledge-Based Risk Management (KBRM) on risk mitigation in construction projects. The study aims to:

- Identify the key risk factors affecting construction projects and assess their impact on project performance.
- Evaluate the role of knowledge-based practices in construction risk management.
- Analyze the relationship between knowledge-based risk management and risk mitigation effectiveness using Spearman's Rank Correlation Analysis.

1.3 Research questions

To address the research objectives, the study focuses on the following key research questions:

- What are the primary risk factors influencing construction projects, and how do they impact project outcomes?
- How do knowledge-based practices contribute to improved risk management in construction?

2.0 Literature Review

Risk management in the construction industry has evolved from traditional reactive approaches to more proactive, knowledge-based strategies. The complexity of construction projects necessitates a structured risk management framework that incorporates historical data, expert judgment, and analytical tools to improve decision-making. This chapter provides an

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overview of risk management methodologies, highlights key risk factors, and explores the role of knowledge-based practices in enhancing risk mitigation.

2.1 Risk management in construction

Risk management in construction involves the identification, assessment, and mitigation of risks that may impact project success. Traditional risk management techniques primarily rely on qualitative assessments and reactive strategies, which often result in inefficiencies and project delays. Modern approaches emphasize the integration of quantitative analysis, technology-driven risk assessment, and knowledge-sharing frameworks to improve risk prediction and mitigation.

Key risk factors in construction

Construction projects are exposed to multiple risks, including:

- *Financial risks:* Cost overruns, budget constraints, and fluctuating material prices.
- *Operational risks:* Delays due to labor shortages, poor project planning, and supply chain disruptions.
- *Technical risks:* Design errors, quality control issues, and material defects.
- *Regulatory risks:* Compliance with safety regulations, environmental laws, and contractual obligations.
- *Environmental risks:* Natural disasters, extreme weather conditions, and climate change impacts.

Understanding these risk factors is essential for developing effective mitigation strategies that enhance project efficiency and reduce uncertainties.

2.2 Methodology: PRISMA approach

The systematic review follows PRISMA methodology, which involves four phases:

- Identification: Searching databases for relevant studies.
- Screening: Applying inclusion and exclusion criteria.
- Eligibility: Evaluating the relevance and quality of studies.
- Inclusion: Finalizing the selection of studies for analysis.

2.3 Systematic literature review flowchart

The Initial search generates 4952 results in many languages from various subject areas. Engineering, Engineering Sciences, CS, Social are vague words, and had attracted many articles from fields like medicine, IT infrastructure, business, etc. Therefore, the irrelevant results/ articles were screened out based on criteria mentioned:

2.4 Knowledge-based risk management (KBRM)

Knowledge-based risk management leverages past project data, expert insights, and collaborative decision-making to improve risk mitigation. Unlike traditional methods, KBRM focuses on:

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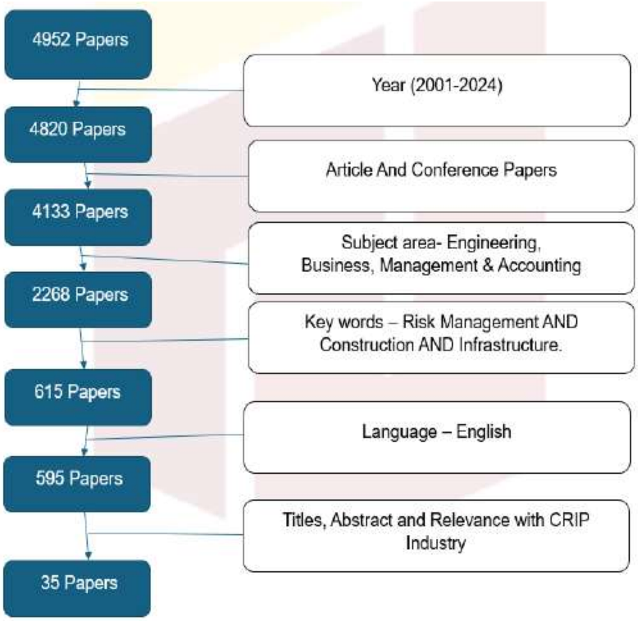
Figure 1: Systematic Literature Review Flowchart



- *Data-driven decision-making:* Using predictive analytics and AI for risk assessment.
- *Expert knowledge integration:* Incorporating lessons learned from previous projects.
- *Collaborative risk management:* Encouraging stakeholder participation in risk identification and resolution.

2.5 Emerging technologies in risk management

Recent advancements in technology have significantly improved risk assessment and mitigation in construction. Key innovations include:

1. *Artificial Intelligence (AI):* AI-powered tools analyze project data to predict potential risks and suggest preventive measures.
2. *Building Information Modeling (BIM):* BIM enhances risk visualization and improves coordination among project stakeholders.
3. *Digital Twins:* Virtual replicas of construction sites enable real-time monitoring and proactive risk management.

2.6 Research gaps and future directions

Limited empirical studies validating the impact of knowledge-based risk management.

- The need for standardized frameworks integrating KBRM into construction practices.
- The role of AI and machine learning in predictive risk analysis remains underexplored.

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3.0 Reseach Methodology

This study adopts a quantitative research methodology to analyze the impact of Knowledge-Based Risk Management (KBRM) on construction risk mitigation. The methodology includes a questionnaire survey**,** Likert scale analysis**,** Relative Importance Index (RII), and Spearman's Rank Correlation Analysis to assess and interpret industry insights.

3.1 Questionnaire survey

A structured questionnaire was designed to collect data from construction industry professionals, including project managers, engineers, risk analysts, and consultants. The survey aimed to capture their perceptions of KBRM effectiveness and how it influences risk mitigation. The questionnaire contained Likert-scale questions to measure respondents' opinions on various risk management factors, such as the role of knowledge-sharing, the impact of past project data, and the efficiency of knowledge-based risk mitigation strategies. The survey was distributed digitally and targeted at professionals with at least five years of industry experience to ensure informed responses.

3.2 Likert scale

A 5-point Likert scale was used to evaluate responses, ranging from Strongly Disagree (5) to Strongly Agree (1). The Likert scale facilitated the quantification of subjective perceptions. The collected responses provided a structured dataset for statistical analysis and ranking of risk management factors.

The Relative Importance Index (RII) is calculated using the following formula:

$$RII = \frac{\sum(W_i \times X_i)}{(k \times n)}$$

Where:

- RII is the Relative Importance Index for an item.
- W_i is the weight assigned to the i^{th} level of the Likert scale.
- X_i is the frequency of respondents who chose the i^{th} level of the Likert scale.
- k is the highest level on the Likert scale.
- n is the total number of respondents.

In the formula, $\sum(W_i \times X_i)$ represents the sum of the product of the weights and frequencies for each level of the Likert scale.

Relative Importance Index (RII) is a widely used statistical tool to determine the relative importance of different factors in research studies, especially in construction management, social sciences, and engineering. It helps in ranking factors based on their level of significance according to survey respondents' ratings.

Spearman's Rank Correlation Analysis was applied to measure the strength and direction of the relationship between KBRM practices and risk mitigation effectiveness. The Spearman coefficient (ρ) was calculated using:

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$$r_s = 1 - \frac{6\sum D^2}{n\left(n^2 - 1\right)}$$

where; rs = Spearman's rank correlation coefficient
D = Difference between the two ranks of each observation
n = number of observations

The coefficient rs ranges from -1 to +1:

- +1+1 indicates a perfect positive correlation, where an increase in one variable is matched by a proportional increase in the other.
- −1-1 signifies a perfect negative correlation, meaning an increase in one variable corresponds to a proportional decrease in the other.
- 00 suggests no correlation, indicating no consistent pattern in the ranking relationship.

4.0 Data Analysis and Result

The data analyzed, is derived from a structured questionnaire distributed among professionals in the construction industry. The responses were collected using a Likert scale, enabling a quantitative assessment of various risk factors and their management through knowledge-based practices. The collected data has been systematically processed and is presented in tabular format for clarity and ease of interpretation.

Table 1: Relative Importance Index (RII)

Questionnaire	**Que.**	**Overall Rank**	**Client**	**Consultant**	**Contractor**
	n = 14	R0	R1	R2	R3
1. Is knowledge management crucial for risk management?	C1	1	3	2	1
2. Do lessons learned reduce future risks?	C2	2	1	4	2
3. Are knowledge-based tools used for risk identification?	C3	8	3	4	13
4. Are risk databases consulted in planning?	C4	12	10	12	7
5. Does expert judgment prevent common risks?	C5	4	8	4	4
6. Is past project data essential for risk strategies?	C6	11	8	12	7
7. Is training provided for knowledge-based risk management?	C7	13	14	11	11
8. Does knowledge sharing minimize execution risks?	C8	2	1	4	2
9. Does technology enhance risk management?	C9	8	5	8	7
10. Is historical data used for risk mitigation?	C10	14	11	12	14
11. Does a knowledge-based approach improve project success?	C11	6	5	8	5
12. Are KM systems updated to address new risks?	C12	4	5	1	11
13. Does access to KM systems aid in unforeseen risks?	C13	10	11	8	7
14. Does KM-based risk management prevent pitfalls?	C14	6	11	2	6

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4.1 Relative Importance Index (RII)

Ranking in Table 1 highlights the key factors influencing knowledge-based risk management in construction projects. The highest-ranked factor, "Is knowledge management crucial for risk management?" (C1), indicates that industry professionals strongly recognize its significance. Similarly, "Do lessons learned reduce future risks?" (C2) is ranked second, reinforcing the importance of past experiences in mitigating risks. Factors such as the use of knowledge-based tools (C3) and historical data (C10) also show high relevance. Conversely, aspects like training for knowledge-based risk management (C7) and database consultation in planning (C4) received lower rankings, suggesting areas for improvement in industry practices. This analysis provides valuable insights for enhancing risk management strategies through structured knowledge-sharing and learning-based approaches.

4.2 Spearman's rank correlation analysis

Values in the Table 2 indicate the strength of agreement between different stakeholder groups (Client, Consultant, and Contractor) regarding the ranking of risk management factors. The highest correlation (R12 = 0.5824) between Clients and Consultants suggests a moderate to strong agreement in their perspectives.

Meanwhile, the correlation between Clients and Contractors (R13 = 0.4923) and between Consultants and Contractors (R23 = 0.4044) shows a moderate level of alignment, though slightly weaker. The average correlation (r-avg = 0.4930) reflects an overall moderate agreement among stakeholders. This suggests that while there is consensus on key risk management factors, some variations in prioritization exist, possibly due to differences in roles, experiences, and risk perception in construction projects.

Table 2: Spearman's Rank Correlation Analysis

Rs 1-2	0.5824
Rs 1-3	0.4923
Rs 2-3	0.4044
R-Avg	0.4930

4.3 Organization type distribution chart

The organizational graph illustrates the structured flow of knowledge-based risk management within a construction firm. It highlights key roles and their interactions, emphasizing how knowledge is shared, processed, and applied to mitigate risks. The hierarchy ensures that risk-related information flows from project teams to decision-makers, facilitating informed choices and effective risk mitigation strategies.

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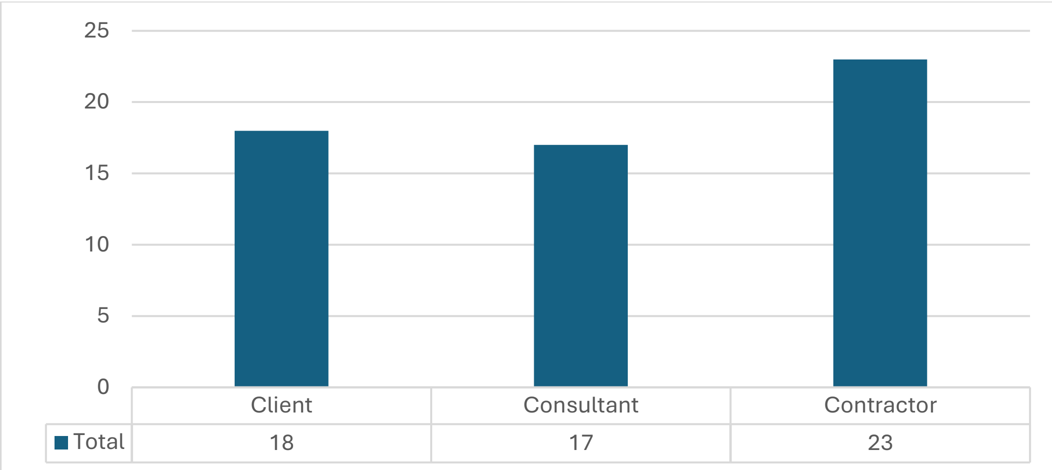
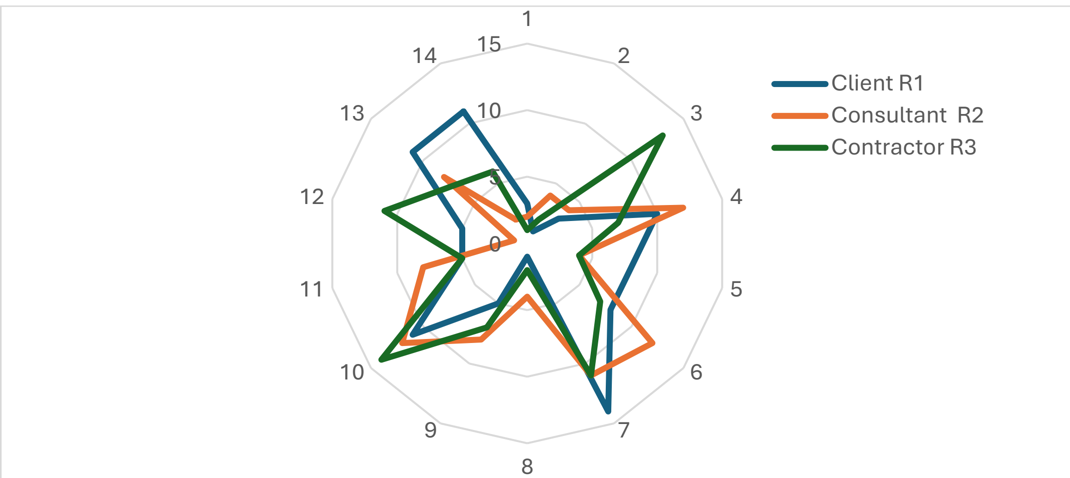
Figure 2: Count of Organization Type



4.4 Radar Chart

Figure 3: Rank Radar



The radar graph visually represents the significance of various risk factors across different stakeholders, such as clients, consultants, and contractors. Peaks in the graph indicate areas of strong agreement, while dips suggest differences in perception. The balanced distribution of values showcases which risk factors are considered more critical and where inconsistencies exist among stakeholders in prioritizing risk management aspects.

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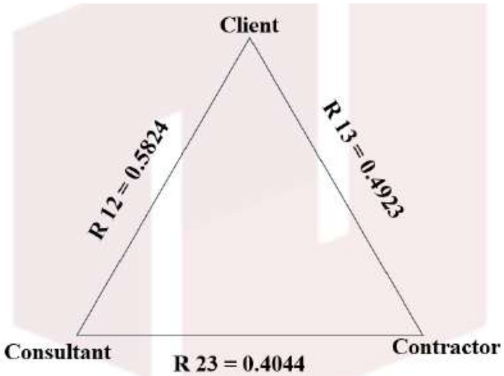
4.5 Spearman's rank correlation triangle (Figure 4)

The Spearman's correlation triangle represents the degree of agreement between different stakeholder groups regarding risk rankings. Higher correlation values indicate strong alignment in risk perception, while lower values suggest differing priorities. This visualization helps assess how well stakeholders align in their risk management strategies and where coordination can be improved for better project outcomes.

Figure 4: Spearman's Rank Correlation Triangle



5.0 Conclusion

This research highlights the significance of Knowledge-Based Risk Management (KBRM) in construction projects by examining its role in mitigating risks through structured learning and data-driven decision-making. The findings confirm that knowledge-sharing mechanisms, historical data utilization, and expert judgment play a critical role in improving risk management effectiveness. The RII analysis revealed that stakeholders prioritize risk management elements differently, while the Spearman's Rank Correlation demonstrated a moderate agreement among clients, consultants, and contractors regarding risk prioritization. Additionally, the integration of technology-driven solutions such as AI, BIM, and Digital Twins further enhances risk management efficiency. However, gaps in training, database utilization, and knowledge system updates indicate areas for improvement. Overall, this study validates that systematic knowledge management enhances risk mitigation and project success in the construction sector.

6.0 Recommendations

- *Implement structured knowledge management systems:* Construction firms should establish centralized knowledge repositories to document lessons learned, risk factors, and mitigation strategies for future projects.

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- *Enhance stakeholder collaboration:* Stronger communication channels between clients, consultants, and contractors can help improve alignment in risk perception and management strategies.
- *Improve training and awareness:* Conduct regular training sessions to equip professionals with knowledge-based risk management skills, ensuring better adoption of structured methodologies.
- *Leverage advanced technologies:* Utilize Artificial Intelligence (AI), Building Information Modeling (BIM), and Digital Twins to improve predictive risk analysis and real-time monitoring.
- *Optimize risk identification and response strategies:* Firms should refine their risk evaluation processes using data-driven decision-making to enhance mitigation measures.
- *Regularly update knowledge-based systems:* Keep knowledge management systems updated with new industry trends, risk factors, and mitigation strategies to ensure relevance and accuracy.
- *Encourage a learning-oriented culture:* Promote a continuous learning environment where professionals can share insights and best practices to enhance overall risk management effectiveness.

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CHAPTER 64

Evaluating Sustainability of Urban Transport in Cities

Poulomee Ghosh[1] *and Rushi Daund*[2]

ABSTRACT

Sustainable urban mobility is crucial in order to solve the urgent issues of growing urbanization, environmental degradation, and socioeconomic inequality in Indian cities. Through the identification of crucial factors obtained from an extensive survey of the global literature, this study explores the idea of sustainability in urban transportation. These criteria guide the creation of a comprehensive assessment methodology that evaluates the success of continuous sustainable transportation projects in Indian cities. The study identifies inequalities and regional obstacles to attaining sustainable urban mobility through a thorough spatial analysis carried out for a representative Indian metropolis. The results draw attention to important gaps and areas that require development, including equity, accessibility, and environmental effect. Building on these discoveries, the study suggests practical, situation-specific ways to improve urban transportation's sustainability. In order to encourage equitable and effective mobility, these solutions highlight the significance of integrated urban planning, the use of cleaner technology, and the improvement of public transportation infrastructure. This research provides a thorough method for urban planners and policymakers to change urban mobility systems, making them resilient, inclusive, and environmentally sustainable while also being in line with the larger objectives of sustainable urban development in India. It does this by fusing theoretical viewpoints with real-world applications.

Keywords: Sustainability urban transport; Evaluation framework; Transport policy; City structure; Public and private transport.

1.0 Introduction

The quick pace of urbanization over the globe has heightens weight on urban foundation, with transportation frameworks bearing a noteworthy share of the burden. Urban transport plays a basic part in forming availability, financial efficiency, and natural supportability, however it remains a major donor to nursery gas outflows, discuss contamination, and activity clog (D'Acierno *et al.*, 2022).

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Within the Indian setting, developing urban populaces and rising private vehicle proprietorship have assist strained transport frameworks, driving to declining discuss quality, expanded mischance dangers, and diminished versatility productivity (Monteiro *et al.*, 2024). Economical urban transport is basic to accomplishing broader advancement objectives. As characterized by the World Commission on Environment and Advancement (1987), maintainable advancement meets show needs without compromising future eras. Connected to transport, this infers frameworks that are financially practical, socially comprehensive, and ecologically mindful (Cheshmehzangi & Thomas, 2016). Endeavors such as metro frameworks, Transport Quick Travel (BRT), Non-Motorized Transport (NMT) foundation, and Brilliantly Transport Frameworks (ITS) have developed in Indian cities, however their adequacy remains changed and context dependent.

1.1 Research gaps in evaluating urban transport sustainability in India

Whereas worldwide writing on economical urban transport is developing, there stay basic investigate holes in assessing the supportability of urban transport activities inside the Indian setting. Systems created in progressed economies offer profitable bits of knowledge but may not straightforwardly apply to the complex socio-economic, infrastructural, and behavioral designs interesting to Indian cities. The tall thickness, blended arrival utilize, casual transport modes, and shifted commuter behavior request a context-specific approach. (*ESCAP-2017-RP-Assessment-Urban-Transport-Systems*, n.d.). In spite of the fact that different pointers and models exist for surveying transport supportability, a comprehensive and custom fitted system suited to Indian urban situations is missing.

Existing appraisals regularly center on disconnected measurements such as emanations or ridership, without tending to the complete range of financial practicality, social inclusivity, and natural affect. Additionally, observational assessments of economical transport activities in India are restricted in scope and once in a while receive a holistic focal point. There's a squeezing has to be recognize and prioritize parameters that reflect the substances of Indian cities, and to create an coordinates assessment framework that captures the interconnected dimensions of supportability. Furthermore, proposed arrangements regularly borrow from worldwide best hones which will not be doable within the Indian setting due to asset imperatives and nearby socio-cultural flow. Inquire about must in this manner center on defining down to earth, versatile, and context-appropriate procedures grounded in neighborhood substances. Bridging these holes is basic for advising arranging choices, directing arrangement, and guaranteeing the advancement of flexible, evenhanded, and feasible urban transport frameworks over Indian cities.

1.2 Aim of this study

In light of the recognized challenges and investigate holes, this ponder points to supply a comprehensive assessment of the maintainability of urban transport frameworks in Indian

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cities. It looks for to recognize key maintainability parameters significant to the Indian setting by investigating worldwide best hones and adjusting them to neighborhood conditions. Drawing from scholarly writing, arrangement reports, and reports with a center on creating economies, the ponder will create a custom-made assessment system that coordinates financial, social, and natural measurements. This system will be connected to survey chosen maintainable transport activities actualized over Indian cities.

The ponder assist points to propose reasonable and context-sensitive arrangements to improve the viability and long-term maintainability of urban transport frameworks. These recommendations will be grounded within the discoveries of the assessment and adjusted with the particular challenges and openings display in Indian urban situations. By tending to these targets, the inquire about extraordinary to offer important bits of knowledge for policymakers, urban organizers, and partners, contributing to more comprehensive, versatile, and ecologically sound urban portability methodologies over India.

2.0 Literature Review

2.1 Definition and background of sustainable urban transport

Economical urban transport is basic to adjusting the developing portability requests of urban populaces and economies with the goal to minimize natural corruption, advance social value, and guarantee long-term financial practicality. As urbanization quickens all inclusive, cities—now domestic to over half the world's population—face expanding weight on their transport framework. The diligent dependence on private vehicles contributes to antagonistic results counting activity clog, discuss and commotion contamination, street mischances, and rising nursery gas emissions. These impacts diminish urban quality of life and force critical financial costs. (Smieszek *et al.*, 2019) Worldwide systems, such as those supported by the European Union, have underscored the direness of turning around these patterns through driven objectives like decreasing transport-related emanations. Maintainable transport adjusts with the broader guidelines of economic improvement, pointing to meet show portability needs without compromising those of future eras.

It is coordinating financial reasonableness, social consideration, and natural stewardship—promoting open, secure, and productive frameworks for both individuals and merchandise. (Comi & Polimeni, 2024). In spite of decades of talk, the operationalization of economical transport remains a worldwide challenge. Modern definitions emphasize an all-encompassing viewpoint, enveloping not as it were natural impacts but to get to openings, open wellbeing, urban livability, and evenhanded development.

This worldview move absent from car-centric arranging is reflected in methodologies that prioritize decreasing travel request, bringing down emanations, and reinforcing open and non-motorized transport frameworks. Instruments such as Economical Urban Versatility Plans (SUMPs) represent this move, advertising coordinates, participatory systems for long-term

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arranging. In any case, their application must be custom fitted to the assorted spatial, regulation, and socio-economic settings of cities(Jordová & Brůhová-Foltýnová, 2021).

The concept of economical urban transport has picked up expanding consideration in later a long time due to the developing natural, financial, and social challenges postured by fast urbanization and motorization. Writing highlights that maintainability in transportation includes advancing open travel, non-motorized modes, decreasing outflows, guaranteeing availability, and upgrading security. Thinks about created and creating nations emphasize the require for coordinates arranging, proficient arrive utilize, and solid organization systems. Creators such as Litman (2017) and Rail (2008) contend that feasible portability goes past foundation to incorporate approach changes, administration, and behavioral alter. Within the Indian setting, different analysts have analyzed transport maintainability using diverse pointers, however there’s a need of a standardized system. Comparative evaluations stay restricted, particularly over numerous Indian cities utilizing overhauled information. This hole highlights the requirement for a uniform assessment strategy, which this ponders addresses by recognizing 39 important parameters drawn from worldwide and national investigate. The audit gives an establishment for evaluating transport systems’ maintainability through an organized, data-driven approach suited to Indian urban settings.

2.2 Past studies in sustainable urban transport

The interest of economical urban transport has picked up critical scholastic and arrangement consideration, driven by the critical got to address the natural, social, and financial impacts of car-dependent urban development. A developing body of multidisciplinary research—spanning building, arranging, financial matters, and natural studies—has reported the antagonistic impacts of motorized transport frameworks, counting diminished open wellbeing, natural debasement, and spatial disparity. These challenges emphasize the require for coordinates transport and land-use arranging that underpins compact, available, and proficient urban situations. (Golbabaei *et al.*, 2021). Later considers highlight a worldview move from routine transport models toward more feasible frameworks, emphasizing options such as open travel, strolling, cycling, shared portability, and low-emission cargo arrangements. Developments like shared independent vehicles (SAVs), last-mile coordinations optimization, and Transit-Oriented Advancement (TOD) are progressively investigated for their potential to diminish emanations, progress openness, and advance evenhanded versatility.

At the same time, rising evaluation frameworks—including execution pointers, multicriteria assessment strategies, and maintainability metrics—seek to degree the adequacy of transport intercessions in accomplishing long-term objectives. (Jordová & Brůhová-Foltýnová, 2021). Arrangement rebellions like Feasible Urban Versatility Plans (SUMPs) have developed as imperative instruments to institutionalize this move, especially in European settings. These plans emphasize partner support, cross-sectoral integration, and steady observing utilizing markers such as security, availability, discuss quality, and outflows. In spite of methodological

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progresses, challenges stay in harmonizing information, adjusting techniques to nearby settings, and adjusting transport frameworks with broader urban improvement objectives. The current talk progressively centers on creating comprehensive, adaptable, and context-sensitive approaches to assessing and directing the maintainability of urban transport frameworks over different city typologies. (Bertolini *et al.*, 2024a).

2.3 Study parameters from literature

Assessing the maintainability of urban transport frameworks requires a comprehensive investigation of interconnected natural, financial, and infrastructural parameters. Key natural pointers incorporate nursery gas emanations, discuss quality (particularly poisons like PM2.5), clamor contamination, and vitality consumption—all of which are impacted by modular choices and mechanical headways. Endeavors to decrease outflows through electric vehicles and progressed open transport are central to climate and open wellbeing goals. From a financial point of view, reasonableness, effectiveness, and transport commitment to urban financial development are basic. This includes looking at the costs of framework improvement, operation, and support, as well as the availability and reasonableness of transport for clients. Infrastructural parameters such as modular share, travel times, blockage levels, and the quality and scope of open transport specifically affect framework execution and maintainability. The accessibility of secure, well-connected foundation for strolling, cycling, and electric portability encourage bolsters a modular move absent from private vehicles. These parameters must be evaluated comprehensively and adjusted to each city's setting, with suitable weighting based on particular urban needs and maintainability objectives. (Jordová & Brůhová-Foltýnová, 2021).

3.0 Methodology

The investigate receives an organized technique to assess the maintainability of urban transport frameworks over five Indian cities—Pune, Bangalore, Hyderabad, Chennai, and Nagpur. The approach coordinating a broad writing survey, auxiliary information investigation, and comparative appraisal of 39 maintainability parameters, enveloping natural, financial, and infrastructural measurements. These parameters were distinguished through a comprehensive survey of insightful articles sourced from Scopus and Google Researcher, centering on topics such as blockage, mischance impacts, framework and operational costs, administration, development, and open cooperation. Information for each parameter was at first extricated from the Comprehensive Portability Plans (CMPs) of the particular cities. To guarantee significance and precision, overhauled information was collected from official sources counting MoHUA, metropolitan organizations, state transport offices, NITI Aayog, and distributed investigation. The information was at that point compared to survey advance, recognizing zones of enhancement or stagnation in transport maintainability. A standardized five-point rating scale was created to assess each city's execution, based on the variance between CMP projections and

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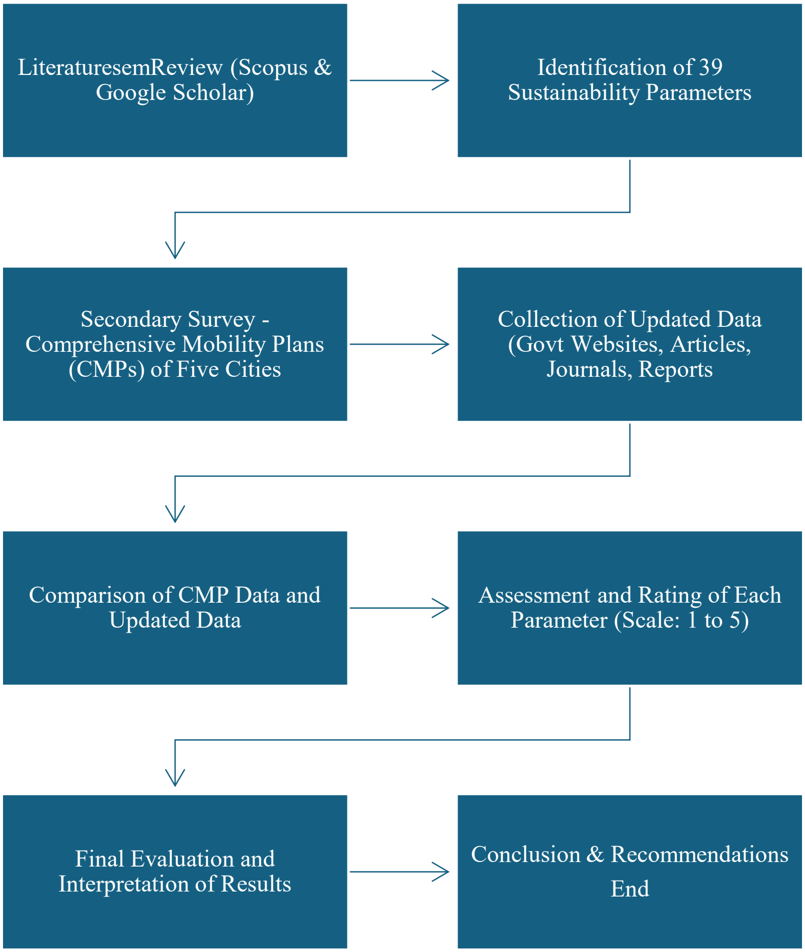
current information, taking under consideration approach execution, foundation advancement, natural affect, and client fulfillment. This strategy empowers a vigorous, comparative understanding of the supportability scene of urban transport in Indian cities.

Figure 1: Flowchart Representation of Methodology



4.0 Result

The supportability execution of urban transport frameworks in five chosen Indian cities—Pune, Bengaluru, Chennai, Hyderabad, and Nagpur—was assessed employing a standardized rating system based on 39 parameters. Each parameter was evaluated on a scale from 1 (Exceptionally Destitute) to 5 (Great), comparing projections from the Comprehensive Portability Plans (CMPs) with upgraded real-time information.

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	Pune	Bengaluru	Chennai	Hyderabad	Nagpur
Transport Infrastructure Cost vs Revenue	3.57	4	4	4	4
Public Transport Cost vs Revenue	3	3	2.75	3.5	3
Transport external costs	3.29	3.75	2.5	4.5	2.5
Financial Health of Transport Institutions	2.3	4	2.5	4	3.5
Accident	3	2.5	3.25	3	1.5
Impacts to habitats	2	1.75	2	3	2.5
Health aspects	2	3.2	3.21	3	2.5
Active citizens	3.5	3	4	4	3
Safety	2.5	3	3.5	4	2.3
Presence	3.5	4	3.14	4.8	2.5
Network/Connectivity	3.43	3.44	3.5	5	4
Accessibility	4	3.75	3.5	4	3
Ridership (Male/Female)	3.5	4	3.25	4	3.5
Multimodal Intergration	4.2	4	4	4	4.5
Emissions	4	3.7	4.5	4	4
Energy consumption	4	2.5	4	4	4
Affordability	3	3	4.4	4	3
Frequency	2	4	3.5	4.5	2.4
Reliability	2.9	4	4	3.5	2.5
Per Hour Per Day Traffic	4	3.25	4	1	3
Modal Share	3	3.5	4	2	2
Vehicle Ownership	4	1.8	2.5	2	2.6
Type of Vehicle	4.5	2	2.6	4.5	1.5
Distance/Avg Distance	4	3	3.46	3	2.3
Energy consumption	3	3	4	3	2
Congestion	3	2	4	3.5	2.5
Pollution	3.5	2.1	4	2	2.5
Road Density	2	2	3	4	2.6
Vehicle Density	2	2	3.85	2	2
Population Density	3.8	3	4	2	3.5
Occupancy	2.5	2.25	4	4	2.8
Land Use Intensity	3	3.65	2.5	4	3
Green Cover lost in Transport Project	3.5	2	2	3	2.5
Noise Pollution	3	2.5	4	3	4
Public Participation in Transport Planning	3.8	5	4	5	4
Policy and Regulatory Frameworks	4	4.5	4	4	3
Governance and Institutional Capacity	3	4	4	3.5	3
Public Transport Subsidies	5	4.3	4	4	4
Innovation in Transportation	3.5	4.5	5	4	4
Final Score	3.276666667	3.203589744	3.548974359	3.546153846	2.948717949

The examination uncovered that Hyderabad developed as the foremost maintainable city with a normal score of 3.56, reflecting viable arrangement usage, framework advancement, and progressed open transport results. Chennai was taken after closely with a score of 3.54,

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demonstrating solid advance in advancing feasible urban portability. Pune and Bengaluru, with scores of 3.22 and 3.17 individually, illustrated direct execution, highlighting the require for changes in transport proficiency and open fulfillment. Nagpur positioned least with a normal score of 2.99, proposing the require for more centered and coordinates techniques to upgrade supportability. These discoveries offer a comparative knowledge into the usage of economical transport measures over Indian cities and emphasize the significance of focused on approach mediations and framework improvement to make strides urban portability frameworks.

5.0 Conclusion

This consider presents a comprehensive assessment of the maintainability of urban transport frameworks over five major Indian cities—Pune, Bengaluru, Hyderabad, Chennai, and Nagpur—using a standardized system of 39 pointers. By comparing anticipated information from Comprehensive Portability Plans (CMPs) with upgraded real-time data, the investigation offers basic bits of knowledge into the adequacy of existing transport procedures and their on-ground usage. The comes about highlight Hyderabad as the foremost maintainable city, taken after closely by Chennai, whereas Nagpur positions least, signaling the require for more focused on intercessions. The discoveries emphasize the significance of persistent approach assessment, speculation in open transport framework, and comprehensive arranging forms to improve supportability results. This investigate not as it were given a replicable system for evaluating urban transport maintainability in Indian cities but moreover emphasizes the require for data-driven, versatile approaches in urban portability arranging. Future endeavors ought to center on coordination multimodal transport, fortifying administration components, and advancing ecologically mindful hones to construct versatile and impartial urban transport frameworks.

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CHAPTER 65

Examining the Land Value Increment Trend along Metro Transit Corridors in Pune

Ponnuru Venkata Phalguna Kumar[1] and Priyanka Bendigiri[2]

ABSTRACT

The Thesis aims to explore the Transit-Oriented Development in Pune along metro corridors. The Primary aim is to gain a comprehensive understanding of TOD principles around metro transit corridors and analysis the how transit-oriented Development effecting the different land use (Residential, Commercial, Health care, Recreational, etc.) in the terms of prices. Through comparative analysis, this research aims to find common trends, best practices, and challenges met in the TOD implementation process across the Pune city. Additionally, the study will assess the impact of TOD on factors such as urban mobility, land use efficiency, environmental sustainability, and social equity. This study gives an understanding about real estate sector of the city how it changes in land prices in TOD Zone and trends of the property prices changes in a period of Time so that we can understand that TOD is influencing the Land-uses. The findings of this research are expected to contribute to the existing body of knowledge on TOD and inform policymakers, urban planners, and practitioners about strategies for promoting sustainable and livable cities through transit-oriented development. By synthesizing lessons learned from diverse urban contexts, this thesis aims to help informed decision-making and support the development of more effective TOD policies and practices in India and beyond.

Keywords: Transit oriented development; Land-use; Land value; MRTS; Comparative analysis.

1.0 Introduction

Transit-oriented development (TOD) represents a pivotal strategy globally aimed at promoting urban and transportation sustainability. A vital challenge to the effectiveness of TOD is the spatial discordance between urban transit and land development (Cong *et al.*, 2024). Faced with the urban sprawl and the increasingly serious urban traffic problems caused by the sustained and rapid economic growth and fast development of urbanization, advocating the development of metro-led cities and intensive and compact development to form a green, transportation-oriented built environment has become a national strategic need (Chen, 2023).

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The Study focus on the effects of Mass Rapid Transit (MRT) systems in metropolitan cities, looking at both existing studies and new areas for future research. The primary goals are to examine the evolving publication scene, identify prominent individuals and entities, analyse keyword networks, and understand current research subjects. The study aims to provide a complete understanding of the effects of MRT systems to guide future research and inform urban planning decisions (Ranjan & Mandal, 2024).

TOD planning in India is necessary to address neighbourhood structure and transportation challenges in metropolitan areas. Transit-oriented development is a concept with different definitions, although it refers to high-density development through transit interaction. This method aims to decongest city nodes, arteries, with public transport to encourage people to walk or use non-motorized transport for significant travel (Dalwadi, 2022). This study aims to understand the Transit Oriented Development functions in different perspectives and public mode of transportation usage. Comparative analysis of TOD in different areas of the city and identifying common issues in that city. As part of this doing land value capture analysis and comparative analysis of different land uses at zones of that area. In this study it focuses on the comparative analysis of Transit Oriented Development of different areas of the city.

In this the Transit oriented development focus in the city but in different areas & different perspectives like Existing metro line surroundings and Proposed Metro line surroundings in different objectives like land value capturing, trend analysis, Analysis the situation of the study area etc.

1.1 Research questions

RQ: How the Transit Oriented Development in Pune city is influencing the functions of land and property development in different Areas?

1.2 Research objectives

The following research objectives are listed below:

RO1: To Identify the key issues that the cities are facing due to implementation of Transit system, Specifically Metro.

RO2: To assess how Transit Oriented Development (TOD) is influencing the land Prices in the Pune city.

RO3: To map the trends of land values of different land uses due to TOD over a time period in Pune city.

RO4: To perform a comparative analysis of land values of different land uses due to TOD over a Time

1.3 Study area

India’s real estate market is undergoing a remarkable transformation, reflecting changing aspirations and evolving spending behaviours that signal a pivotal shift for the sector.

While the luxury housing segment has gained prominence in recent years, there is an increasing tilt toward practical and mid-segment housing options, indicating a redefinition of buyer priorities. (Pai, 2024)

Maharashtra was the one of the states with having highest Property prices across the India due to rapid infrastructure development, population growth, Employment opportunities, etc. In Maharashtra Mumbai is the capital city and financial capital city so after this Pune is only city with has bit similar features with has good infrastructure development, network connectivity, and educational hub where students come from other cities, states and countries. At the same time there is lot of traffic congestion in Pune due to Infrastructure development, migration of people for better employment, and due to tourism attraction of the city.

The Pune District administration has intensified efforts to finalize land acquisition for the Pune Ring Road project; a critical infrastructure initiative aimed at reducing the city's traffic congestion. Of the total 1,740 hectares required, 1,300 hectares have already been acquired, leaving 200 hectares to be completed. (Pune News- Report)

So, we have selected Pune as study area and here we are concentrating on Metro routes of the city in different parameters like

- Metro connectivity should be available.
- Comparation between Proposed Metro Line and Existing metro line.
- Property Rates of the area should be available for last 10Years.
- Passenger Data of metro line in selected area.

So, we have selected 2 Study Areas they are:

Table 1: Study Area Details

District	Taluka	Village	Metro Strech	Metro line distance	Metro Type	Land Uses
Pune	Haveli	Kothrud	Vanaz to Ideal Colony	2 Kms	Elevated	Open Land, Residential Flat, Office, Shop, Industries
Pune	Haveli	Balewadi, Baner	Ram Nagar – Baner Gaow	3.3Kms	Elevated	Open Land, Residential Flat, Office, Shop, Industries

Source: Google Earth

2.0 Literature Review

2.1 Introduction

The Literature Review aims to analyse existing research on TOD, particularly in the context of Indian Metropolitan areas. The main theme was transit-oriented development

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impacting the land values around the TOD zone which was not comparable with the other areas of that city. It shows the effect on different land uses in that city. The relationship between metro system and land value appreciation has been a focus point in study. Transit accessibility often leads to increase property prices its surrounding areas.

2.2 Scopus search

The Scopus research database is used to find papers for literature review. ((“transit-oriented development”) AND (“cities”) AND (“Property Rates”) search string was used, which identified 747 papers from multidisciplinary fields of study. Out of them abstracts of 60 research papers were studied and analysis was drawn.

2.3 Theming

Based on the analysis drawn the papers were themed into 8 categories which are:

Table 2: Themes Identified from Papers

S. No	Title	Author	Summary
Case Studies and Comparative Analysis			
1	From city center to suburbs: Developing a timeline-based TOD assessment model to explore the dynamic changes in station areas of Tokyo metropolitan area	Yang W.; Yan W.; Chen L.; Li H.	The study develops a quantitative model to assess the sustainability of Transit-Oriented Development (TOD) station areas over time, using node-place-carbon dimensions and K-means cluster analysis, revealing a trend towards sustainability with some deviations and increased centralization in Tokyo’s station areas.
2	Spatial Relationships between Population, Employment Density, and Urban Metro Stations: A Case Study of Tianjin City, China	Lai Y.; Zhou J.; Xu X.	The study uses mobile phone data and spatial analysis methods to evaluate the impact of metro stations on population and employment densities in Tianjin, China, finding significant concentration around stations and identifying key factors influencing these patterns to support sustainable urban development.
3	Determination of Oriented Transit Development at Light Rail Transit Stations by the Process Hierarchy Analysis	Widyaningsih N.S.H.; Wan Mohtar W.H.M.; Muhammad I.R.	The study uses Analytic Hierarchy Process (AHP) to evaluate and select the Pasar 16 Ilir area in Palembang as the most suitable location for implementing Transit Oriented Development (TOD) among several options.
4	Built Environment Renewal Strategies Aimed at Improving Metro Station Vitality via the Interpretable Machine Learning Method: A Case Study of Beijing	Wang Z.; Li S.; Zhang Y.; Wang X.; Liu S.; Liu D.	The study uses extreme Gradient Boosting (XGBoost) and various pedestrian catchment area (PCA) combinations to assess the impact of the built environment on metro ridership in Beijing, identifying optimal PCA sizes and renewal priorities for metro stations.
5	Nonlinear effects of public transport accessibility on urban development: A case study of	Gao L.; Chong H.-Y.; Zhang W.; Li Z.	The study uses gradient-boosting decision tree (GBDT) analysis to examine the nonlinear relationship between public transport accessibility and urban development in the

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	mountainous city		mountainous city of Chongqing, China, highlighting the impact of metro and street accessibility.
Equity and Inclusivity in Urban Development			
6	Reflections on TOD in China: From land finance to inclusive growth	Su Y.; Wu Y.; Choguill C.L.; Luo J.; Yu X.	The paper evaluates the implementation of transit-oriented development (TOD) in China, using Hangzhou as a case study, and advocates for inclusive growth models that integrate TOD with affordable housing to address housing affordability and promote balanced urban development. This method involves analysing the impact of current land finance models and proposing new approaches for equitable urban growth.
7	Evaluating the level of access and equity of the bus rapid transit (BRT) system: The case of Dar-Es-Salaam, Tanzania	Mwesigwa L.; Yin Z.; Farber S.	The study evaluates the equity of Dar-es-Salaam's Bus Rapid Transit (BRT) system, finding that its benefits disproportionately Favor wealthier populations and suggesting improvements for better access for poorer communities. They used infrastructure-based measures of proximity to transit stations and stops to assess transit access and coverage relative to socio-economic strata.
8	Creating inequality in access to public transit? Densification, gentrification, and displacement	Lutz E.; Wicki M.; Kaufmann D.	The paper uses linked person-housing unit data to analyse the impact of densification around train stations in Zurich on socioeconomic population composition, revealing that while densification increases low-income residents in absolute terms, it primarily benefits higher-income households and increases displacement risks for low-income residents.
9	Towards an equity-centred model of sustainable mobility: Integrating inequality and segregation challenges in the green mobility transition	Tammaru T.; Sevtsuk A.; Witlox F.	The Special Issue presents an Equitable Sustainable Mobility Model, integrating non-auto accessibility with daily activity destinations, and addresses urban structure, segregation, and mobility to promote greener, more equitable urban mobility solutions.
Integrated Land Use and Transportation Planning			
10	Land Change Pattern in High-Speed Rail Station Area: Empirical Research on Yangtze River Delta Region in China from 2010 to 2020	Wang X.; Pan H.	The study uses statistical analysis of land cover scale and compactness indices to evaluate how high-speed rail (HSR) stations in the Yangtze River Delta have influenced land cover changes and urban development patterns over a 10-year period.
11	Analyzing the effect size of urban growth driving factors: application of multilayer-perceptron Markov-chain model for the Riyadh city	Al-Shaar W.	The study uses a Multi-Layer Perceptron Markov Chain model to predict urban growth in Riyadh for 2030 and 2050, focusing on the impact of road networks, railways, and other driving factors on future urban expansion.
Spatial Dynamics and Transportation Integration			
12	Integrating spatial vitality and node-place model to evaluate and classify metro station areas in Wuhan	Wu T.; Li M.; Gao L.; Zhou Y.	The paper introduces the node-place-vitality (NPV) model, incorporating vitality as a third dimension into the node-place model for Transit-Oriented Development (TOD), and uses it with K-means++ clustering in a case study of

			Wuhan, China, to re-evaluate TOD performance and spatial patterns.
13	Exploring Nelspruit as a Historical Spatial Jigsaw Corridor-Based Secondary City: A Spatial Governance Geographical Perspective	Chakwizira J.	The paper uses Transit-Oriented Development (TOD) theory to analyse and propose improvements for Nelspruit's urban development, focusing on integrating land use and transport systems to address inefficiency and enhance growth.
Sustainability and Environmental Considerations			
14	Smart urbanism, citizen-centric approaches and integrated environmental services in transit-oriented development in Jakarta, Indonesia	Suryawan I.W.K.; Mulyana R.; Yenis Septiariva I.; Prayogo W.; Suhardono S.; Sari M.M.; Ulhasanah N.	The paper introduces the node-place-vitality (NPV) model, incorporating vitality as a third dimension into the node-place model for Transit-Oriented Development (TOD), and uses it with K-means++ clustering in a case study of Wuhan, China, to re-evaluate TOD performance and spatial patterns.
15	Sustainable Low-Carbon Layout of Land around Rail Transit Stations Based on Multi-Modal Spatial Data	Liu W.; Zhang J.; Jin L.; Dong J.; Alfarraj O.; Tolba A.; Wang Q.; He Y.	The paper uses a "bottom-up" theoretical calculation method to model and analyze carbon emissions from transport, focusing on the distribution of land use around rail transit stations to propose strategies for reducing emissions.
16	Strategic planning for a sustainable local-regional transit-oriented development	Björling N.; Capitao Patrao C.	The paper discusses using strategic local-regional planning and mutual learning between local and regional actors to address uneven development and optimize regional investments in the context of Transit-Oriented Development (TOD) in Sweden.
Transit Oriented Development (TOD) Performance and Impact			
17	Macro level performance study of Ahmadabad bus rapid transit system: Janmarg	Pathak S.; Upadhyay R.K.	The research evaluates the factors limiting the ridership and growth of Janmarg, India's longest BRTS, and recommends strategies for optimizing its effectiveness using a combination of primary and secondary research methods.
18	Role of Transit-Oriented Development (TOD) in Making Healthy Cities—Case Delhi	Patill V.; Singh K.	The paper evaluates Delhi's Transit-Oriented Development (TOD) policy, integrated into the Master Plan for Delhi 2021, which aims to address urban challenges through mixed-use, pedestrian-friendly transit zones to improve liveability, sustainability, and environmental quality. The study analyses policy impacts and benefits on urban planning and quality of life.
19	Accessibility and Land Use Effect of Residential Area with Different TOD Typology to Value Creation	Arliani V.; Sjafruddin A.; Santoso I.; Winarso H.	The paper evaluates the impact of Transit-Oriented Development (TOD) on value creation by analysing accessibility and land use factors in different areas of Jakarta using AHP to compute TOD indices and correlating them with land and building prices, providing insights for targeted urban planning.

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20	The equity implications of TOD in Curitiba	Turbay A.L.B.; Pereira R.H.M.; Firmino R.	The paper analyses the socioeconomic and spatial impacts of Curitiba's Bus Rapid Transit (BRT) system on access to economic activities and public services, highlighting how TOD can exacerbate inequalities and affect low-income communities.
21	Equitable TOD (eTOD): Current Thinking and Solutions for the Future	Davis M.M.	The article reviews current literature on Transit Oriented Development (TOD) and equitable TOD (eTOD) methodologies, focusing on balancing the benefits of TOD with strategies to mitigate displacement and segregation of vulnerable urban residents.
Urban Expansion and Property Prices			
22	The Effect of Salt Marsh on Residential Property Values	Gardner, G.	This study uses a hedonic property price method to evaluate the effects of salt marshes on residential property values in the Eastern Shore of Virginia. Contrary to findings from wetland literature, results show an insignificant relationship between proximity to salt marsh and residential property values.
Commercial Real Estate Trends in CBDs			
23	Understanding green building energy performance in the context of commercial estates: A multi-year and cross-region analysis using the Australian commercial building disclosure database	Gui, X., Gou, Z.	To understand the relationship between green building energy performance and regional commercial estates, this study analysed Australia's Commercial Building Disclosure (CBD) program database.
24	Dynamics of the intra-urban hierarchy in Istanbul's metropolitan area	Kok, H.	Forecasted demographic growth and the massive urban development task, the commercial real estate market in Istanbul is likely to be among the most dynamic ones in Europe

Source: Scopus

- *Case studies and comparative analysis:* Examining urban development projects across different contexts to identify best practices and lessons learned.
- *Equity and inclusivity in urban development:* Assessing how urban policies and projects promote fair access to housing, mobility, and public spaces for all social groups.
- *Integrated land use and transportation planning:* Exploring strategies that align land use patterns with efficient transportation systems to enhance accessibility and reduce congestion.
- *Spatial dynamics and transportation integration:* Analysing how urban spatial structures influence travel behaviour and infrastructure development.
- *Sustainability and environmental considerations:* Evaluating the environmental impact of urban growth and planning strategies for sustainable development.

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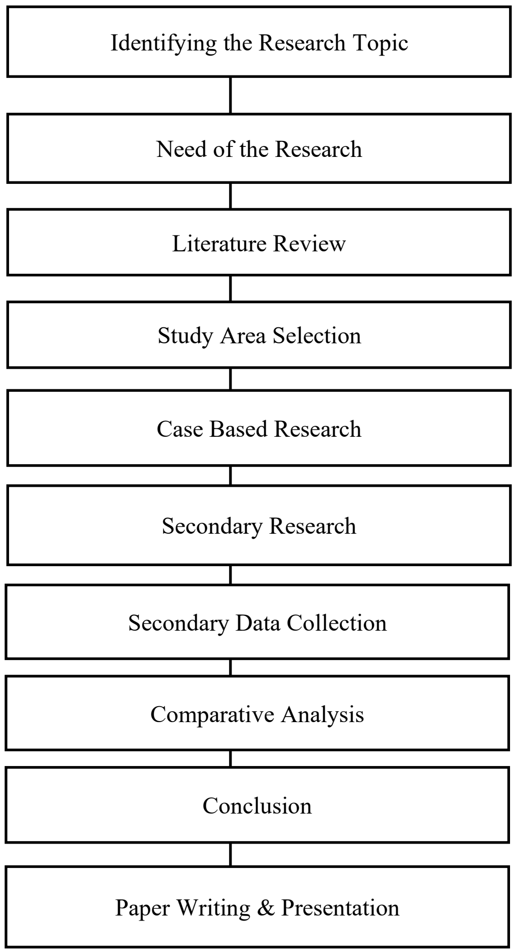
- *Transit Oriented Development (TOD) performance and impact:* Measuring the effectiveness of TOD initiatives in improving urban mobility, reducing car dependency, and fostering economic growth.
- *Urban expansion and property prices:* Investigating the relationship between urban sprawl, land availability, and fluctuations in real estate values.
- *Commercial real estate trends in CBDs:* Tracking market dynamics, demand shifts, and policy influences on commercial property development in central business districts.

3.0 Research Methodology

Figure 1: Research Methodology Structure



Source: Compiled by authors

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- *Identifying the research topic:* The research begins with selecting a relevant topic based on existing gaps, contemporary issues, and academic or practical significance. A well-defined topic ensures focused study and meaningful outcomes.
- *Need of the research:* Establishing the necessity of the research involves identifying the problem statement, its implications, and how the study contributes to academic knowledge, policy-making, or practical applications.
- *Literature review:* A thorough review of existing studies, theories, and research papers helps in understanding the subject, identifying gaps, and forming the conceptual framework for the study.
- *Study area Selection:* The study area is chosen based on its relevance to the research objectives, availability of data, and suitability for analysis. It ensures that the findings can be generalized or applied effectively.
- *Case based research:* Case studies are examined to understand real-world applications, best practices, and challenges. This approach helps in drawing comparative insights and supporting theoretical discussions.
- *Secondary research:* The study relies on existing literature, reports, and databases to build a strong foundation. It provides background information and supports primary research, if applicable.
- *Secondary data collection:* Relevant data is gathered from government reports, research articles, surveys, and statistical sources to analyse trends, patterns, and relationships within the study area.
- *Comparative analysis:* systematic comparison of different case studies, datasets, or policy approaches is conducted to identify similarities, differences, and best practices that inform the research findings.
- *Conclusion:* Key findings are summarized, highlighting their implications and contributions to the field. Recommendations may be provided based on the study's outcomes.
- *Paper writing & presentation:* The final research paper is structured, formatted, and refined to meet academic standards. The findings are then presented effectively for academic or professional dissemination.

4.0 Data Analysis

4.1 Transportation

4.1.1 Introduction

India stands as the most populous country globally. It is experiencing rapid urbanization as people increasingly migrate to major cities like Bengaluru, Mumbai, Delhi, and Kolkata in search of better educational and employment opportunities. This migration is gradually expanding urban areas and increasing the demand for efficient infrastructure. According to SBI

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Research, India's urban population, which was 31.1% of the total population in the 2011 Census, is expected to reach 35-37% by the 2024 Census. (Reporter, 2025) As of 2020, transportation in India contributed 14% of the country's energy-related direct carbon dioxide emissions, and 90% of this came from road transport. Decarbonizing the transport sector is a crucial goal for the country. As India strives to achieve its climate and environmental objectives, it's critical to have clear targets and defined intermediate milestones to help ensure that the pace of transition to clean transportation is in line with national goals. (Kohli, 2024)

4.1.2 Transportation in Pune

Pune is a rapidly developing city with an ambitious plan to improve sustainable mobility for its people. For years, the city has embraced radical approaches and initiatives that prioritise efficient and sustainable forms of transport. Pune has made several path-breaking interventions to develop walking, cycling, and public transport facilities across the city. (Mohol, 2021) The district is well connected with the state capital and surrounding district headquarters through road and rail linkages. The road network consists of Express Highways, National Highways, State Highways and Major District Roads. The rail network consists of both broad gauge (Electrified and Non-Electrified) double track as well as single track lines. The district headquarters has connectivity through airways for transport and trade to major airports within the country and to select international destinations.

In spite of the availability of perennial river stretches, there is no significant utilization of waterways in the district. (Government of Maharashtra, 2025) The district has a total length of 13,642 km of roads (2001) of which 5394 km roads are Bituminous surface, 3554 km roads of water bound macadam surface and 4694 km of other surface roads i.e. unmetalled road. The roads are classified according to their importance. Of the total road length in the district, 331km road length is covered by National Highways and 1368 km by State Highways. The major and other district roads have a total length of 5388 km, which passes through all the talukas. Almost all the villages are well connected by water bound macadam road. The total length of village roads is 6555 km. (Government of Maharashtra, 2025)

4.1.3 Role of metro in transportation

Metro rail transportation, also known as mass rapid transit (MRT), heavy rail, or metro, is a type of high-capacity public transport that is generally built in urban areas. It's a fully segregated rail-based mass transit system, which could be at grade, elevated, or underground. Due to its physical segregation and system technology, metro rail can have a very high capacity of 40,000 – 80,000 passengers per hour per direction. (Kavitha, 2023)

The success of the Delhi Metro highlighted the role of metro systems in improving urban connectivity and reducing traffic congestion in metropolitan cities. Its implementation inspired other cities to adopt metro systems as an efficient solution for addressing urban mobility challenges. Between 2011 and 2020, several cities introduced metro networks to

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enhance public transportation. Below is an overview of the metro systems established during this period. (Reporter, 2025) Metro is used to reduce the traffic congestion and increase the better transportation facilities to the public and reduce the road accidents. As we know India is a developing country Transportation sector is developing day by day. Will increasing the utilities, infrastructure development, employment facilities etc it makes more traffic congestion there is modification of transportation network.

As India promoting sustainable practices will coming to the transportation perspective promote the public transport and reduce the personal vehicles metro is the best example, but metro is Tier 1 cities like Delhi, Mumbai, Hyderabad, Bangalore etc.

4.1.4 Key issues in metro network in cities

Metro systems in cities face several key issues that impact their efficiency, sustainability, and effectiveness. There are Several Issues in Metro during construction and after running they are

- Over-estimation of Traffic Demand Forecasts/Ridership Estimation
- Land/Property Acquisition and Resettlement and Rehabilitation Related Issues
- Loss of Trees/ Green Cover
- Noise Pollution and Vibration Issues
- Accidents During Construction Phase
- Traffic Issues during Construction Phase

4.1.5 Metro condition in Pune city

Pune city is known in the world map because of its educational, research and development institutions, IT Parks and automobiles industry in western Maharashtra. In last decades, the city witnessed a rise in population and people migrating from a different part of the country for job opportunities. However, the sustainable infrastructure to facilitate easy commute to the citizens was missing. Average travel time for citizens using public transport in Pune is over ~100 mins a day. This makes more and more citizens use their personal vehicle, which causes traffic chaos and congestion issues. (Pune Metro Rail Project, n.d.) Here in, Pune Metro, will help tackle all these issues, provide comfortable and convenient commute in the city by significantly reducing the travel time by 75%. It will facilitate many youths, students, professionals, etc. traveling to their destination. (Pune Metro Rail Project, n.d.)

4.2 Property prices

4.2.1 Introduction

Real estate sector in India is expected to reach US$ 1 trillion in market size by 2030, up from US$ 200 billion in 2021. India's real estate market is estimated to increase at a CAGR of 19.5% during 2017- 2028. The market is forecast to reach US$ 650 billion, representing 13% of

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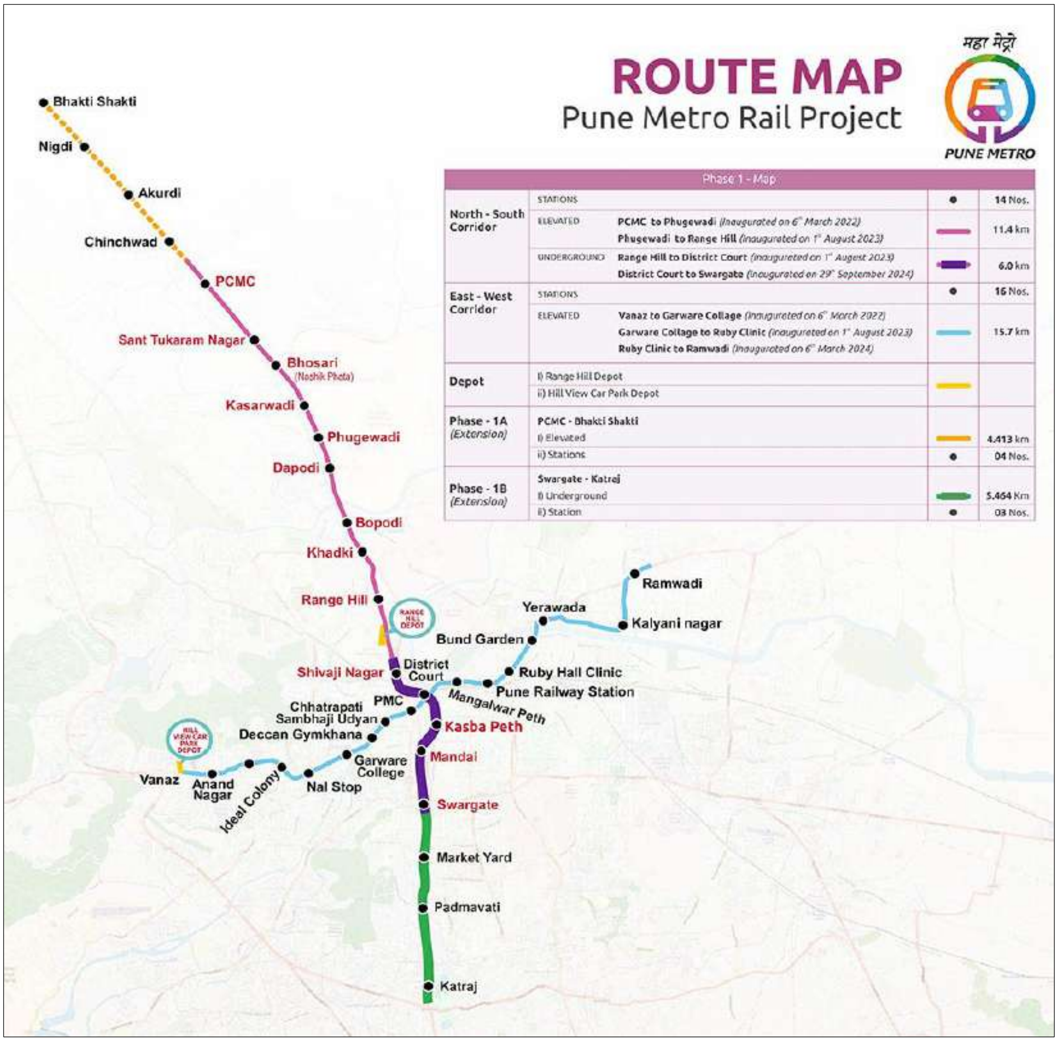
India's GDP by 2025. (India Brand Equity Foundation, 2024) Average home prices in India are set to rise steadily over the coming years driven mainly by demand from wealthy individuals, while the rising cost of living will make owning a property unattainable for most people, a Reuters poll found. (Trivedi & Mishra, 2024) While India's middle class tightens its belt, cutting back on everything from tea to two-wheelers due to soaring consumer inflation, the richest 1% who own 40% of the country's wealth are snapping up homes in cities with well-paying jobs. (Trivedi & Mishra, 2024)

Figure 2: Pune Metro Existing Route Map



Source: Pune Metro Rail Project

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4.2.2 Reason for increasing property prices

The Property prices were increases due to several reasons one of the major reasons is change of Land use in those areas, due to development of Infrastructure development, employment facilities etc. India home prices to rise 6.5% in 2025, driven by demand from wealthy. After rising 4.3% last year, home prices in India - broadly referring to housing in major cities - were expected to rise 7.0% this year, 6.5% in 2025 and 7.5% in 2026, median forecasts from the Nov. 12-29 survey of 12 property market experts showed. (Trivedi & Mishra, 2024)

4.2.3 Property prices in Pune

Pune is one of India's fastest-growing cities, with a thriving real estate market. The city has seen a surge in demand for both residential and commercial properties as the government focuses on improving infrastructure and the growth of various industries. Several factors influence the Pune real estate market, including government policies, construction rates, and property valuation. Pune has become a hotbed for property investment in recent years, with many people looking to buy homes in the city's prime locations. (Property, 2023) Pune's stamp duty and local body tax (3% stamp duty plus 1% local body tax) were also reduced, affecting Pune land prices further. Several real estate developers were willing to pay the GST on the buyer's behalf. This is regarded as one of the primary reasons for the 58% increase in sales. (Property, 2023)

Figure 3: Vanaz Metro Station

Source: Pune Metro Rail Project

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4.3 Relation between transportation and property prices

The relationship between transport accessibility and land value rises in connection with the concept of land value capture. A study looked at the relationship between transport accessibility and land value with the implication of a local model, geographically weighted regression (GWR). Traditional techniques, such as hedonic models, used to understand the attributes of land value, are global models that could be misleading in examining spatially varying relationships, such as transport accessibility and land value. (Hongbo & Corinne, 1977)

4.4 Metro network effecting the property prices in Pune

The Metro Project starts in December 2016 before Pune property price are growing in 5-15%. But after proposal of Metro the property prices were increasing rapidly than expected due increase of Infrastructure, Transportation facilities, Employment opportunities etc. While compared in our study area with existing and new line proposed metro line. The proposed metro line increases rapidly nearly 20-50% prices are increased within 10Years even the existing metro line surrounding areas are also increases but there is difference in change in property prices.

4.5 Study area analysis

4.5.1 Study Area1: Vanaz – ideal colony

Vanaz is a terminal station of Vanaz-Ramwadi corridor. To the north of Vanaz is a hilly area with a small residential enclave along Paud Rd.

The major residential area in the region is Kothrud, to the south of Vanaz metro station. To its east, beyond a hillock, is a township called Bavdhan. Connectivity has been established with surrounding areas via buses and autoroutes; wherever connectivity is poor, considerations are being made to deploy buses in those directions. (Pune Metro Rail Project, n.d.) The alignment from the ideal Colony Metro Station goes south-westward toward Anand Nagar, both of which are densely populated residential areas. Various studies point toward the growth of the city in this direction, all the way westward to Vanaz. (Pune Metro Rail Project, n.d.)

4.5.2 Study Area2: Ram Nagar – Baner Gaow

The Baner-Balewadi was a rural area that was transformed into a residential suburb and is now metamorphosing into a commercial and educational hub of Pune city. This area is now a part of Pune Municipal Corporation and is occupied by various schools, universities, and IT companies. The decadal population growth rate of the Baner-Balewadi area is 275%; it is much higher than the Pune districts and city's growth rate, which makes it a fascinating area for this study. A cross-sectional survey was conducted in this area covering three major regions: Balewadi Highstreet, Baner-Balewadi Road, and NICMAR University (Dhaarna, 2024).

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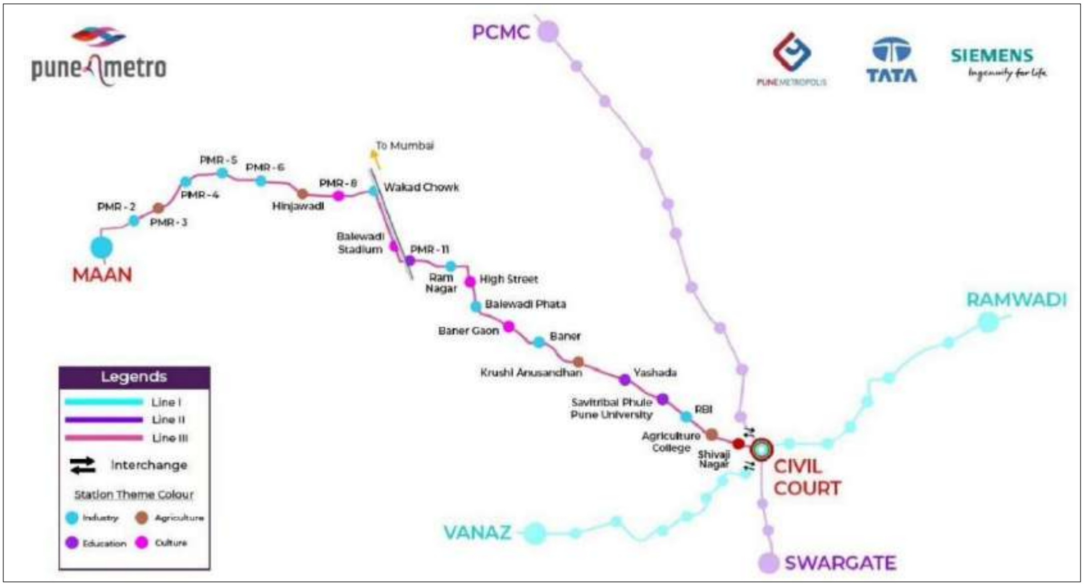
Figure 4: Proposed New Metro Line



Source: Puneri Metro

Table 3: Property Prices of the Study Area

Parameters	Vanaz – Ideal Colony	Ram Nagar – Baner Gaow (Balewadi)	Ram Nagar – Baner Gaow (Baner)
Taluka	Haveli	Haveli	Haveli
Village	Kothrud	Balewadi	Baner
Type of Metro	Elevated	Elevated	Elevated
Distance of the study area stretch	2KM	3.3Km	3.3Km
Open Land Price in 2015	30930	21580	15560
Open Land Price in 2024	37170	31430	28860
Change in Percentage	**20.17%**	**45.64%**	**85.47%**
Residential Plot Price in 2015	70170	61990	57120
Residential Plot Price in 2024	83980	77790	84630
Change in Percentage	**19.68%**	**25.48%**	**48.16%**
Shop Price in 2015	182130	76850	89370
Shop Price in 2024	199860	97230	117300
Change in Percentage	**9.73%**	**26.51%**	**31.25%**
Office Price in 2015	121970	66000	72530
Office Price in 2024	118780	89460	97330
Change in Percentage	**-2.61%**	**35.54%**	**34.19%**
Average Growth Rate	**48.92%**	**106.51%**	**173.42%**

Source: Annual Statement of Rates, Maharashtra

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The Baner – Balewadi has high potential growth in real – estate sector perspective because of change in land use, implementation of metro line, and due to Education sector and IT sector. Lots of students and employees are not only from Maharashtra but also all over India are coming to Pune. The Educational Institutes like NICMAR University, MIS International School, Bharati Vidyapeeth Rabindranath Tagore School of Excellence etc and IT Sectors companies like BOSCH, HILTI, TEC, Cummins etc.

4.6 Comparative analysis

As both study areas have been compared with several parameters mentioned below table. They are classified as range wise the color green indicates highest value, yellow indicates medium value, and red indicates lowest value.

5.0 Conclusion

As mentioned in above table the comparison between two study areas they are equal potential for both areas but in Vanaz to Ideal colony the property prices are already in higher values from last 10Years but growth percentage of that is lower compared another study area. In Kothrud the Offices Property prices are falling to -2.61% due to there is high demand for shops and residential plots and most of the IT offices are located in Baner, Hinjawadi like these areas where the new metro line under construction is proposed. In Ram Nagar to Baner Gaow there are 2 villages they are Balewadi and Baner will comparation of both villages except open land rest of the all-other land uses are having higher property prices will be compared to balewadi but not with Kothrud. The growth percentage is higher in Baner village compared with Balewadi and Kothrud. This is because in Kothrud there is already existing Metro line so there are highest property values since last 10 Years, but the growth percentage is low compared to other study area. But new proposed line with is under construction starts rising values due to Transportation facility is improved more so the land use got changing and there is hug demand compared to other study area. The Average Growth is like Kothrud: Balewadi: Baner is 1: 2.17: 3.54

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CHAPTER 66

Exploring Agile Practices in Megaprojects: A Systematic Literature Review on Stakeholder Engagement, Innovation, and Sustainability

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ABSTRACT

Megaprojects play a key role in driving economic growth and long-term development, reflecting a nation's ambitions and progress. However, their successful execution often faces challenges such as complex processes, diverse stakeholders, regulatory hurdles, and limited resources. This study systematically examines the relationship between Agile techniques, stakeholder engagement, innovation, and sustainability in Indian megaprojects. It analyses the unique challenges posed by India's diverse socioeconomic structure, legal frameworks, and cultural variations in the context of Agile implementation, filling crucial gaps in the existing literature. This study assesses the methodological quality and thematic relevance of existing research through a rigorous systematic literature review approach guided by the PRISMA methodology and the TCCM framework. Key findings demonstrate strong theoretical connections between Agile techniques and better stakeholder engagement, yet considerable gaps exist in their operationalization that promote innovation and sustainable megaproject delivery. The incorporation of Agile principles like iterative feedback, cross-functional cooperation, and dynamic communication is particularly underexplored in India. To close this gap, a conceptual model is proposed that describes how Agile approaches can be adjusted to improve stakeholder participation, encourage innovation, and achieve long-term project success. The model emphasizes practical strategies for leveraging Agile to enhance engagement and performance across diverse project stakeholders. This review contributes valuable insights for academics and practitioners alike, providing a foundation for future empirical research and practical applications of Agile in Indian megaprojects.

Keywords: Agile methodologies; Stakeholder engagement; Megaproject innovation; Indian megaprojects; Sustainable project delivery.

1.0 Introduction

The Indian construction industry is widely acknowledged and recognized for its scale, aspiration, and inventive approach.

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The entity plays a crucial part in promoting economic expansion and sustainable development. Agile approaches enhance project delivery by encouraging by active participation of stakeholders and adapting to conditions as needed.

1.1 Overview of complex Indian projects

India's aspiration for a $5 trillion economy is reflected in its extensive infrastructure projects. Initiatives like the Delhi-Mumbai Industrial Corridor (DMIC), Mumbai-Ahmedabad Bullet Train and Navi Mumbai International Airport demonstrates the nation's dedication and commitment to modernization and economic development. These projects enhance the infrastructure, stimulate employment and regional development.

1.2 Complexity and importance for economic growth

Complex projects are typically characterised by numerous stakeholders, significant regulatory hurdles and substantial resource allocation. They draw in foreign investment, stimulate job creation and promote technological progress. The Smart City Mission demonstrates India's commitment to urban development, improving and enhancing its global competitiveness and sustainable future goals.

1.3 Importance of stakeholder engagement

For a project to be successful, it is essential to engage stakeholders such as communities, investors and government organisations. Collaboration promotes and encourages innovation, aligns with objectives and ensures sustainability. Inclusive decision-making and transparency can significantly increase the lifespan of a project, as evidenced by adoption of microgrids in renewable energy initiatives.

1.4 Rationale for agile approach

Agile methodologies had originally derived and developed in software development industry, which are now gaining traction in construction for their wider range of adaptability. Scrum and Kanban provides to acquire continuous feedback, improved efficiency and lesser rework. Agile promotes innovation, sustainable processes, and quick response to challenges like site conditions and regulatory changes. By incorporating Agile, construction projects can optimize resources, minimize waste, and ensure timely completion, thereby driving industry transformation.

2.0 Literature Review

Agile approaches have gained significant attention in construction megaprojects for their iterative nature, stakeholder engagement potential and emphasis on innovation and sustainability. The literature suggests that Agile helps in stakeholder alignment by improving communication, collaboration and adaptability (Bahadorestani, Karlsen, and Farimani n.d.) thereby mitigating project uncertainties.

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Table 1: Shows the Relationship between Agile, Stakeholder Engagement, Innovation and Sustainability in Construction Projects

Relationship	Key Findings	References
Agile & Stakeholder Engagement	Agile improves collaboration, openness, and faith among stakeholders, thereby increasing stakeholder satisfaction.	(Bahadorestani *et al.,* n.d.), (Bryde & Schulmeister 2012), (Baxter & Turner 2023), (Babineau & Lessard 2015)
Agile & Innovation	Agile encourages continuous innovation through iterative feedback, open knowledge sharing and structured methodologies like Agile-QFD.	(Denning 2013), (Anes *et al.,* 2023), (Raj & Vinodh 2016)
Agile & Sustainability	Agile supports eco-friendly construction methods which reduce waste and promote knowledge retention for long-term sustainability.	(Levy *et al.*, 2021), (Al-Zabidi *et al.,* 2021), (Papademetriou *et al.,* 2023), (Venugopal & Saleeshya 2019)
Stakeholder Engagement & Innovation	Engaged stakeholders contribute to better designs and service-oriented innovations, enhancing project adaptability.	(Hollebeek *et al.*, 2022), Lievens & Blažević (2021)
Stakeholder Engagement & Sustainability	Stakeholder collaboration strengthens efforts, leading to better project outcomes through regulatory frameworks and digital engagement.	Lievens & Blažević (2021); Lehtinen & Aaltonen (2024); Goh *et al.*, (2023); Valdes-Vasquez & Klotz (2013); Tirumala & Upadhyay (2023)
Innovation & Sustainability	Innovative approaches improve efficiency and sustainability, leading to eco-friendly construction and innovative digital transformation.	Ozorhon & Oral, (2017), Mihardjo *et al.,* (2019)
Agile, Innovation & Sustainability	Agile promotes resource efficiency, economic growth, and sustainable project execution.	Andriyani *et al.,* (2024), Endres *et al.*, (2022), Chauhan *et al.*, (2023), Erbguth *et al.,* (2022), Kopytko *et al.,* (2023)
Agile, Stakeholder Engagement & Sustainability	Agile-driven collaboration enhances sustainable development, ensuring resilience in complex projects.	Burlereaux *et al.*, (2015), Silva *et al.,* (2022)

Research by (Flyvbjerg 2021) underlines the importance of scalability in Agile applications for megaprojects, emphasizing the need for continuous adaptation to meet the changing and evolving project demands. Studies also underscore Agile's role in promoting innovation (Denning, 2013) through iterative development and rapid adaptability, particularly in open innovation contexts (Anes *et al.,* 2023). Similarly, research based on sustainability has explored Agile's capacity to balance environmental issues in supply chains (Al-Zabidi *et al.*, 2021) and its role in green construction and workforce adaptability (Papademetriou *et al.,* 2023).

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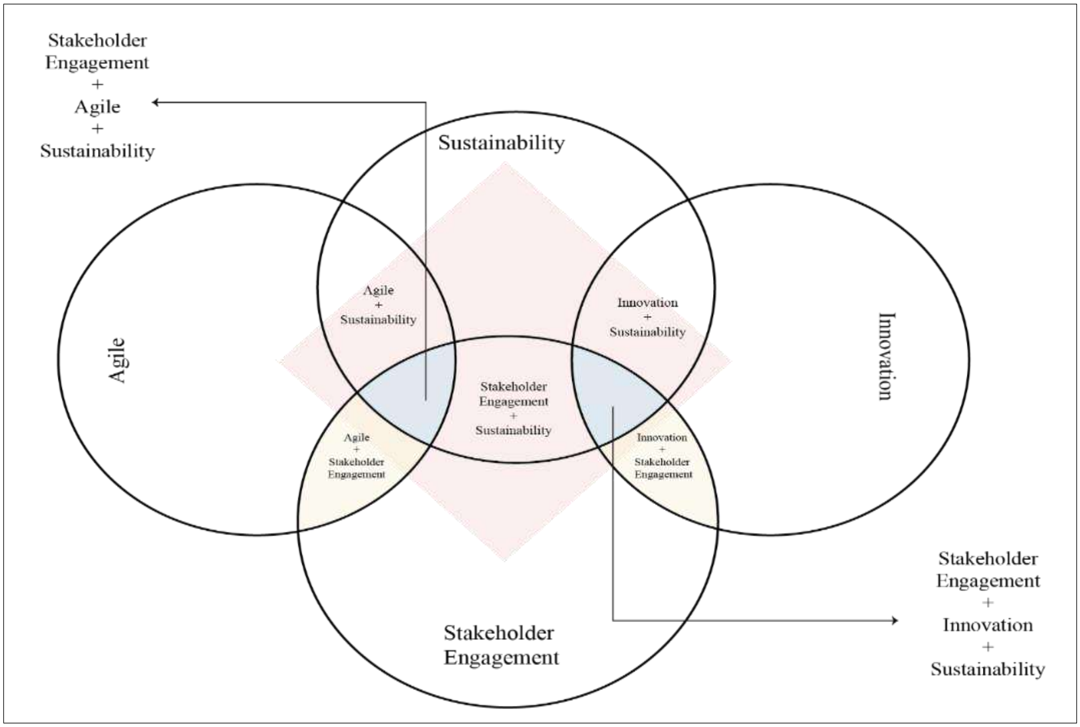
The interplay between Agile, innovation and sustainability are evident in frameworks that integrate Lean-Agile principles to improve efficiency while reducing waste (Venugopal & Saleeshya 2019). Additionally, stakeholder engagement has been shown to directly influence sustainability outcomes by promoting collaborative frameworks and co-creation models (Mihardjo *et al.,* 2019). The convergence of these elements Agile, stakeholder engagement, innovation and sustainability has led to the development of integrative methodologies such as digital ecosystems (Mihardjo *et al.,* 2019) and Lean-Agile combinations (Bryde & Schulmeister 2012) that support sustainable project execution. Table 1 provides a structured view of the relationships between Agile, stakeholder engagement, innovation, and sustainability in construction projects with key findings from each research paper.

Figure 1: Different Variables and Relationships



3.0 PRISMA

To identify relevant research papers, PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach was followed for this study. For the selection of high-impact papers, Scopus was used for the screening process. The initial search used keywords related to Agile, stakeholder engagement, innovation, and sustainability in

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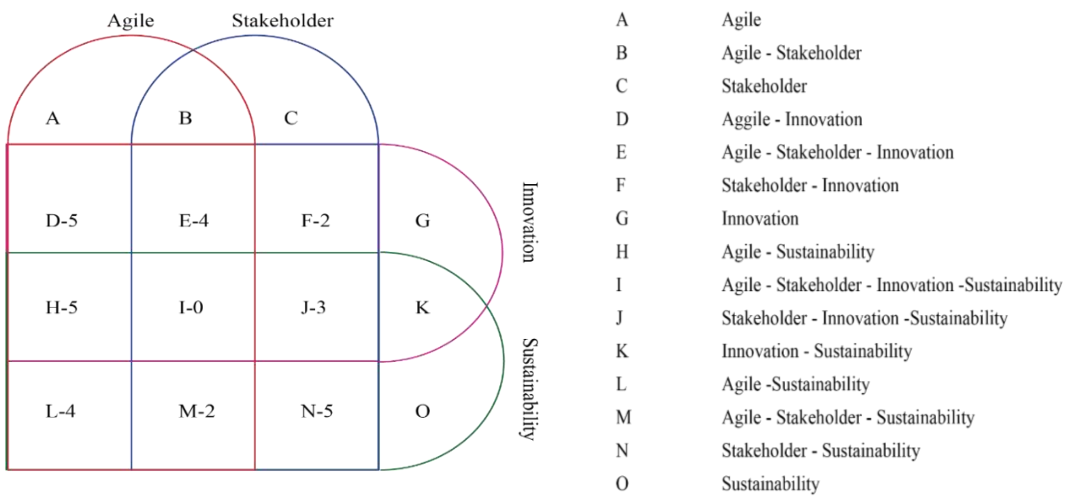
megaprojects, focusing on conference papers and peer-reviewed journal articles. To align our criteria, the identification phase involved retrieving a wide set of articles. Irrelevant papers were removed during the screening phase, based on title and abstract review. The selected studies should contribute meaningful insights into the relationships, for that a full-text assessment was included in eligibility phase. Finally, in the inclusion phase, only those papers which address precise interaction between Agile, stakeholder engagement, innovation, and sustainability were incorporated. The entire process that was carried out for the literature review This process ensured that our literature review was supported by strong and thoroughly examined collection of studies, providing a solid foundation for analysing the relationships among Agile, stakeholder engagement, innovation, and sustainability.

Figure 2: Thematic Relationship Matrix



3.1 PRISMA process

For the systematic filtration and analysis of relevant research articles related to Agile, stakeholder engagement, innovation, and sustainability in megaprojects the PRISMA approach was utilized. During the Identification phase a total of 73,466 papers were retrieved from Scopus using keyword-based searches across multiple topics. In the Screening phase, the first level of screening, which applied keyword limitations, reduced this to 16,626 papers. The selection was narrowed down to 3,678 papers during second-level title screening, helpful to remove irrelevant papers. In the Eligibility phase, in-depth abstract reviews were conducted on these papers, and 2,008 papers were considered relevant. However, 704 papers did not align with the study's focus and were eliminated. The final inclusion phase involved a full-text review, resulting in 315 studies which were initially considered for qualitative analysis, of which 46

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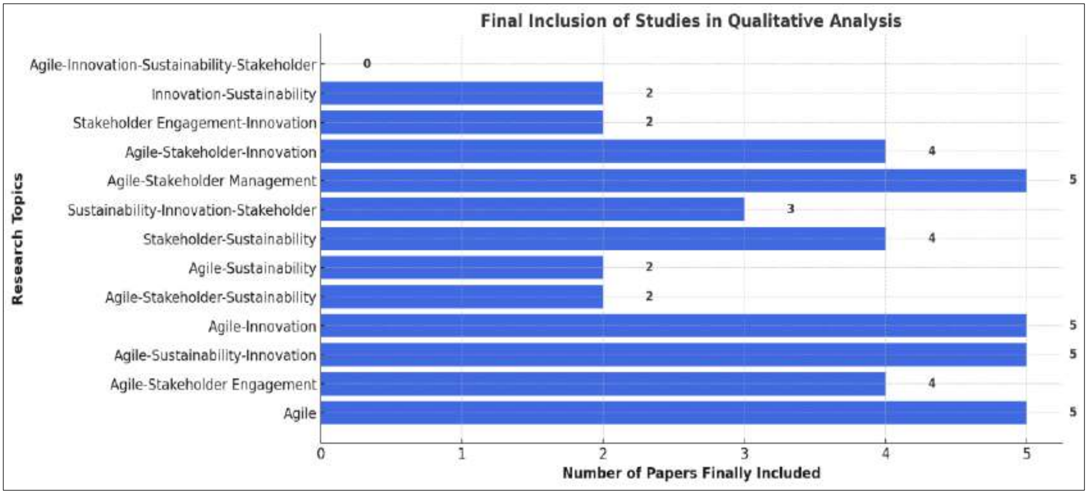
were ultimately included after thorough and precise analysis. Figure 2 categorizes the research based on different thematic relationships.

Figure 3: Final Inclusion of Research Papers in Qualitative Analysis



Topics like Agile (5 papers), Agile-Stakeholder Engagement (4), Agile-Innovation (5), Stakeholder-Sustainability (4), and Stakeholder Engagement-Innovation (2) shows the number of final papers included. Some of the categories had high initial screening numbers but lower final inclusion, emphasizing the robust and highly validated filtering process and the final inclusion of papers has been shown in Fig 3. This structured methodology ensures the selection of good-quality, relevant studies, ensuring a strong foundation for investigating Agile methodologies impact on stakeholder engagement, innovation, and sustainability in large-scale projects. The results highlight potential research gaps due to the lack comprehensive studies linking all four aspects.

4.0 TCCM Framework

The TCCM (Theory, Context, Characteristics, and Methodology) framework helps in analysing research in complex fields like construction, sustainability, and stakeholder management. It combines various theories such as Complex Adaptive Systems Theory, Grounded Theory, Stakeholder Theory, Value Creation Theory, Expectation Disconfirmation Theory, Fuzzy Set Theory, and Agile Methodology, which explain how large projects adapt, innovate, and manage different stakeholder needs ((Nyarirangwe & Babatunde 2019); (Levy *et al.,* 2021);(Lehtinen *et al.*, 2019); (Mihardjo *et al.,* 2019);(Bahadorestani *et al.,* n.d.);(Saka-helmhout *et al.,* 2024);(Mohammed & Karri 2020)). This framework is useful in different sectors, including public buildings, construction, the ICT industry, and healthcare ((Papademetriou *et al.,* 2023);(Simon *et al.,* 2018);(Lee *et al.*, 2011)).

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Table 2: TCCM Framework

Theory	Context	Characteristics	Methodologies
Complex Adaptive Systems Theory	Public buildings	Quick responsiveness	Qualitative Data Analysis
Grounded theory	Construction Industry	Green Competencies	Focus Groups.
Quadruple Helix theory	ICT industry	Green motivation	Experiments.
Stakeholder theory	Health care sector	Competency	Secondary Data Analysis.
Value creation theory	Pharmaceutical industry	Flexibility	Semi-Structured interviews
Expectation disconfirmation theory	Manufacturing Industry	Green organizational citizenship behaviour	Agile KM RE methodology (AKM-REM)
Fuzzy set theory	Small and Medium Enterprises (SMEs)	Decision-making	six-step bibliometric analysis
Agile Methodology		Pull-driven scheduling	Multiple case studies
Toyota Production System (TPS)	Complex Projects	Strategic management	Quantitative data analysis
Scrum framework	IT industry	Incremental and Iterative Development	Exploratory approach

Each industry has its own challenges, such as managing risks, improving communication, and implementing sustainable solutions. For example, in construction, Agile methods help improve flexibility and collaboration among stakeholders ((Mohammed & Karri 2020);(Anes *et al.,* 2023);(Sultan *et al.,* 2024)). The main characteristics of the TCCM framework include quick responsiveness, green competencies, motivation, and competency development. These factors help improve project outcomes by encouraging sustainability and innovation. Companies that focus on environmental practices and skills development are more successful in delivering sustainable projects ((Zhang *et al.*, 2018);(Papademetriou *et al.,* 2023)). Different research methods support the framework, such as qualitative data analysis, focus groups, experiments, and secondary data analysis ((Mihardjo *et al.,* 2019);(Simon *et al.,* 2018);(Papademetriou *et al.,* 2023)). These approaches help researchers study project performance, stakeholder involvement, and innovation in a structured way. By bringing together these elements, the TCCM framework provides a clear way to understand the challenges in megaprojects. It offers useful insights for making projects more sustainable, improving teamwork, and adapting to changes in different industries.

5.0 Research Gap

India's massive infrastructure projects are gradually looking at Agile methodologies to improve stakeholder involvement, drive innovation and ensure sustainable practices. But there is a big gap in research on how well Agile works in this unique environment. Existing studies

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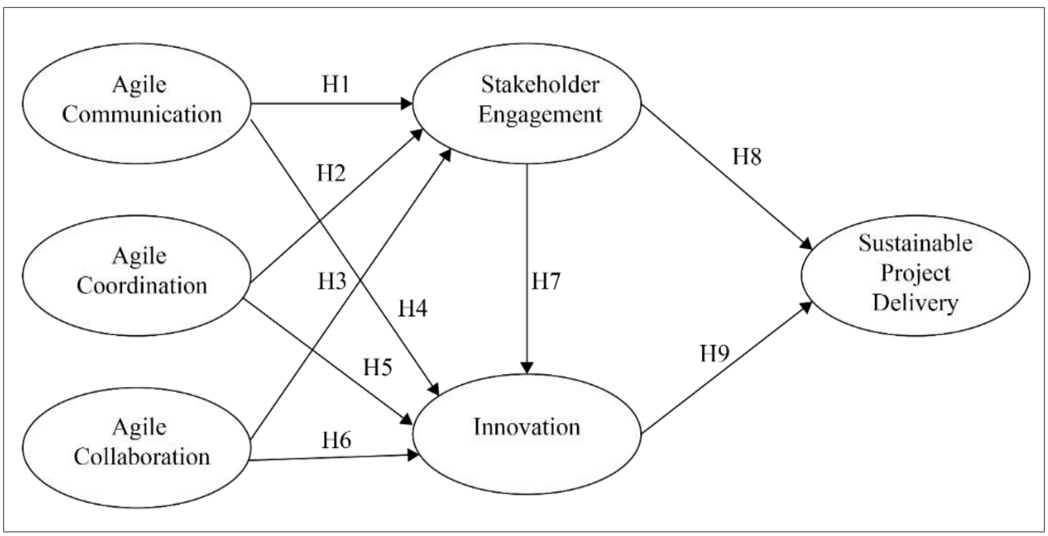
focus on Agile in software development or in Western contexts, which do not consider the complexities of large-scale construction in India. There is a need to explore deeper into how Indian factors like social and economic diversity, specific regulations and cultural dynamics impact agile implementation in these mega projects.

There is a need to explore the cultural, organizational and government-related aspects that influence the use of Agile in Complex Indian Projects. While some studies acknowledge the potential benefits of Agile in Complex Projects and a lot of emphasis is given in the literature on stakeholder engagement, innovation and sustainability in Complex Projects, but not enough on how these factors work together within the Agile framework. The research should focus on developing frameworks, methodologies and best practices specifically designed for implementing Agile in Indian infrastructure projects, considering the unique challenges and opportunities this landscape presents. Hence, we propose a new research model that explores how Agile practices can create a collaboration between stakeholder engagement, innovation and by achieving sustainability goals.

5.1 Proposed model of agile-stakeholder engagement-innovation-sustainability

For overcoming the above-mentioned research gap, we are proposing a model for further studies as shown in Fig 3. which will enable us to understand the interrelation between Stakeholder engagement, Innovation and sustainability within the Agile coordination, Agile communication and Agile collaboration framework for attainment of long-term beneficial project outcomes and goals.

Figure 4: Proposed Conceptual Model



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6.0 Conclusion and Future Research Direction

The literature review highlights that Agile methodologies have been widely studied in different fields like software development, construction, and manufacturing. Research shows that Agile improves stakeholder engagement, fosters innovation, and enhances sustainability. However, these aspects have mostly been studied separately or in limited combinations. The PRISMA analysis further confirms this gap—there is no research that brings together Agile, stakeholder engagement, innovation, and sustainable project delivery in a single framework. While many studies discuss Agile's benefits in megaprojects, none provide a holistic approach that links these four aspects.

To systematically analyse existing research, the TCCM framework was used, helping us categorize theories, contexts, characteristics, and methodologies relevant to our study. Despite several studies on Agile and stakeholder engagement, innovation, and sustainability, none combine all four elements in a way that is suitable for Indian megaprojects, which face unique challenges such as regulatory barriers, diverse stakeholders, and resource constraints. This research gap highlights the need for a structured approach that integrates Agile practices to drive both innovation and sustainability while improving collaboration among stakeholders. To bridge this gap, we propose a new conceptual model where Agile coordination, Agile communication, and Agile collaboration act as key drivers that help megaprojects adapt to challenges, improve stakeholder relationships, and promote long-term sustainability. This model provides a practical approach for project managers, policymakers, and industry leaders to implement Agile in megaprojects more effectively. For future research, the proposed model should be tested and validated using real-world case studies and quantitative techniques like PLS-SEM. Further studies can explore how emerging technologies like AI, digital twins, and blockchain can enhance Agile-driven project management. This research lays a strong foundation for transforming Indian megaprojects into more adaptive, stakeholder-focused, and sustainability-driven developments.

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CHAPTER 67

Exploring Liveability and City Systems as measures of Urban Competitiveness in India

Ramakrishna Nallathiga[1] *and Samruddhi Tambe*[2]

ABSTRACT

As global urbanization accelerates, cities face increased competition for investment, talent, and opportunities. In India, where urban areas are expected to house more than 40% of the population by 2030, the demand for sustainable, resilient, and competitive cities is critical. This study investigates the relationship between liveability and city systems, examining their roles as indicators of urban competitiveness in the Indian context. This study is based on secondary data on the liveability index and city systems that focus on Indian cities and cluster them according to geographical and demographic factors. The research identifies major patterns and trends, providing insights into Indian cities' triumphs and problems in improving liveability and competitiveness. The findings emphasize the significance of specific governance systems, regional planning, and public participation in ensuring sustainable urban expansion. The paper makes concrete recommendations to legislators and urban planners to improve infrastructure, governance, and citizen-centric services. This study lays the groundwork for future research into constructing resilient, liveable, and competitive cities in India.

Keywords: Urban competitiveness; Liveability; City systems; Masterplans; Smart cities.

1.0 Introduction

The world is witnessing the largest wave of urbanization. More than 50 percent of the world's population is now living in the cities. This ratio is expected to rise to 70 percent by 2050. In India, urban areas are currently home to over 31 percent of population and are projected to house more than 40 percent of its population by the year 2030. Also, the people migrating from rural to urban areas have dreams and aspirations to improve their quality of life with better facilities for living and livelihood that includes physical, social, institutional and economic infrastructure.

Liveability, as measured by housing affordability, environmental quality, access to essential amenities, and social infrastructure, has a direct impact on urban dwellers' quality of life and well-being.

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City systems, which include governing frameworks, transportation networks, waste management, water supply, and digital infrastructure, ensure that cities run and operate efficiently. It uses frameworks such as the Ease of Living Index and the Annual Survey of India's City Systems to evaluate and analyze urban performance. This study aims to investigate the interrelationships between liveability, city systems, and urban competitiveness in Indian cities, with a focus on how these aspects form and impact one another in the larger context of urban development strategies. This research makes a substantial addition by focusing on regional disparities and demonstrating how spatial, socioeconomic, and governance variations affect urban competitiveness. Furthermore, it fills a major gap in the existing research by combining liveability and city systems into a single framework for assessing urban competitiveness. This study aims to analyze liveability and city systems in Indian cities to assess their impact on urban competitiveness. It evaluates the effectiveness of governance models, infrastructure development, and policy implementation in shaping sustainable and competitive cities.

The objectives include:

- Identifying key factors that contribute to urban competitiveness.
- Examining the role of governance in improving city performance.
- Analyzing infrastructure development and its impact on liveability.
- Comparing liveability indices and city systems in Indian metropolitan areas.

2.0 Methodology

For this study, a Systematic Literature Review (SLR) was conducted to analyze the relationship between urban competitiveness, livability, and city systems. The SLR methodology, involved comprehensive Thematic analysis using NVIVO, a tool for constructing and visualizing thematic networks. The review focused on peer-reviewed publications from 2014 to 2024, retrieved from Scopus, a leading academic database. A structured search strategy was employed to compile a robust dataset, ensuring relevance and academic rigor.

Table 1: Criteria for Selecting publications for Review

Parameter	Criteria
Database	Scopus
Keywords	"Urban competitiveness", "Livability", "city systems".
Subject Area	Social sciences, urban studies, Environmental studies
Document Type	Journal articles
Peer-reviewed Status	Only peer-reviewed documents
Language	English
Year	2021-2024

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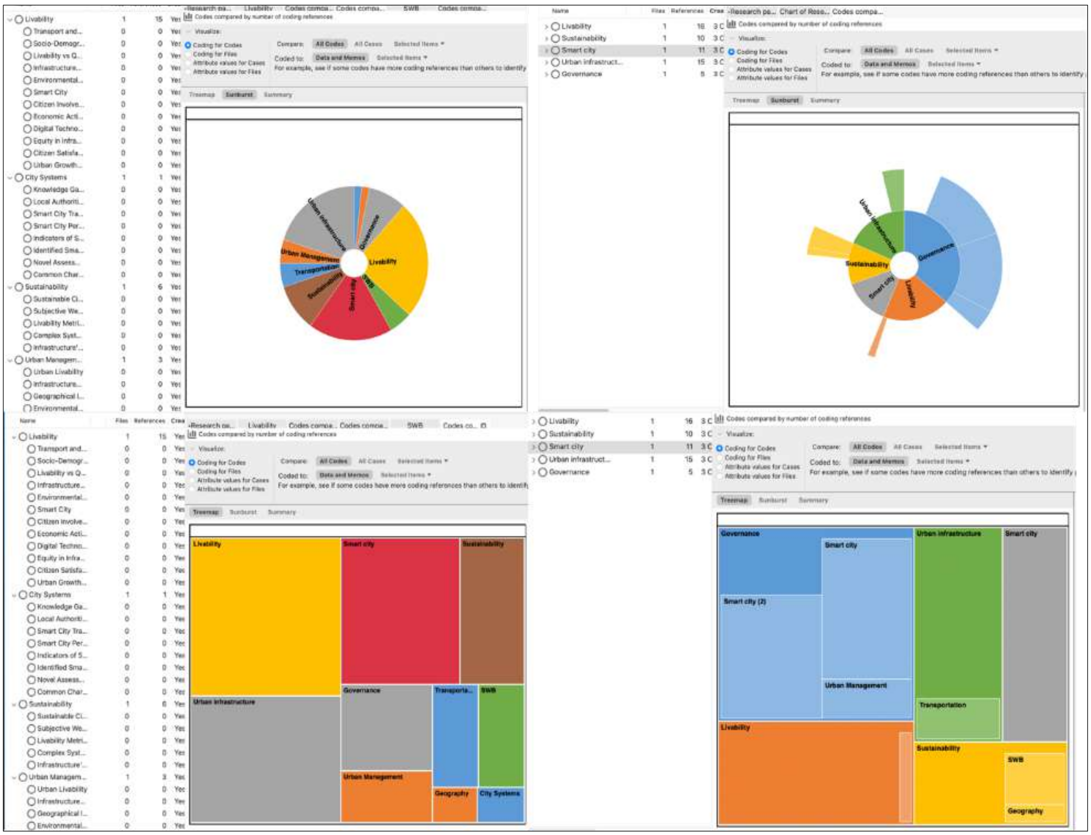
The search was conducted using a combination of keywords: “urban competitiveness,” “liveability,” “urban governance,” “infrastructure,” “sustainable development,” and “citizen participation.” Articles were confined to peer-reviewed journal publications in the social sciences, ensuring academic rigor. Only articles published between 2014 and 2024 were included to ensure the relevance of recent contributions. Publications were filtered based on abstract screening, keyword co-occurrence, and citation relevance. A final set of 45 relevant studies was selected for in-depth content analysis.

Figure 1: Thematic Analysis Done on NVIVO



This literature review synthesizes insights from six research papers, categorized into four themes: urban governance, urban infrastructure, sustainable development, and citizen participation. Thematic analysis using NVivo software was employed to code and categorize findings, providing a comprehensive understanding of the interdependence of these factors in shaping urban competitiveness.

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Theme 1: Urban Governance Urban governance plays a pivotal role in shaping the success of smart city initiatives and overall urban competitiveness. Critiques existing governance frameworks and calls for refined measurement methodologies to better reflect ground realities. These studies collectively underscore the need for adaptive, place-based governance strategies to address urban challenges effectively.

Theme 2: Urban Infrastructure Urban infrastructure is a cornerstone of livability and competitiveness for assessing infrastructure's impact on livability, emphasizing the need for participatory approaches and spatial equity.

Theme 3: Citizen Participation: Citizen engagement is increasingly recognized as a critical factor in urban planning and governance highlight the importance of participatory approaches in assessing and improving urban livability. These studies advocate for inclusive urban planning strategies that prioritize equity and community well-being.

Theme 4: Sustainable Development Sustainable development is integral to long-term urban competitiveness and livability provide frameworks for evaluating sustainability in diverse contexts, highlighting the need for tailored policy interventions.

Papers spanning multiple themes: Several studies explore the intersection of governance, infrastructure, citizen participation, and sustainability. These studies underscore the interconnectedness of urban systems and the need for holistic approaches to urban development.

Framework and methodology to assess liveability index: The four pillars of the Ease of Living Index are Quality of Life, Economic Ability, Sustainability, and inhabitants Perception Survey. These factors are used to assess the well-being of Indian inhabitants in 111 cities. In total, 14 categories were used to analyze 49 indications.

Figure 2: Components to assess Livability

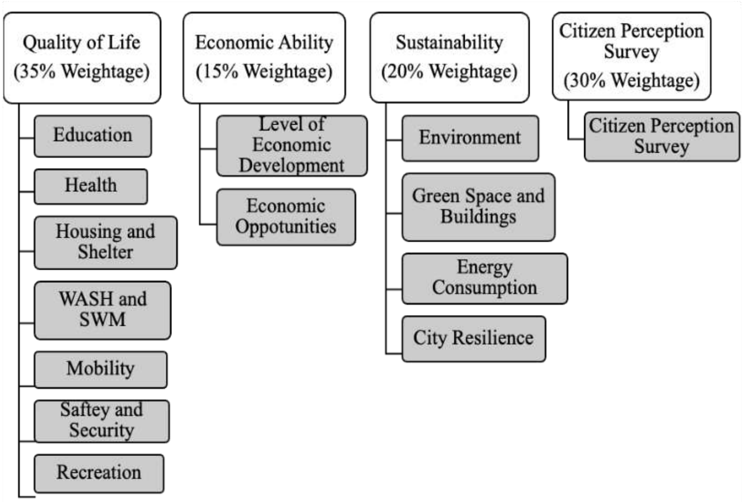

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Table 2: Classification of cities

Classification	Population Range
Less than Million	Population <1 million
Million+	Population >1 million

Table 3: Million+ Category Rankings in Ease of Living Index

City	Liveability Score	Rank	City	Liveability Score	Rank
Bengaluru	66.70	1	Gwalior	53.72	31
Pune	66.27	2	Prayagraj	53.29	32
Ahmedabad	64.87	3	Patna	53.26	33
Chennai	62.61	4	Aurangabad	52.90	34
Surat	61.73	5	Agra	52.58	35
Navi Mumbai	61.60	6	Meerut	52.41	36
Coimbatore	59.72	7	Hubli Dharwad	51.39	37
Vadodara	59.24	8	Nashik	51.29	38
Indore	58.58	9	Vasai Virar	51.26	39
Greater Mumbai	58.23	10	Faridabad	51.26	40
Thane	58.16	11	Vijayawada	50.35	41
Kalyan Dombivali	57.71	12	Ranchi	50.31	42
Delhi	57.56	13	Jabalpur	49.94	43
Ludhiana	57.36	14	Kota	49.52	44
Visakhapatnam	57.28	15	Amritsar	49.36	45
Pimpri Chinchwad	57.16	16	Guwahati	48.52	46
Solapur	56.58	17	Bareilly	47.73	47
Raipur	56.26	18	Dhanbad	46.96	48
Bhopal	56.26	19	Srinagar	42.95	49
Rajkot	55.94	20			
Jodhpur	55.80	21			
Madurai	55.78	22			
Jaipur	55.70	23			
Hyderabad	55.40	24			
Nagpur	55.33	25			
Lucknow	55.15	26			
Varanasi	54.67	27			

In order to facilitate better analysis, cities were categorized into various tiers based on their differing population sizes and diverse stages of development throughout India. All cities covered by the Smart Cities Mission (regardless of their population size) and all cities with a population of more than one million people as per the population projections through 2019 (all metropolitan and megapolis cities) were included in the comprehensive investigation. In

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conclusion, 111 cities in all were chosen to be assessed using the Ease of Living Index. These cities have mostly been divided into two groups: 1) "Million+" cities, which have a population of one million or more, and 2) "Less than Million" cities, which have a population of less than one million.

Table 4: Less than Million Category Rankings in Ease of Living Index

City	Liveability Score	Rank	City	Liveability Score	Rank
Shimla	60.90	1	Thanjavur	52.18	31
Bhubaneswar	59.85	2	Jalandhar	52.18	32
Silvassa	58.43	3	Ujjain	52.04	33
Kakinada	56.84	4	Jhansi	51.71	34
Salem	56.40	5	Shillong	51.65	35
Vellore	56.38	6	Kavaratti	51.58	36
Gandhinagar	56.25	7	Dharamshala	51.51	37
Gurugram	56.00	8	Moradabad	51.43	38
Davanagere	55.25	9	Kochi	51.41	39
Tiruchirappalli	55.24	10	Rae Bareli	51.21	40
Agartala	55.20	11	Gangtok	51.18	41
Ajmer	54.89	12	Port Blair	51.13	42
Puducherry	54.78	13	Thoothukudi	51.12	43
Diu	54.64	14	Saharanpur	50.91	44
Karnal	54.48	15	Amravati	50.38	45
Panaji	54.44	16	Tirupati	50.33	46
Tirunelveli	54.04	17	Belagavi	50.28	47
Tiruppur	54.03	18	Udaipur	50.25	48
Warangal	54.01	19	Kohima	49.87	49
Mangalore	53.95	20	Imphal	49.64	50
Thiruvananthapuram	53.93	21	Dahod	49.40	51
Karimnagar	53.27	22	Bilaspur	49.19	52
Tumakuru	53.06	23	Itanagar	48.96	53
Erode	52.87	24	Rourkela	48.89	54
Sagar	52.86	25	Pasighat	48.78	55
Shivamogga	52.86	26	Dindigul	48.34	56
Jammu	52.49	27	Aizawl	48.16	57
Bihar Sharif	52.42	28	Aligarh	47.15	58
Dehradun	52.41	29	Rampur	46.88	59
Bhagalpur	52.19	30	Namchi	46.46	60
Thanjavur	52.18	31	Satna	45.60	61
Jalandhar	52.18	32	Muzaffarpur	45.53	62
Ujjain	52.04	33			

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2.1 Methodology for assessing city system

With 89 questions encompassing 150 factors and 3900 points of investigation, ASICS 2017 is an objective benchmarking of 23 Indian cities in 20 states. It employs a methodical, data-driven approach to urban government and assigns cities a score between 0 and 10. Additionally, it contrasts Indian cities with benchmark cities like London and New York, which are seen as providing a high standard of living for their residents and have functioning democracies. The strategy used in ASICS editions since 2013 is expanded upon in ASICS 2017. The inclusion of Guwahati and Visakhapatnam in the evaluation has expanded the survey's breadth and representativeness in this edition. In an attempt to strengthen the survey, 16 new questions were added, and the evaluation methodology for 15 preexisting items was changed to make them more pertinent. AMRUT's guidelines and the goal of smart cities were taken into consideration in this regard. The primary factors used by ASICS to determine which cities are included in the study are their size (in terms of population) and geographic spread. Individual scores are a reflection of the quantitative evaluation used by ASICS. Administrators and politicians are intended to use the city-to-city comparison score sheet to diagnose the systemic changes that are required in their particular regions.

Figure 3: City Systems Components and Number of Questions within them

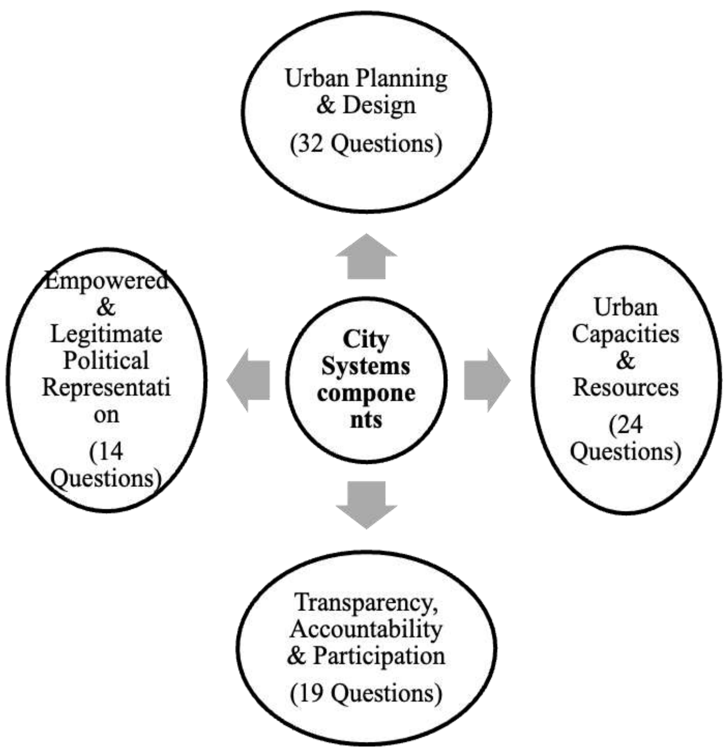

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Table 5: Classification of Cities

Mega cities (5+ Mn)	Ahmedabad, Bengaluru, Delhi, Hyderabad and Mumbai
Large cities (1+ to 5 Mn)	Bhopal, Chennai, Jaipur, Kanpur, Kolkata, Lucknow, Ludhiana, Patna, Pune, Surat and Visakhapatnam
Medium cities (upto 1 Mn)	Bhubaneshwar, Chandigarh, Dehradun, Guwahati, Raipur, Ranchi and Thiruvananthapuram

Table 6: Cities Ranked for City Systems

City	Score	Score Change over 2016	Rank
Pune	5.1	0.9	1
Kolkata	4.6	0.5	2
Thiruvananthapuram	4.6	0.2	3
Bhubaneswar	4.6	1.1	4
Surat	4.5	1.3	5
Delhi	4.4	0.8	6
Ahmedabad	4.4	1.1	7
Hyderabad	4.3	0.3	8
Mumbai	4.2	0.1	9
Ranchi	4.1	0.8	10
Raipur	4.0	0.7	11
Kanpur	3.9	0.2	12
Lucknow	3.8	0.5	13
Guwahati	3.8	--	14
Bhopal	3.7	--	15
Ludhiana	3.5	0.5	16
Visakhapatnam	3.4	--	17
Jaipur	3.4	0.8	18
Chennai	3.3	-0.3	19
Patna	3.3	-0.1	20
Dehradun	3.1	--	21
Chandigarh	3.1	1.0	22
Bengaluru	3.0	-0.3	23

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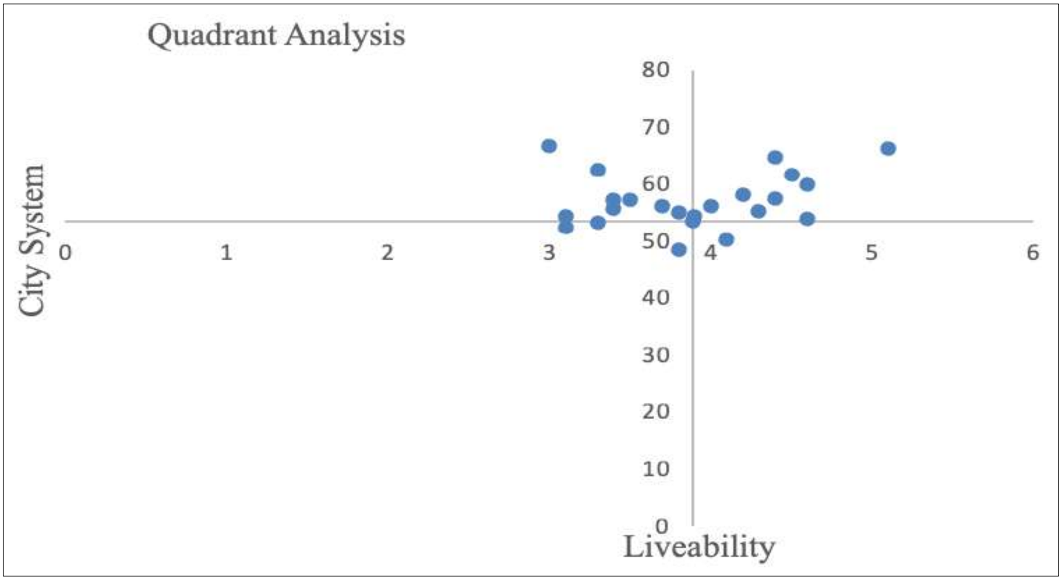
3.0 Analysis

Figure 4: Quadrant Analysis Diagram



3.1 Quadrant analysis interpretation

The quadrant analysis of cities based on their City System Score and Liveability scores provides a comprehensive understanding of urban performance. High liveability scores suggest cities that are more attractive and comfortable for inhabitants. Together, these metrics provide a holistic view of urban performance, helping identify areas that require attention and improvement. Cities in the Top-Right Quadrant--High City System Score, High Liveability include Bhubaneswar, Pune, Ahmedabad, Surat, Greater Mumbai, Delhi, and Raipur. These cities have a balanced approach to development, with strong infrastructure enabling a good standard of living. They demonstrate how effective systems can improve the well-being of residents and act as examples for integrated urban planning.

Low Liveability, High City System Score (Bottom-Right Quadrant): This category includes cities like Thiruvananthapuram and Ranchi. Although these cities have adequate infrastructure, their lack of liveability shows a gap between the well-being of their citizens and the effectiveness of the system. These cities face the difficulty of closing this disparity by tackling the causes of their poor liveability. Include investing in healthcare and educational facilities to improve quality of life, establishing environmental conservation initiatives to improve living circumstances, and boosting community involvement in urban planning to answer local needs and improve social infrastructure. Cities in the Top-Left Quadrant—which

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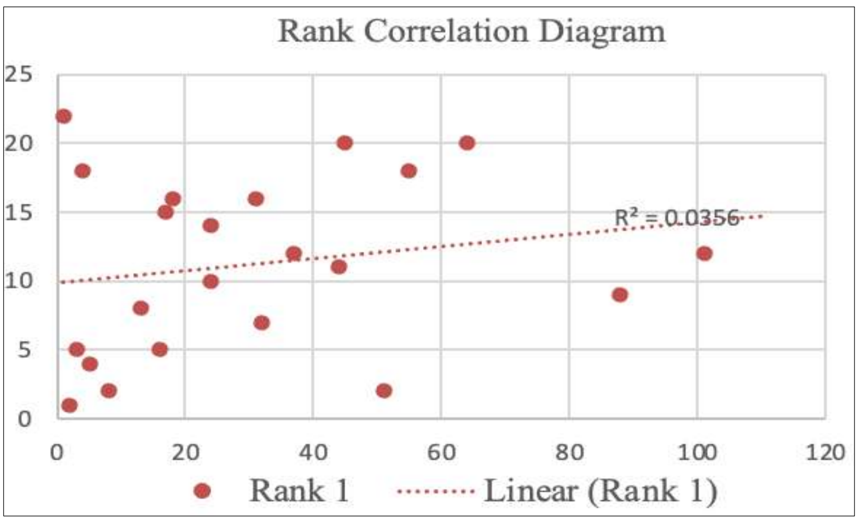
includes Bengaluru, Chennai, Ludhiana, Visakhapatnam, Bhopal, Jaipur, Hyderabad, Lucknow, Kanpur, Chandigarh, Patna, and Dehradun—have a low city system score and high liveability. Despite having lower infrastructure rankings, these places continue to have high liveability, indicating that quality of life is influenced by strong social and cultural variables. Improving public services like waste management and water supply, creating affordable housing developments to serve all income levels, and giving infrastructure development a priority to support expanding populations and economic activity are other recommendations.

Guwahati is the main city in the bottom-left quadrant, with low liveability and a low city system score. It faces difficulties in both areas. Urban regeneration is required. Developing and implementing integrated urban development plans that address infrastructure and quality of life, encouraging economic development initiatives to raise living standards and create jobs, and strengthening disaster resilience to guard against natural disasters and guarantee long-term sustainability are some of the recommendations made for Guwahati.

3.2 Correlation analysis

Figure 5: Rank Correlation Diagram



3.3 Correlation analysis interpretation

The quality of urban infrastructure, government, and services is represented by the city systems rank, which is shown on the y-axis. Better systems are indicated by lower numbers. On the x-axis, the liveability rank indicates how livable a city is; more liveability is indicated by lower values. The R2 value of 0.0356 indicates that there is a modest association between these two metrics, indicating that liveability cannot be strongly predicted by city systems rank alone

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with the best city systems ranking (1) and the second-highest liveability ranking (2), Pune is clearly a top performer. This suggests that Pune's excellent liveability is mostly due to its well-managed urban systems. With a city systems rating of 2 and a liveability rank of 8, Bhubaneswar similarly performs well, supporting the notion that good municipal systems can improve citizens' quality of life. Consistency is also evident in Ahmedabad and Surat, which have high liveability rankings (3 and 5, respectively) and solid city systems rankings (5 and 4, respectively). These cities are prime examples of how strong urban government and infrastructure improve livability.

Bengaluru has the highest liveability rating (1) but a comparatively low city systems ranking (22). This disparity raises the possibility that Bengaluru's high liveability is being driven by elements outside of city systems, such as economic prospects, cultural attractions, or climate. Conversely, Ranchi and Guwahati have relatively low liveability rankings (88 and 101, respectively) but moderate city systems rankings (9 and 12, respectively). This suggests that even while they have decent urban infrastructures, their liveability may be adversely affected by other issues like social problems, economic situations, or geographic isolation. Cities like Patna, Chandigarh, and Dehradun, liveability rankings are low (55, 45, and 64, respectively), even if their city systems rankings are moderate (18, 20, and 20, respectively). This may indicate problems that have a substantial impact on liveability but are not fully represented by the city systems rating, such as poor healthcare, education, or environmental quality.

4.0 Conclusion

The intricacy of urban liveability is highlighted by the weak overall association, even if there is a general trend that stronger city systems are associated with higher liveability. How livable a city is probably influenced by a number of factors, including social infrastructure, economic opportunity, environmental conditions, and cultural attractions. In order to improve the general quality of life for inhabitants, this research emphasizes the necessity of a more comprehensive approach to urban planning, one that takes into account a wide range of elements beyond only city systems. Insights into urban performance and the elements impacting the standard of living in Indian cities may be gained from the quadrant and correlation analyses of cities according to their City System Score and Liveability scores. These studies demonstrate how intricately government, sociocultural elements, and urban infrastructure interact to determine a city's liveability.

The results highlight the significance of a well-rounded strategy for urban development, wherein people' well-being is improved by giving equal weight to hard and soft social infrastructure.The quality of life in cities is also greatly influenced by other elements, including social cohesiveness, cultural amenities, economic opportunity, and environmental quality. While Bengaluru and other exceptions illustrate that non-infrastructure elements can also influence liveability, Pune, Bhubaneswar, Ahmedabad, and Surat show that well-managed urban systems

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can improve liveability. Cities like Ranchi and Guwahati, on the other hand, demonstrate how socioeconomic or topographical issues can jeopardize liveability even in the case of modest urban systems. The results of the correlation and quadrant analyses highlight how urban liveability is a complex idea impacted by a range of sociocultural elements, governance, economic possibilities, and hard infrastructure. To achieve sustainable and equitable urban development, investments in social infrastructure and inclusive planning must be made in addition to strong urban systems. Successfully incorporating these components into a city can set an example for others, improving everyone's quality of life and advancing urban India as a whole.

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CHAPTER 68

Exploring the Efficiency of Lean Construction Tools in Boosting Safety on Construction Sites

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ABSTRACT

The construction industry often faces unpredictable and fluctuating processes, leading to higher risks of accidents and unsafe working conditions. This study explores how Lean Construction techniques can improve safety on Indian construction sites. It synthesizes reliable research in safety management to evaluate the potential of Lean tools such as the Last Planner System, Visual Management, the 5S methodology, and Error- proofing in promoting safety. The study identifies key managerial challenges in the Indian construction sector that impact safety. This study evaluates the impact of Lean Construction techniques—Last Planner System, Visual Management, 5S, and Poka-Yoke in enhancing site safety performance. It also examines barriers to their implementation and proposes a process map for improving site safety. To achieve the objectives, questionnaire surveys and case studies were conducted. The analysis of these data facilitated the design of a process map for implementing Lean practices to enhance safety on construction sites. The findings demonstrate that Lean Construction techniques have significant potential to improve worker safety, reduce accidents, and create safer working environments by effectively addressing existing challenges.

Keywords: Lean construction; Safety management; Lean tools; Lean and safety.

1.0 Introduction

The construction sector plays a crucial role in global economic development, contributing approximately $10 trillion annually (McKinsey Global Institute, 2017). In India, the industry is expected to reach $1.4 trillion by 2025. Construction sites are known for high accident rates, making them one of the most hazardous industries worldwide (ILO, 2020). Insufficient safety measures, low productivity, and frequent cost overruns are common challenges (Hosseini *et al.*, 2018). Developing nations face additional safety challenges due to weak regulations, untrained labor, and high unemployment rates (Tam *et al.*, 2004). The mortality rate in Middle Eastern construction is 18.6 per 100,000 workers, significantly higher than in industrialized countries (ILO, 2020).

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Inadequate adherence to safety standards and the lack of a lean culture contribute to these issues (Salem *et al.*, 2005). Accidents occur due to human errors, equipment failures, poor site management, and ineffective safety enforcement (Tam *et al.*, 2004). Human factors include inadequate training and unsafe behaviors (Choudhry *et al.*, 2007; Zhou *et al.*, 2015). Faulty equipment and lack of maintenance contribute to risks (Hallowell & Gambatese, 2009). Poor site planning and management deficiencies also lead to incidents (Jannadi & Bu- Khamsin, 2002; Waehrer *et al.*, 2007). Proper training and adherence to safety protocols reduce accidents (Tam *et al.*, 2004).

Lean construction faces challenges during implementation such as top management support, finance, education, regulations, technical aspects, and worker resistance (Forbes & Ahmed, 2010; Salem *et al.*, 2005; Alarcón *et al.*, 2005; Tam *et al.*, 2004; Sacks *et al.*, 2010; Hallowell & Gambatese, 2009). Lean culture prioritizes safety by investing in employees, promoting engagement, and implementing continuous improvements (Abdelhamid & Everett, 2000; Forbes & Ahmed, 2010; Demirkesen & Arditi, 2015).

Lean Construction aims to enhance project efficiency by minimizing waste and maximizing value (Koskela *et al.*, 2002). By integrating safety into lean methodologies, risks can be reduced, and operations can be optimized (Demirkesen & Arditi, 2015). Techniques such as eliminating waste, standardizing safety procedures, and leveraging technology improve site safety (Seppänen *et al.*, 2010). Moreover, fostering a strong safety culture is essential in an industry with high accident rates.

2.0 Research Methodology

The research methodology involves a comprehensive literature review, during which articles were located using the keywords “lean construction,” “lean culture,” “construction safety,” “lean safety,” and “lean culture for health and safety” across platforms such as Google Scholar, Science Direct, Research Gate, and Taylor and Francis.

This study begins by examining the managerial challenges associated with implementing safety measures in the construction industry. It then examines existing research on safety management and how Lean Construction might help to improve worker safety. To further assess its impact, the study evaluates the potential of Lean Construction techniques—such as the Last Planner System, Visual Management, 5S, and Poka-Yoke - in enhancing safety performance on construction sites.

However, the adoption of Lean Construction in India faces significant barriers, including a lack of awareness and the complexity of implementing lean tools in on-site operations. To address these challenges, the study incorporates findings from the analysis to create a process map that uses Lean Construction concepts to improve safety management and encourage safer construction methods.

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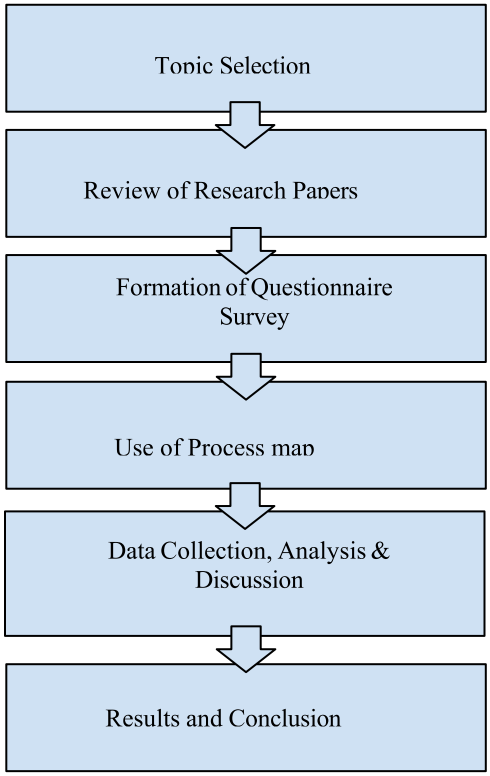
Figure 1: Research Methodology Flow Chart



A structured questionnaire survey is designed using the Delphi technique described below:

2.1 Delphi technique

The Delphi technique is a structured method for collecting expert opinions through multiple rounds of sections aimed at reaching a consensus among professionals. The participants in the study were exceptionally qualified, with the majority possessing between 2 to 10 years of experience in the construction industry. A sample size of 50 respondents was taken for a questionnaire survey.

2.2 Questionnaire survey

A structured questionnaire survey was prepared and circulated to experts, consisting of five key sections, and administered via Google Forms

- *Part 1) Personal Information:* This section gathered information regarding the respondents' educational qualifications, professional experience, years in the industry, job roles, and their engagement with safety and Lean practices.

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- *Part 2) Managerial Challenges during safety implementation:* This section seeks to obtain insights into the challenges encountered by managers within the construction sector, particularly concerning their effects on safety on construction sites. It identifies significant project management issues such as poorly organized workplace, Human error / Skilled labor shortage, Inadequate supervision, Lack of task coordination, Risk of falling objects and Organizational pressure. Additionally, it examines causes of safety issues at site like lack of training, communication issues, poor maintenance of machines, common safety hazards on-site, such as falls, equipment-related incidents, and insufficient personal protective equipment (PPE).
- *Part 3) Evaluation of Lean Construction Tools for Enhancing Safety Performance:* This section aims to assess the effectiveness of Lean Construction tools—such as the Last Planner System, Visual Management, 5S, and Poka-Yoke in enhancing safety on construction sites. A rating system from 1 to 5 (1- Strongly Disagree, 2- Disagree, 3- Neutral, 4- Agree, 5- Strongly Agree) is utilized, and the Relative Importance Index (RII) is calculated to rank each lean tool based on its significance.

2.3 Key lean tools covered in Section 3

- *Visual Management:* Uses visual tools like charts, dashboards, and signage to improve communication, transparency, and workplace organization.
- *Last Planner System (LPS):* A collaborative planning approach to minimize waste, improve coordination, and enhance site safety through structured scheduling and task commitment.
- *5S Methodology:* A structured approach (Sort, Set in Order, Shine, Standardize, Sustain) to enhance site organization, reduce clutter, and improve safety.
- *Poka-Yoke (Error Proofing):* A mistake-proofing technique that prevents errors or detects them early, ensuring compliance with safety standards and improving efficiency in construction.
- *Part 4) Barriers to implement Lean construction tools for enhancing Safety performance:* This section discusses critical barriers to Lean Construction adoption in India, including a lack of understanding, reluctance to change, high costs, and industry fragmentation. Participants assess the challenges and rate the complexity of implementing Lean tools (Visual Management, Last Planner system, 5S, Poka-Yoke) for site safety using a scale of 1 (Easy), 2 (Moderate), and 3 (Difficult). Additionally, the Relative Importance Index (RII) is calculated to rank the most difficult Lean tool to implement on construction sites as per the responses received. They also offer solutions for addressing challenges, such as technology integration, policy changes, and training programs. By tackling important implementation issues, the insights seek to improve Lean adoption.
- *Part 5) Feedback Survey:* A feedback survey was conducted to gather respondents' opinions on promoting use of Lean tools to improve construction site safety.

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We gathered respondent data through a questionnaire survey, focusing on managerial challenges related to safety, causes of safety issues at sites, the potential impact of lean tools on enhancing safety, and the key barriers to implementing these tools. After collecting the necessary data, the lean tools were ranked using the Relative Importance Index (RII) and also assess their difficulty level based on RII.

2.4 Relative Importance Index (RII)

The Relative Importance Index (RII) is a statistical method used to prioritize factors based on expert opinions, allowing for the identification of key elements influencing a given outcome (Hosseini *et al.*, 2018). RII helps to determine which lean tools have the most significant impact on enhancing site safety (Hallowell & Gambatese, 2009).

$$RII = \frac{5n5+4n4+3n3+2n2+1n1}{A*N}$$

$$RII = \frac{\Sigma W}{A\times N}$$

Where: W = Weight assigned to each factor by respondents (e.g., 1 = Strongly Disagree, 5 = Strongly Agree) A = Maximum weight (e.g., if 5-point scale is used, A = 5)

N = Total number of respondents

Responses are collected using a Likert Scale (e.g., 1 = Not Important, 5 = Very Important) (Zhou *et al.*, 2015). The highest-ranked factors are considered most critical for improving safety using Lean Construction techniques.

3.0 Results and Discussions

In section 1, we collected the basic information of respondent like name, age, email ID, professional background, considering 2-10 years of experience and we found total 54 responses, out of 54 responses - 34 respondent (63%) have worked on construction sites without direct involvement in Lean Construction, while 20 respondent (37%) have used the lean tools at their project site. This indicates that a significant proportion of professionals—63% (34 respondents)—lack awareness of lean construction methodologies.

In section 2, we discussed the key managerial challenges in safety implementation and we got (54 responses): Poorly organized workplace – 36 responses(66.7%), Human error / Skilled labor shortage – 31 responses(57.4%), Inadequate supervision – 28 responses(51.9%), Lack of task coordination – 25 responses(45.3%), Machine failures – 23 responses(42.6%), Excessive stress – 21 responses(38.9%), Risk of falling objects – 20 responses (37%) and Organizational pressure – 19 responses (35.2%). We found the top 3 managerial challenges having major impact on safety implementation which are Poorly organized workspace, Human error/ Skilled labour shortage and inadequate supervision. We also discussed the causes of safety issues at sites: Communication issues – 38 responses (70.4%), Lack of training – 36 responses (66.7%), Insufficient PPE – 32 responses (59.3%), Poor equipment maintenance – 32 responses (59.3%), Hazardous conditions – 29 responses (53.7%), Consumption of alcohol & drugs on-site

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– 20 (37%). We found the top 3 causes of safety issues at sites were communication issues, lack of training and insufficient PPE. In section 3, We evaluated the effectiveness of selected lean construction tools to enhance safety performance, (RII) was used to rank the lean tools based on their effectiveness for enhancing safety at site

Figure 2: Last Planner System

Figure 3: Visual Management

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Figure 4: 5S

Figure 5: Poka-Yoke

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(Figure 2- Last Planner system) shows a survey result with an average rating of 3.26. The majority of respondents (40%) rated 3, followed by 22% rating 2, 20% rating 4, and 16% rating 5. A small percentage (2%) rated 1, indicating a generally moderate response with room for improvement. (Figure 3 - Visual Management shows a survey result with an average rating of 4.43, indicating a highly positive response. The majority of respondents rated 4 (49%) and 5 (47.1%), while a very small percentage (3.9%) rated 3, and no one rated 1 or 2.

(Figure 4 - 5S) shows a survey result with an average rating of 3.24, indicating a neutral to slightly positive response. The majority of respondents rated 3 (37.3%), followed by 2 (25.5%) and 4 (25.5%), while 11.8% rated 5 and no one rated 1.

(Figure 5 – Poka-Yoke) shows a survey result with an average rating of 3.02, indicating a neutral response. Ratings are fairly distributed, with 28% ratings, 4, 22% rating 3, and 18% each for 1 and 2, while 14% rated 5.

(Table 1: RII for the impact of lean construction tools enhancing safety) presents survey results evaluating four Lean tools based on respondent ratings. Visual Management ranked highest (RII = 0.886) with positive feedback, followed by the Last Planner System (RII = 0.652) in second place. 5S received a neutral response (RII = 0.647), ranking third. Poka-Yoke, with the lowest RII (0.604), showed the most mixed feedback. The results highlight Visual Management as the most well-received tool, while Poka-Yoke needs improvement. We found visual Management (Rank 1, RII-0.886) as the most effective tool with clear visual signs and organized workspaces enhancing safety. Last Planner System (Rank 2, RII-0.652) – Emphasizes proactive planning and coordination, reducing safety risks. 5S (Rank 3, RII-0.647) – Highlights the role of a structured, clutter-free workplace in improving safety. Poka-Yoke (Rank 4, RII-0.604) – Though ranked lowest, it remains valuable in preventing human errors through error-proofing techniques.

Table 1: RII for the Impact of Lean Construction Tools Enhancing Safety

Sr No	Lean Tools	5n5	4n4	3n3	2n2	1n1	Total	Total Number (N)	A*N	RII	Rank
1	Last Planner system	40	40	60	22	1	163	50	250	0.652	2
2	Visual Management	120	100	6	0	0	226	51	255	0.886	1
3	5S	30	52	57	26	0	165	51	255	0.647	3
4	Poka-Yoke	35	56	33	18	9	151	50	250	0.604	4

In section 4 it collects data related to (Part 1) barriers to implementing Lean tools for enhancing safety performance and (Part 2) the Complexity of Lean tools in implementing them on construction sites to enhance safety. In the first part, we got the following responses - Lack of training or skilled personnel – 35 responses (67.3%), Lack of awareness or understanding – 30 responses (57.7%), High initial costs – 28 responses (53.8%), complexity of lean tools and methods - 26 responses (50%), Resistance to change among workers and managers - 25 responses (48.1%), Inadequate leadership commitment - 11 responses (21.2%), Others - 4 responses (7.7).

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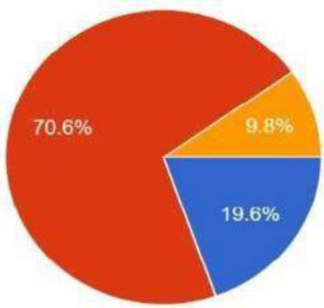
We found the top 3 barriers as Lack of training or skilled personnel (67.3%), lack of awareness or understanding (57.7%) and high initial costs (53.8%). In the second part, we are now evaluating the complexity of Lean tools in implementing it on construction sites enhancing safety using the relative importance index (RII).

The four pie charts (Figures 6–9) depict the complexity levels of lean tools in implementing on sites, which are classified as Easy (blue), Moderate (red), and Difficult (yellow). In the first chart, the majority of replies (70.6%) were rated as moderate, 19.6% as easy, and 9.8% as difficult. The second chart with 54.9% rating is moderate, 37.3% easy, and 7.8% difficult. According to the third figure, 63.5% of respondents rated it moderate, 21.2% easy, and 15.4% difficult. In the fourth chart, 60.8% rated as moderate, 27.5% as difficult, and 11.8% as easy. RII was used to rate the lean tools based on the difficulty level the respondent faced to implement (1- Easy, 2- Moderate, 3- Difficult)

Figure 6: Complexity of Visual Management



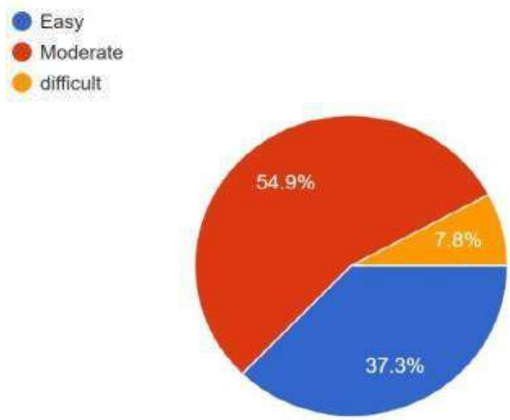


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Figure 8: Complexity of 5S

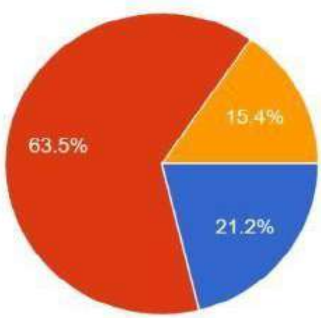

Figure 9: Complexity of Poka-Yoke

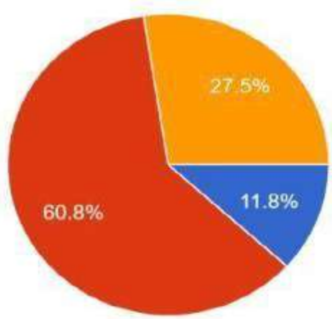

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Table 2: RII for Complexity of implementation of lean tools in enhancing safety on sites. The table evaluates the perceived difficulty of four Lean tools based on survey responses. Poka-Yoke ranked as the most difficuilt (RII = 0.431), with the highest number of respondents finding it difficult. 5S followed closely (RII = 0.389), indicating moderate difficulty. The Last Planner System (RII = 0.38) ranked second in ease of use, while Visual Management (RII = 0.345) was considered the easiest. Overall, the results suggest that Poka-Yoke is the most difficult tool, while Visual Management is the most easy.

We found that Poka-Yoke (Rank 1, 0.431) is most challenging due to reliance on specialized error- proofing mechanisms and advanced training. 5S (Rank 2, 0.389) is moderately difficult, requiring continuous commitment to workplace organization. Last Planner System (Rank 3, 0.380) & Visual Management (Rank 4, 0.345) are easier to implement, as structured planning and visual guidance are more adaptable.

Table 2: RII for Complexity of Implementation of Lean Tools in Enhancing Safety on Sites

Sr No	Lean Tools	Easy (1)	Moderate (2)	Difficult (3)	(1n1)	(2n2)	(3n3)	Total	Total Number (N)	A*N	RII	Rank
1	Last Planner system	10	36	5	10	72	15	97	51	255	0.38	2
2	Visual Management	19	28	4	19	56	13	88	51	255	0.345	4
3	5S	11	33	8	11	66	24	101	52	260	0.389	3
4	Poka- Yoke	6	31	14	6	62	42	110	51	255	0.431	1

In section 5, According to survey feedback given by respondent, Lean Construction improves safety, workflow optimization, and continual improvement. The 5S method for organization, LPS for improved planning, and VSM for spotting inefficiencies were all acknowledged by the respondents. Also, JIT reduces clutter and risks, whereas kaizen fosters a proactive safety culture. Standardized Work guarantees conformity, Poka-Yoke avoids errors, and Visual Management raises awareness of potential hazards. Large companies use these tools well, but local contractors encounter difficulties. Overall, safety, effectiveness, and long-term cost savings are increased when Lean technologies are tailored to certain stages of construction.

After analyzing the survey data, I examined managerial challenges in implementing safety measures in construction. Key Lean techniques, including the Last Planner System, Visual Management, 5S, and Poka- Yoke, are evaluated for their impact on safety performance. However, adoption in India faces challenges like low awareness and implementation complexity. These findings guided us to the development of a process map given below in (Figure 10: Process map) integrating Lean Construction concepts to improve safety management.

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Figure 10 shows the process map shows a five-step process for safety management, depicted as a horizontal timeline.

- *Risk identification:* Focuses on risk identification by analyzing past incidents and site observations.
- *Lean tool implementation:* Involves implementing Lean tools like Visual Management, 5S, and Last Planner System.
- *Control measure implantation:* Emphasizes control measure implementation, including visual safety signs and colour-coding, alongside safety checklists.
- *Continuous safety training:* Highlights continuous safety training through toolbox talks, workshops, and safety checklists.
- *Monitoring and improvement:* Concerns monitoring and improvement, tracking incident and near-miss rates, and adjusting Lean strategies.

4.0 Conclusion

Safety management has become a crucial aspect of modern construction, ensuring overall project success. This study explores how lean construction tools can be implemented to improve safety. The present study identifies key managerial challenges, prioritizes lean tools to enhance safety, and develops a process map for incorporating lean principles to improve safety at construction sites.

Figure 7: Process Map

The respondents identified a poorly organized workspace as the top managerial challenge, followed by human error and unskilled labor as the second, and inadequate supervision as the third. The lean tool 5S could be an ideal solution for organizing the workplace, and many researchers have also found it useful for improving housekeeping. A structured training program specifically targeting unskilled labor, along with the development of

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standardized checklists, would help address the second and third managerial challenges identified by the respondents. The major causes of safety issues at the site, as highlighted by respondents, include a lack of training, poor communication, and a shortage of personal protective equipment (PPE). The collaborative approach promoted by lean philosophy is well-suited to enhancing coordination, thereby improving overall efficiency. The top three lean tools prioritized by respondents for enhancing safety at construction sites are visual management, the Last Planner System, and 5S. Since unskilled labor plays a significant role in maintaining safety, visual management techniques—such as visual boards for standard procedures and safety parks—can be effective.

The Last Planner System encourages the involvement of execution teams in planning, enabling the setting of realistic targets that prevent worker overburden and optimize the planning process. The top three barriers identified by respondents are lack of training, lack of awareness or understanding, and high initial implementation costs. This highlights the need for training in lean construction to facilitate its integration into construction practices. Respondents also rated lean tools based on their complexity, finding Poka-Yoke and the Last Planner System more complex compared to 5S and Visual Management. Therefore, firms looking to initiate lean implementation may consider starting with 5S and Visual Management, as they are relatively easier to adopt. These findings led to the development of a process map for integrating lean construction concepts into safety management at construction sites. This framework provides guidance on using lean principles to enhance safety performance. Future research should explore cost-effective strategies to promote the adoption of lean tools in construction safety management.

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CHAPTER 69

Factors Affecting Employability of Technical Graduates in Indian Construction Industry

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ABSTRACT

This study examines the most important determinants shaping employability among civil engineering graduates in India's construction industry based on the Relative Importance Index (RII) approach. The data was gathered via an online survey and interviews, generating both quantitative and qualitative information. The analysis selected the top five factors that contribute most to employability: Communication Skills (RII: 0.751), Willingness to Learn (RII: 0.751), Teamwork Skills (RII: 0.751), Personal Integrity (RII: 0.744), and Interpersonal Skills (RII: 0.743). These selected factors indicate a balanced concentration on technical and soft skills, emphasizing the need for holistic competency development. Communication skills were the most essential, indicating the need for graduates to be able to articulate ideas. Willingness to learn and teamwork ability were also critical, reflecting the emphasis on flexibility and collaboration. Personal integrity and interpersonal ability were also high priorities, showing the significance of ethical conduct and relational ability. The results add to knowledge of employability dynamics, offering insights for curriculum development and professional growth.

Keywords: Employability; Technical graduates; Construction industry; Skill gap; Industry-academia collaboration.

1.0 Introduction

Employability is a critical factor in ensuring career longevity and success, particularly in a rapidly evolving job market influenced by technological advancements and shifting economic conditions. For technical graduates, employability encompasses not only the ability to secure initial employment but also the adaptability to meet changing industry demands. In the context of the Indian construction industry, which is a significant contributor to the nation's GDP and employment, the employability of technical graduates is increasingly vital. However, a persistent gap exists between the skills imparted by educational institutions and the practical, technical, and soft skills required by the industry.

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The Indian construction sector is undergoing a transformation, driven by advancements such as Building Information Modelling (BIM), automation, and sustainable practices. These changes have heightened the demand for technically sound professionals who are adept at using modern tools and technologies. Despite this demand, technical graduates often lack the practical experience, exposure to cutting-edge technologies, and essential soft skills needed to thrive in the industry. This mismatch between industry requirements and academic preparation underscores the need for a comprehensive study to identify and address the factors affecting the employability of technical graduates. This research aims to explore the key determinants influencing the employability of technical graduates in the Indian construction industry. By analyzing the gaps in skills and competencies, the study seeks to provide actionable insights for educational institutions, policymakers, and industry stakeholders. The findings will contribute to the development of a more aligned and responsive educational framework, ensuring that graduates are well-equipped to meet the evolving demands of the construction sector and contribute to its sustainable growth.

1.1 Objectives

- Identify the key factors influencing the employability of students.
- Empirically validate the identified factors in the Indian construction sector.

2.0 Literature Review

Skills and attributes expected by employer worldwide: Employability has garnered significant global attention, particularly in the context of a competitive and globalized job market. Numerous studies have identified the skills and attributes employers seek in graduates and professionals, with the construction industry being no exception. While extensive research has been conducted in regions like South Africa, there is a notable scarcity of studies in the Indian context, especially within the construction sector. In India, studies such as (Rajput *et al.,* 2022) have identified eight critical factors influencing the employability of civil engineering graduates: site administration, business development, managerial, design management, procurement and material management, risk management, planning and scheduling, and ethics and professionalism. These skills highlight the need for a blend of technical expertise and soft skills like communication and leadership. Similarly, (Valli *et al.,* 2019) emphasized generic employability skills such as communication, problem-solving, and interpersonal skills, which are essential for engineering graduates in the global labor market. (Krishna *et al.,* 2021) highlighted the role of internships in enhancing employability, as they provide hands-on experience and bridge the gap between theoretical knowledge and industry requirements. (Chinnan *et al.,* 2019) further underscored the importance of aligning academic curricula with industry needs, particularly in areas like Building Information Modelling (BIM), which, despite slow adoption in India, equips students with critical skills for modern construction projects.

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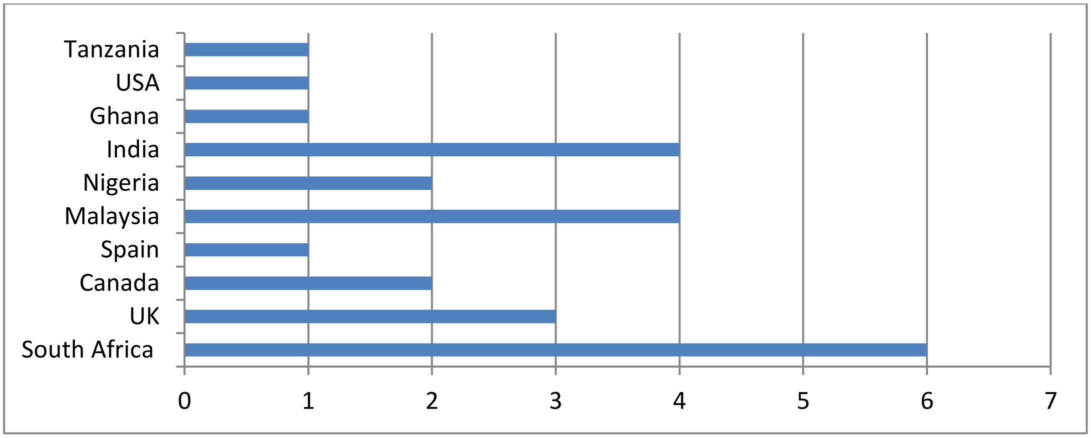
Figure 1: No. of Studies Done Globally



Source: Compiled by author

Internationally, studies such as (Miller *et al.,* 2005) have emphasized the importance of communication skills, which are crucial for teamwork, project management, and client interactions. (Arain *et al.,* 2010) identified construction competence, project management, leadership, and communication as key competencies for construction graduates, while (Devaney *et al.,* 2012) highlighted the role of personal attributes and labor market conditions in determining employability. (Machi *et al.,* 2013) identified intrinsic barriers such as reluctance to relocate and poor communication skills as factors limiting employability, particularly in sectors requiring global mobility. (Jainudin *et al.,* 2015) stressed the importance of balancing technical and soft skills, with the latter advocating for mandatory industrial training to bridge the theory-practice divide. (Paul *et al.,* 2015) and (Anastasiu *et al.,* 2017) proposed innovative approaches like virtual workplace environments and interdisciplinary modules to enhance employability skills. Further studies, such as (Aigbavboa *et al.,* 2017) and (Rizwan *et al.,* 2018), highlighted the need for curricula revisions to address the mismatch between graduate skills and employer expectations, particularly in developing countries. (Eldeen *et al.,* 2018) and (Gerber *et al.,* 2019) emphasized the importance of teamwork and interpersonal skills, which are often prioritized over technical competencies by employers. (Ismail *et al.,* 2019) and (Saleh *et al.,* 2019) reinforced the value of practical training and communication skills in civil engineering education, while (Munifi *et al.,* 2019) identified gaps in project management and transferable skills among graduates. Recent research by (Arian *et al.,* 2020) and (Aliu *et al.,* 2020) highlighted the importance of industry-specific knowledge, lifelong learning, and university-industry collaborations in enhancing employability. (Mtshali *et al.,* 2020) and (Obi *et al.,* 2020) explored the impact of the Fourth Industrial Revolution (4IR) on skill requirements, emphasizing the need for digital literacy and adaptability. (Jack *et al.,* 2021) and (Yussof *et al.,* 2021) underscored the effectiveness of Competency-Based Training (CBT) and the need to align

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graduate competencies with employer demands. (Aliu *et al.,* 2021) and (Gomes *et al.,* 2022) identified leadership, critical thinking, and prior industry experience as key factors influencing employability. (Palomino *et al.,* 2022) and (Sicadsicad *et al.,* 2022) highlighted discrepancies in perceptions of required skills among students, graduates, and practitioners, calling for curricula tightening and enhanced field training. Collectively, the literature reveals a persistent skills gap between academic training and industry expectations in the construction sector. While Indian studies focus on aligning curricula with industry needs and integrating practical training, international research extends into areas like 4IR skills, interdisciplinary learning, and postgraduate education. Future research should explore innovative pedagogical approaches and technology-driven training models to bridge this gap and enhance graduate employability on a global scale.

3.0 Research Methodology

This research employs a mixed-methods approach to examine the factors influencing the employability of civil engineering graduates in India's construction industry. Quantitative data is collected through an online survey using a Likert scale to assess employer priorities, while qualitative insights are gathered via semi-structured interviews to explore skill gaps, technological impacts, and experiential learning. Snowball sampling is utilized to recruit industry professionals, ensuring diverse perspectives.

Data analysis combines the Relative Importance Index (RII) for quantitative findings, integrating both to provide a comprehensive understanding of employability determinants.

$$\text{RII} = \frac{\Sigma(\boldsymbol{W}\times\boldsymbol{f})}{(N\times A)} \qquad ...1$$

Ethical considerations, including informed consent and confidentiality, are rigorously maintained throughout the study.

4.0 Data Analysis

The table presents the Relative Importance Index (RII) scores for various competencies in civil engineering, indicating their perceived significance in the field. Technical Knowledge (0.7618) and Legal Study Knowledge (0.761) rank highest, emphasizing the importance of engineering principles and legal compliance in construction. Leadership Skills (0.738), Communication Skills (0.747), and Personal Integrity (0.751) also score highly, highlighting the need for strong leadership, ethical conduct, and effective interaction. Mid-range scores for skills like Site Surveying (0.673) and Project Management (0.689) suggest they are valued but slightly less critical, while Work Experience (0.704) and Postgraduate Qualifications (0.725) underscore the importance of both practical and advanced academic training. Overall, the data reflects a balanced emphasis on technical expertise, soft skills, and professional ethics in civil engineering.

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Table 1: Relative Importance Index (RII)

Questions	RII
Technical Knowledge (knowledge of engineering principles and technologies)	0.7618
Legal Study Knowledge (understanding of laws relevant to construction)	0.761
Applied Knowledge (ability to apply theoretical knowledge to practical situations)	0.731
Construction Acumen (interpreting plans, drawings, and material specifications)	0.737
Site Surveying (conducting inspections of construction sites)	0.673
Measurement and Estimating (calculating quantities and costs)	0.713
ICT Skills (use of software applications and digital tools)	0.712
Management Skills (coordinating tasks within a team or project)	0.712
Business Acumen (understanding of business and organizational practices)	0.721
Project Management (planning, scoping, scheduling, and budgeting)	0.689
Procurement and Materials Management (sourcing materials and managing supplies)	0.718
Planning and Scheduling (ability to organize and prioritize tasks)	0.736
Risk Management Skills (identifying and mitigating risks in projects)	0.719
Problem-Solving Skills (creativity and practicality in solving construction challenges)	0.721
Analytical Thinking (ability to analyze information and make decisions)	0.713
Leadership Skills (ability to guide teams to achieve project goals)	0.738
Personal Integrity (displaying honesty and adherence to ethical standards)	0.751
Discipline (adherence to rules and responsible conduct)	0.711
Ethics and Professionalism (acting with high moral standards in professional settings)	0.73
Communication Skills (effective conveyance of information)	0.747
Report Writing (ability to produce clear, concise reports)	0.74
Interpersonal Skills (ability to work effectively in diverse teams)	0.743
Willingness to Learn (capacity for continuous learning and skill improvement)	0.751
Teamwork Skills (ability to work well in collaborative environments)	0.751
Customer Relationship Skills (ability to manage customer needs and maintain satisfaction)	0.733
Postgraduate Qualification (value of advanced degrees in civil engineering)	0.725
Work Experience (value of prior experience in the construction industry)	0.704

Source: Compiled by author

Top Factors Affecting Employability

Based on the highest RII values, the top factors influencing employability are:

- *Communication Skills (0.751):* The most critical factor, as effective communication is essential in any work environment.
- *Planning and Scheduling (0.748):* The ability to prioritize and organize tasks is highly valued.
- *Teamwork Skills (0.747):* Collaboration in team-based projects significantly impacts employability.
- *Personal Integrity (0.744):* Ethical behavior and honesty are crucial in professional settings.
- *Willingness to Learn (0.743):* Continuous learning and skill improvement make a candidate more employable.

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5.0 Conclusion

The study highlights the multi-faceted nature of employability in civil engineering, where technical skills and soft skills have equal importance. Through RII analysis, Communication Skills (0.751), Willingness to Learn (0.751), Teamwork Skills (0.751), Personal Integrity (0.744), and Interpersonal Skills (0.743) were the top five factors recognized as instrumental. Communication skills were found to be the most significant factor with the point stressed upon being the clear expression and sharing of information. In the same way, willingness to learn depicts the dynamic state of the industry, where there is a constant need for upskilling. Teamwork abilities emphasize the need for teamwork in construction undertakings. Personal integrity indicates the emphasis on ethical conduct and trustworthiness, which is crucial in upholding professional standards. Interpersonal skills once again emphasize the significance of relational dynamics in a collaborative industry. These findings offer practical recommendations for educational institutions, recommending an integrated curriculum that emphasizes technical skills, ethical knowledge, and soft skills. Employers can also use these findings to develop more effective recruitment standards and professional development initiatives. This study generally adds to the employability debate by emphasizing the essential balance between technical expertise and interpersonal skills.

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CHAPTER 70

Feasibility Study on the Use of Industrial Waste for Sustainable Construction

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Abhishek Singh Shekhawat[1] and Sudarshan Kore[2]

ABSTRACT

There are many types of waste generated during various mining and industrial operations. Among them the fly ash and crushed fine aggregate are on highest generated waste in the thermal power plants and mining of stones respectively. The project aims to promote sustainable construction by repurposing plastic waste and industrial byproducts into eco-friendly outdoor sitting bench, reducing environmental waste and offering a cost-effective, durable alternative. This research explores a sustainable construction method utilizing recycled materials such as plastic bottles, fly ash, crushed sand and bamboo to create environmentally responsible sitting chairs. By repurposing plastic waste and leveraging renewable materials, this approach reduces landfill waste and carbon emissions while promoting resource efficiency. The study demonstrates the feasibility of integrating recycled materials into construction as a scalable and economical solution, aligning with international sustainability standards and supporting the circular economy. The finding highlights waste utilization, reduce carbon emissions, and material costs, setting a precedent for future green construction initiatives.

Keywords: Cement; Flyash; Construction; Cost; Sustainability.

1.0 Introduction

1.1 Sustainability and waste management within the construction industry

The construction sector is among the biggest industries in the world economy, with a key role to play in development, urbanization, and infrastructure development. The sector works with intricate supply chains and utilizes huge amounts of resources to respond to increasing demands of development.

Engineering and construction (E&C) firms are increasingly being subjected to pressure to resolve sustainability issues while ensuring economic feasibility in a rapidly competitive environment. Its influence stretches beyond direct construction activity to encompass longer-term operational factors, and as such, the built environment is an essential priority for sustainable development initiatives (Deloitte, 2024).

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1.2 Importance of sustainability in construction

Sustainability is necessary in construction because it has a major impact on the environment, with 39% of global operational and embodied carbon emissions coming from the built environment (Deloitte, 2024). More than 90% of US construction companies have reported increasing client pressure to lower embodied carbon, reflecting the movement toward sustainable operations. With rapid urbanization, the environmental footprint of construction increases, and conserving resources and reducing pollution becomes essential for sustainable development (Aranca, 2024).

1.3 Waste generation in construction sector

Construction produces heterogeneous waste streams, which differ according to project type and local operations. Typical wastes such as concrete, wood, metal, bricks, and plastics typically find their way into landfills with associated environmental impacts (Aranca, 2024). It was revealed in one study conducted in Malaysia that the Conventional Construction Method (CCM) resulted in the greatest waste at 197.657 tons (0.046 tons/m^2), while the Industrialized Building System (IBS) generated much lower at 77.188 tons (0.018 tons/m^2) (ETASR, 2018). This calls attention to how construction activities affect the production of waste, with a focus on choosing effective methods to reduce waste.

Figure 1: Anatomy of the Wall

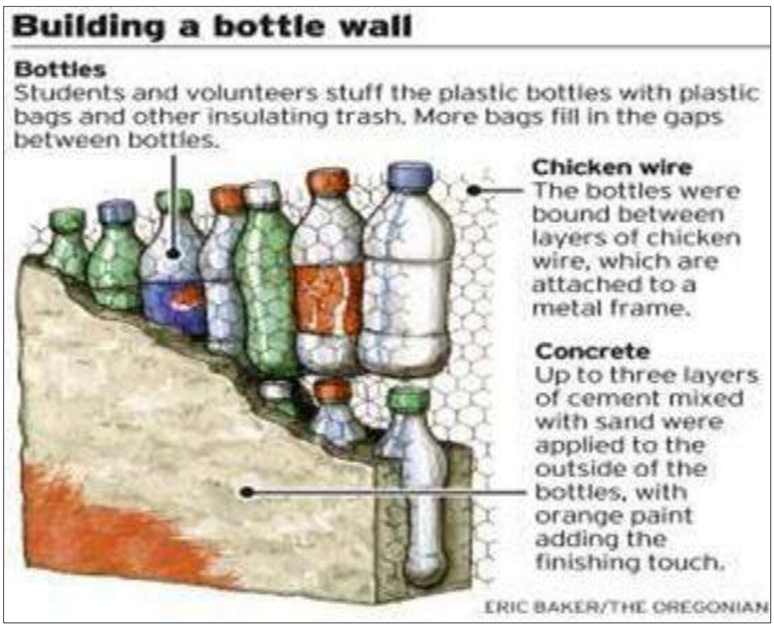

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Figure 2: Placement of Bottles in the Wall

Figure 3: Finished Wall Bottle School in Guatemala

Source: Bright Vibes

2.0 Literature Review

2.1 Plastic waste incorporation in concrete

The global plastic waste crisis has led scientists to explore new applications for such materials beyond conventional recycling streams. Polyethylene terephthalate (PET), the polymer in beverage bottles and packaging for foods, represents an abundant waste stream with physical characteristics of potential application in construction materials. Recent studies have

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investigated the effect of chemical pre-treatment on PET waste before application in concrete mixes. When plastic waste is mixed into concrete, chemical treatment has been demonstrated by scientists to significantly improve compatibility with cementitious materials. Hydrogen peroxide and calcium hypochlorite solutions treat plastic aggregates to produce a rough surface on plastic aggregates and enhance the mechanical bond with the concrete paste around them. This modification overcomes one of the principal problems in plastic-concrete composites: the low quality of the interfacial transition zone between plastic particles and the paste of the cement. Testing between percentages of replacement between 10% and 30% demonstrates treated plastic aggregates enhance compressive strength and concurrently reduce concrete permeability and porosity compared to their non-treated counterparts (Lee *et al.*, 2019).

2.2 Fly ash as a sustainable cement substitute

Portland cement manufacturing is a major source of global carbon emissions and as such there exists interest in supplementary cementitious materials with the potential to reduce environmental impact at no loss of performance. Fly ash, the finely divided residue of coal combustion in power plants, has been an extremely successful partial substitute for cement. It is siliceous and aluminous in character and when properly activated in concrete mixes develops strength over the longer term by pozzolanic reaction.

Environmental studies indicate that the utilization of fly ash in concrete mixtures offers considerable sustainability benefits. Environmental impact assessments demonstrate that incorporating fly ash into concrete mixtures delivers substantial sustainability benefits. Research indicates that replacing 25% of cement with fly ash reduces the global warming potential of concrete by 22-30.6%, while 50% replacement levels achieve reductions of 44-51.4%. These environmental advantages stem primarily from avoiding the carbon-intensive cement production process, with each unit of fly ash substitution preventing approximately equivalent CO_2 emissions. Beyond climate impacts, fly ash utilization provides additional environmental benefits including reduced energy consumption and conservation of landfill capacity that would otherwise be required for ash disposal (Green Education Foundation, 2023).

2.3 Recycled aggregates as natural material alternatives

The construction and demolition sector generates substantial waste volumes annually, much of which holds potential value as secondary materials. Recycled concrete aggregates, produced by processing demolition waste, offer a promising alternative to natural aggregates in new concrete production. This approach simultaneously addresses waste management challenges and reduces demand for virgin material extraction. Performance analysis of recycled aggregate concrete indicates that strength development depends on multiple factors including the quality of source materials, processing methods, and mixture proportions. Water absorption characteristics of recycled aggregates differ significantly from natural materials, requiring adjustments to mixture designs to maintain workability and performance. As the replacement

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percentage of recycled aggregates increases, modifications to sand ratios become necessary to optimize mechanical properties. Research suggests that incorporating supplementary cementitious materials like fly ash alongside recycled aggregates can help address strength development challenges, though early-age performance may be affected differently than long-term properties (Darpan International Research Analysis, 2024).

2.4 Alternative waste materials in construction

Beyond plastic and fly ash, researchers have investigated numerous other waste streams for potential concrete applications. Bamboo fiber, derived from a rapidly renewable plant resource, has shown promise as a reinforcement material in concrete mixtures. These natural fibers, comprising primarily cellulose, hemicellulose, and lignin, provide tensile reinforcement that can help control cracking and enhance concrete durability.

Experimental studies incorporating bamboo fibers into concrete mixtures demonstrate improvements in several performance characteristics. Research indicates that optimal fiber content levels (approximately 0.75%) help limit concrete shrinkage, reduce crack propagation, and positively influence tensile properties. However, fiber content must be carefully controlled, as excessive amounts can negatively impact concrete workability. When combined with other supplementary materials such as waste marble powder and waste glass powder at replacement levels around 10%, bamboo fiber-reinforced concrete exhibits enhanced mechanical properties including improved compressive strength, shear resistance, and bond characteristics (Ramos-Fernández *et al.*, 2021).

From the above literature review it is observed that the conventional construction material environmental impact requires embracing sustainable alternatives. This study is focused on the development of an environmentally friendly bench using waste materials like plastic bottles, bamboo, fly ash, and waste crushed sand to make it durable and sustainable while limiting environmental effects. PET bottles are to be converted into structural parts with chemical modification to improve the bonding with cementitious materials. Bamboo, with its high tensile strength and renewability, will be utilized as reinforcement to enhance load-carrying capacity and resistance to cracks.

Fly ash will be employed as a partial cement replacement to reduce carbon emissions while aiding in long-term strength development through pozzolanic reactions. Waste crushed sand will also replace natural fine aggregates, maximizing the use of resources and reducing reliance on natural sand. This research will analyze the mechanical properties, durability, and sustainability advantages of the suggested material mixtures in terms of compressive strength, permeability, and structural stability. By incorporating waste materials into functional products such as urban furniture, this research seeks to advance circular economy principles and sustainable building practices. The results will help create effective, low carbon building solutions, showcasing the potential of substitute materials in contemporary infrastructure while tackling global sustainability issues.

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3.0 Key Waste Materials for construction Applications

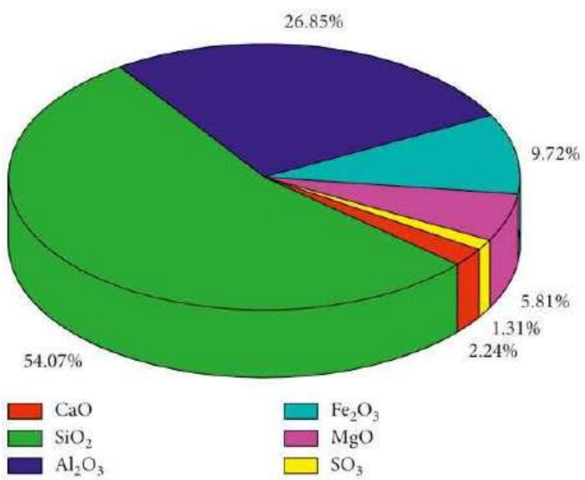
3.1 Plastic waste utilization

Plastic waste, particularly polyethylene terephthalate (PET) bottles, poses a global disposal challenge. Their high tensile strength, chemical resistance, and strength-to-weight ratio make them suitable for modular construction (Modification of Waste Aggregate PET, 2019). Additionally, recycled aggregates from construction and demolition waste, along with industrial by-products like coal bottom ash, offer sustainable alternatives to natural aggregates, supporting a circular economy by reducing landfill waste and conserving resources (Evaluating Recycled Concrete Aggregate, 2024).

Figure 4: Polyethylene Terephthalate (PET) Bottle

Source: Plastics for change

Figure 5: Main Chemical Composition of Fly Ash



Source: Zhiyu Tang, Nianchun Deng Research gate

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3.2 Fly ash as a cementitious material

For external bonding among bottles, the paste is normally designed with 10-15% Portland cement content to facilitate rapid development of strength and weather resistance. Optimum proportioning of water content (water-to-solid ratios of 0.28-0.35) achieves satisfactory workability without compromise in strength development. Prototype bench structural testing has demonstrated compliance with relevant standards for public seating, including ISO 7173:1989 (Furniture — Chairs and stools — Determination of strength and durability). The structure is able to withstand concentrated loads of 1.2-1.8 kN and distributed loads of 3-5 kN/m² and experiences gradual deformation rather than catastrophic failure under overloading—a critical safety consideration for public installations.

3.3 Crushed sand

Crushed sand (M-sand) is a sustainable alternative to natural sand, addressing resource scarcity and environmental concerns from riverbed mining. Research shows that up to 40% replacement of natural sand in concrete maintains compressive strength, while 60-70% substitution enhances tensile strength (International Journal of Engineering Research and Technology, 2022). It also improves flexural strength at 28 days and is cost-effective due to lower transport costs (Singh, 2021). Studies confirm its viability in pavement construction and full replacement in M20 concrete with proper mix adjustments (Darpan International Research Analysis, 2024; Green Education Foundation, 2023). Additionally, its shape properties influence elasticity and shrinkage, supporting its use as a fine aggregate (Ramos-Fernández *et al.*, 2021).

Figure 6: Fly Ash Sample

Source: Indiamart

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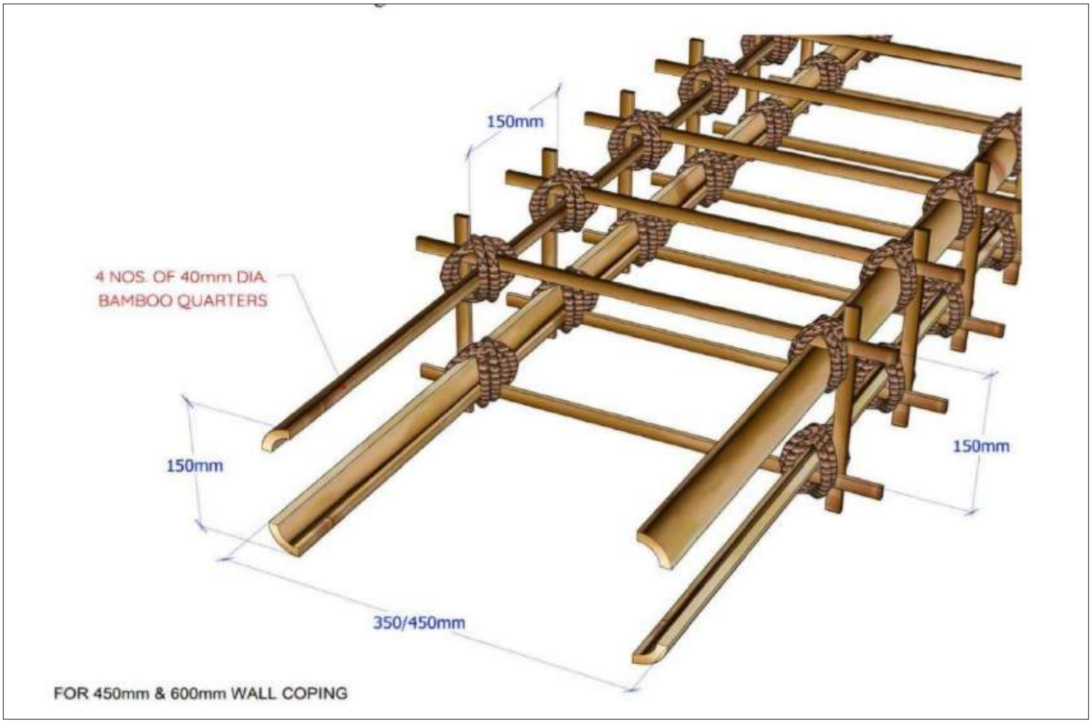
Figure 7: Bamboo as a Reinforcement in Green Carbon Building



3.4 Bamboo for sustainable construction

Bamboo is emerging as a sustainable alternative in construction due to its rapid growth, high tensile strength comparable to steel, and natural resistance to decay and moisture (Revista Electronica De Veterinaria, 2021). Its flexibility allows it to absorb seismic loads, making it ideal for earthquake-resistant structures (UN-Habitat, 2022). Bamboo also sequesters large amounts of CO_2, reducing carbon emissions compared to steel and concrete (Green Building Council, 2023). Economically, bamboo construction is 20-30% cheaper than conventional materials, making it viable for low-cost housing and disaster-resistant structures (World Economic Forum, 2023; Disaster Resilience Journal, 2024). Additionally, its full utilization could generate over $1.2 billion annually, supporting sustainable economic growth (International Bamboo and Rattan Organisation, 2024).

4.0 Methodology Adopted

To develop the sustainable bench for that purpose following methodology has been developed. The procedure starts with material preparation by combining fly ash and crushed

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sand in the proportion of 1:6 with a water-fly ash ratio of 0.25 to achieve desirable consistency. The fly ash and crushed sand mixture is properly mixed without any segregation and bleeding, with proper storage to prevent contamination. Then, plastic bottles are washed and filled with the prepared mortar in three layers with each layer compacted 25 times with a tamping rod to eliminate air pockets. The bottles are sealed with their original caps once full and left aside for curing. In structural construction, bottles are laid in a header bond fashion, toe-to-toe, in four layers, like bricks. There are proper leveling and alignment checks, and pointing is done using a 1:6 cement-fly ash-crushed sand mortar mix with a water-to-cement ratio of 0.40 to provide stability. Bamboo supports are fitted at the back for strengthening, with 28 vertical and 4 horizontal members fixed securely with nails. The bamboo is treated to be durable, not to decay or absorb moisture. This green approach guarantees a robust, sustainable, and affordable option for the production of outdoor bench.

Figure 8: Flow Chart of Methodology

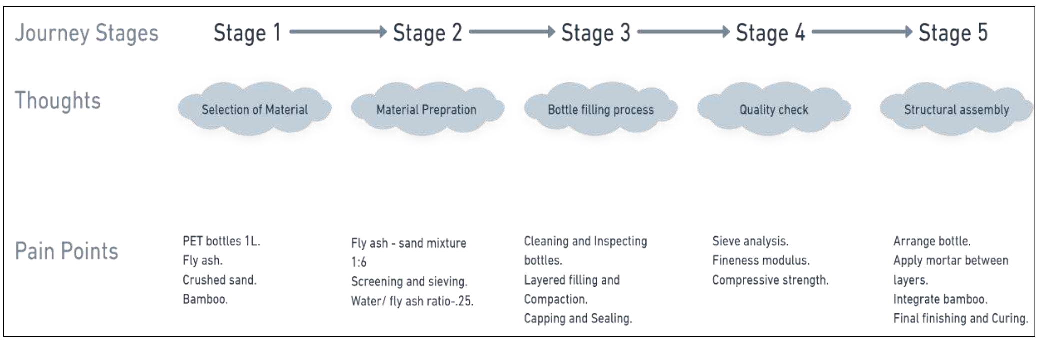

Figure 9: Fly ash and Crushed Sand Mix

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Figure 10: Bottle Filling

Figure 11: Mortar with Fly Ash

Figure 12: Curing of Chair

Figure 13: Sustainable Chair

Table 1: Typical Sieve Analysis Results for Crushed Sand (as per IS 383:2016)

SIEVE SIZE	RETAINED WEIGHT(g)	CUMULATIVE RETAINED WEIGHT(g)	% RETAINED	%PASSING
4.75	0	0	0%	100%
2.36	50	50	5%	95%
1.18	200	250	25%	75%
0.6	300	550	30%	45%
0.3	250	800	25%	20%
0.15	150	950	15%	5%
0.075	40	990	4%	1%
PAN	10	1000	1%	0%

Interpretation: Zone II Fine Aggregate as per IS 383.

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5.0 Tests and Calculations

5.1 Sieve analysis of crushed sand

Sieve analysis assesses the particle size distribution of crushed sand, verifying its compliance with construction standards.

5.2 Fineness modulus

Fineness Modulus (FM) = 3.59

Interpretation: Since the FM is between 2.3 and 3.6, the crushed sand qualifies as fine aggregate as IS 383:2016. This FM indicates moderately coarse sand, suitable for concrete and masonry work.

Table 2: % Cumulative Retained (as per IS 383:2016)

Sieve Size	Cumulative % Retained
4.75	0
2.36	5
1.18	25
0.6	55
0.3	80
0.15	95
0.075	99

5.3 Compressive strength of bottle

Assessing load and strength is essential to evaluate the structural performance and safety of the bench constructed using plastic bottles filled with fly ash and sand. Various testing methods, including compression tests, finite element modeling, and long-term performance evaluations, are used to verify compliance with safety and durability standards.

5.3.1 Compressive strength of filled bottles

Laboratory tests confirm that the compressive strength of a single filled bottle, measured using a Compression Testing Machine (CTM), is approximately 100 kN. This indicates the bottle's ability to withstand significant compressive forces before failure. While empty PET bottles have limited load-bearing capacity, the densely packed fly ash and sand mixture significantly enhances their structural stability.

5.3.2 Structural load capacity

Finite element modeling and experimental tests confirm that the bench structure can support distributed loads ranging from 3-5 kN/m², making it suitable for public seating applications. Additionally, the bench design withstands concentrated loads of 1.2-1.8 kN,

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meeting ISO 7173:1989 standards for public furniture. Since the bottles are arranged in a staggered pattern and embedded in a binding mortar mix, compressive forces are evenly distributed throughout the structure. The interaction between the bottles, mortar, and bamboo reinforcements ensures that the bench remains structurally sound under prolonged use. Bamboo components provide additional tensile reinforcement, preventing deformation under stress. High-tensile cross-filament tape further enhances stability by securing the bottle layers and minimizing lateral displacement.

5.3.4 Impact resistance and safety

Testing through dynamic impacts indicates the bench's ability to take sudden loads very fast and safely for everyday use. Reinforcement of joints with bamboo and external cladding increases its durability in high traffic areas. The bench is structurally sound and suitable for sustainable construction with the tested compressive strength of 100 kN per bottle.

6.0 Cost Analysis

6.1 Economic considerations for implementation

The economic feasibility of construction from waste depends on material purchase costs, processing costs, and methods of implementation. For the proposed bench structure, plastic bottles are an inexpensive material when purchased from recycling programs or garbage collectors at approximately ₹2.90 per bottle. Fly ash pricing varies significantly based on proximity to thermal power plants, ranging from ₹2,697 to ₹7,865 per ton, though partnerships with power producers can potentially reduce these costs as they seek waste management solutions. Supporting materials include sand (approximately ₹2,282 per ton), bamboo (₹166.5 per linear meter), and cross-filament tape (₹103.75 per meter).

Table 3: Quantity and Rate Analysis

S. No.	Items	Unit	Rate (Rs)	Quantity	Amount
1.	Plastic Bottles	Kg	50	3	150
2.	Fly Ash	Kg	3	100	300
3.	Sand	Kg	2.6	600	1,560
4.	Bamboo	No.	45	17	765
5.	Cross Filament Tape	No.	188	6	1,128

Processing costs primarily involve labor for bottle preparation, material mixing, and assembly, with bamboo processing representing the most skill-intensive component. Engaging local community groups and artisans for these processes can create employment opportunities while reducing overall production costs. The circular economy approach to waste management not only addresses environmental challenges but offers economic advantages as well. A recent

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UN report suggests that maintaining current waste management practices would cost more than \$417 billion annually by 2050, while circular approaches emphasizing waste reduction and recycling could reduce costs to less than \$255 billion annually while delivering superior environmental outcomes.

6.2 Total material and processing costs (INR)

The total material and processing costs for a standard 1.5-meter bench ranges approx. ₹4972, representing approximately 30-50% of the cost of conventional concrete bench alternatives.

6.3 Carbon analysis

When compared to traditional options, the suggested bench design's lifecycle assessment (LCA) shows notable environmental benefits. Bench production results in greenhouse gas emissions of about 25–35 kg CO_2-equivalent per standard unit, which is 65-75% lower than concrete benches of similar size (80–120 kg CO_2-equivalent) and 50–60% lower than steel- framed alternatives (60–80 kg CO_2-equivalent). The use of waste materials instead of virgin resources and the low processing energy requirements are the main causes of this advantageous carbon profile (Siddique, 2010; Zhang *et al.*, 2008). Because fly ash's cementitious qualities enable it to reduce or eliminate Portland cement, which normally produces 800-900 kg CO_2 per ton produced, it delivers especially large climate advantages. In a similar vein, recycling plastic bottles cuts down on emissions from landfilling or incineration of waste as well as emissions from the creation of virgin plastic (about 2.5 kg CO_2 per kg of PET) (Yousuf & Ahmed, 2019; Medina *et al.*, 2015).

The production process uses only a small amount of water, about 15 to 25 liters per bench unit, compared to 80 to 120 liters for similar concrete alternatives. The production process is completely free of hazardous chemicals, which eliminates the possibility of soil or water contamination, and the physical containment of fly ash in sealed bottles prevents the leaching of trace elements that could otherwise cause environmental problems (Pacheco-Torgal *et al.*, 2012; Malhotra & Mehta, 2005). The bamboo components are the most environmentally sensitive material input, requiring responsible harvesting practices to prevent habitat destruction and ensure regeneration. Bamboo is a carbon-negative material that sequesters about 5-8 kg CO_2 per bench unit when it comes from stands that are correctly managed, which further improves the design's favorable climate profile.

7.0 Conclusion

Our evaluation of benches manufactured from plastic bottles filled with sand and fly ash, bound with bamboo and cross-filament tape, reveals promising results across multiple dimensions. The design successfully repurposes problematic waste materials while creating

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functional outdoor furniture suitable for public spaces. Testing confirms these benches can withstand normal usage scenarios, with load-bearing capacity meeting requirements for public seating applications when properly constructed. However, maintaining consistent quality during scaled production represents a significant challenge that must be addressed through standardized processes and quality control measures. From an economic perspective, this design shows favorable production costs compared to conventional alternatives. Material procurement and manufacturing expenses remain substantially lower than traditional concrete or metal benches, creating potential for competitive market positioning based on cost advantages alone.

The environmental benefits represent perhaps the most compelling aspect of this design. Lifecycle assessment demonstrates a 65-75% reduction in carbon footprint compared to concrete equivalents. Additionally, the visible reuse of waste materials provides educational value beyond immediate environmental impacts, showcasing practical circular economic principles in everyday settings.

The social sustainability advantages further enhance the value proposition of these benches. Local communities can participate in production processes, creating income opportunities while developing practical skills. This aspect proves particularly valuable in contexts where combined social and environmental outcomes are prioritized.

Despite these advantages, several obstacles must be overcome before widespread implementation becomes feasible. Market perception represents a significant barrier, as potential buyers may question durability and quality compared to traditional products. Weather resistance in various climate conditions requires further testing and possible modifications to treatment methods. Regulatory hurdles related to building codes and safety standards must be navigated, while ensuring consistent quality across production batches remains challenging.

To address these issues, we recommend developing standardized production protocols with clear quality benchmarks. Selectively mechanizing repetitive processes could improve consistency while maintaining opportunities for manual labor where appropriate. Engagement with policy stakeholders would help develop supportive regulatory frameworks, while strategic marketing should emphasize performance characteristics alongside sustainability benefits.

When these factors are addressed, the bottle-bamboo bench design offers a compelling alternative to conventional products, particularly in contexts where environmental impact and social benefits carry significant weight in purchasing decisions. The successful implementation of this approach could serve as a model for other construction applications seeking to incorporate waste materials, contributing to broader adoption of circular economic principles in the built environment.

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CHAPTER 71

Financial Risk Assessment of PPP Infrastructure Projects

Maitreyee Tiwari[1], Anmol Joshi[2], Ravi Prakash Singh[2] and Rhugwed Arun Khule[2]

ABSTRACT

Public Private Partnerships (PPPs) are vital for meeting the infrastructure demands of developing nations like India, but their multi-stage nature brings financial risks that can deter government involvement and risk consortium bankruptcy. This study prioritizes financial risks across various project phases to aid in better decision-making. The research objectives include identifying critical financial risks, analyzing their impact using the Analytical Hierarchical Process (AHP), and determining the project phase requiring the most attention. A comprehensive literature review, supplemented by expert insights through a structured questionnaire survey, forms the basis of the study. The findings reveal that the execution phase is the most financially vulnerable, with construction cost overruns, delays, and market liquidity crises identified as the highest-priority risks. Further, a case study is also presented to show the application of AHP in choosing from the different models of PPP. These results emphasize the importance of targeted risk management during the execution phase to minimize uncertainties and improve project outcomes.

Keywords: Financial risk; PPP projects; Analytical hierarchical process; Construction phase; Risk prioritization.

1.0 Introduction

PPP projects have become a key solution for addressing infrastructure deficits in India, which hosts one of the largest PPP programs with over 2000 projects in various stages of execution (Department of Economic Affairs, 2020). The evolution of PPP models such as Build-Operate-Transfer (BOT), Design-Build-Finance-Operate-Transfer (DBFOT), and the Hybrid Annuity Model (HAM) showcases India's adaptability in infrastructure development (Asian Development Bank, 2020).

However, despite their benefits, PPP projects face financial risks making effective risk management essential for their long-term success (Shiwakoti & Dey, 2022). Over the years, financial risk assessment in PPP projects has been widely studied in India and globally.

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In the Indian context, early models such as the Net Present Value at Risk (NPV@Risk) introduced by Ye & Tiong (2000) combined the weighted average cost of capital (WACC) with expected NPV to manage financial uncertainties. Singh and Kalindi (2006) explored the annuity model to manage traffic revenue risks in PPP road projects, providing insights into risk allocation. Building on this, Bagui & Ghosh (2012) enhanced the NPV@Risk model by incorporating Monte Carlo simulations, enabling a more comprehensive assessment of NPV under various discount rate strategies. Deshpande & Rokade (2017) identified key financial risks in Indian highway projects, highlighting construction cost, interest rates, and inflation as primary risk parameters. Kagne & Vyas (2020) further identified six financial risk parameters influencing NPV in BOT road projects, with the discount rate being the most critical.

More recently, Gilbile & Vyas (2021) applied the Net Present Worth (NPW)-at-risk method combined with Monte Carlo simulations to assess financial risks in HAM projects, providing valuable insights into risk exposure. Globally, financial risk assessment in PPPs has evolved through diverse methodologies. Nguyen *et al.* (2010) employed Interpretative Structural Modeling (ISM) to identify and prioritize seventeen key risks, including financial closure delays and cost overruns. Makovšek (2013) compared PPPs with traditionally financed projects, revealing that while PPPs incurred 24% higher costs, they experienced fewer overruns due to improved risk management practices. Alasad *et al.* (2014) applied the Analytical Network Process (ANP) to prioritize demand risk factors in infrastructure projects, while Han *et al.* (2017) utilized Monte Carlo simulations to assess financial risks in toll highway infrastructure projects, identifying revenue and cost uncertainties as the most significant risks. While various methodologies have been employed to quantify and evaluate financial risks, they primarily focus on individual risk factors or overall project risks without considering their phase-specific impact. They often lacked the ability to systematically prioritize financial risks across different phases of PPP projects, making it challenging for decision-makers to effectively allocate resources and implement targeted risk mitigation strategies.

Furthermore, although the AHP has proven effective in multi-criteria decision-making, limited research has applied it to prioritize financial risks in PPP infrastructure projects, particularly in the Indian context. With India's growing reliance on PPPs to meet its infrastructure demands, there is a pressing need for a phase-wise financial risk prioritization framework that offers a clear and structured approach to identifying, assessing, and ranking financial risks. This study addresses this gap by employing AHP to systematically prioritize financial risks across the phases of PPP projects. By doing so, it provides a comprehensive and structured framework that enhances decision-making, helps stakeholders allocate resources more effectively, and improves overall risk management practices in PPP infrastructure projects. The study also demonstrates the application of AHP in a case study, comparing different PPP models to evaluate financial risk exposure. The scope of this research encompasses a comprehensive literature review (see Figure), a structured questionnaire survey, and AHP-based analysis to derive risk prioritization. The study specifically focuses on PPP infrastructure

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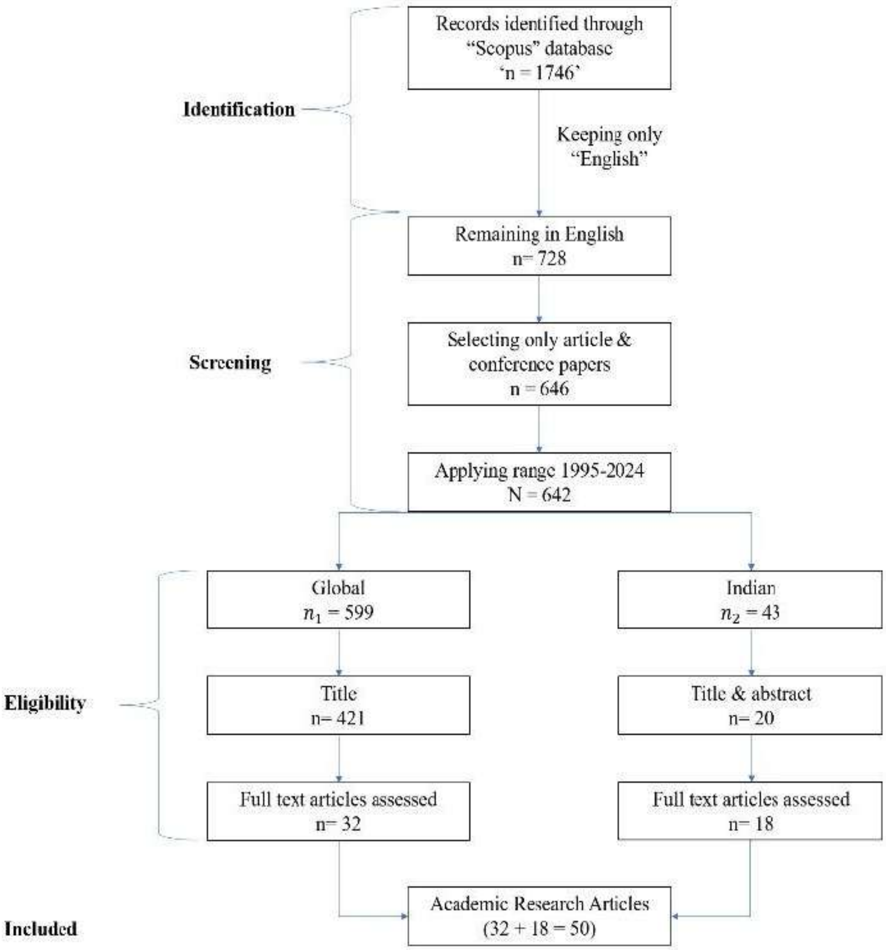
projects in India and uses expert judgment for pairwise comparisons, which may introduce some level of subjective bias. Nonetheless, by capturing expert insights, the study ensures that the financial risks identified reflect practical industry experiences, adding depth and reliability to the analysis.

Figure 1: Approach Followed for Literature Survey



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The organization of the paper is as follows: Section 2 presents the Literature Survey (Indian and Global Scenarios), Section 3 covers the Research Methodology, Section 4 provides the Research Analysis (Results and Interpretation), Section 5 details the Case Example, Section 6 concludes with Future Recommendations, followed by Annexures and References.

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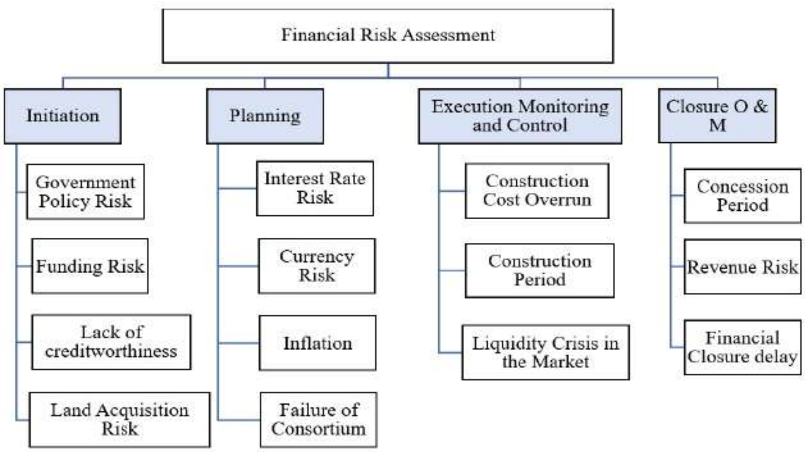
2.0 Research Methodology

AHP is a decision-making tool introduced by Thomas L. Saaty (1980) that provides a structured framework for evaluating complex problems with multiple criteria and alternatives. It integrates both quantitative and qualitative factors by breaking down the objective into hierarchical components, representing the relationships between the goal, criteria, and options. The process involves pairwise comparisons, assigning values from 1 to 9 to indicate relative importance, where 1 denotes equal relevance and 9 indicates high importance (Saaty, 2008). The consistency ratio (CR), which should be below 0.1, ensures reliable assessments. Finally, weighted scores are synthesized to rank the alternatives, with the highest-ranking option being the most preferred.

2.1 Identification of financial risks

A comprehensive literature survey was conducted to identify 14 financial risks associated with PPP projects in the Indian context. These risks were categorized into four phases of the construction life cycle based on the Project Management Institute (PMI) framework. The financial risks associated with PPP projects span across various phases as shown in Figure 2.

Figure 2: Hierarchy for AHP



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2.2 Data collection and questionnaire design

The questionnaires were designed to collect expert opinions and conduct pairwise comparisons for each financial risk. There are two questionnaires prepared which are answered by 40 people. Some of the responses were discarded due to inconsistency in results. The first questionnaire is prepared to determine the priority of different phases, and the second one consists of choosing from three alternative projects.

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3.0 Research Analysis

In this stage a set of pairwise matrix is prepared for comparison from the questionnaire responses. Every element at a higher level is utilized to evaluate the items in the level that is directly below it. A scale is used ranging from 1 to 9 to ascertain the relative relevance of two compared items. This matrix is a square reciprocal matrix (p = [a_{ij}]) of nth order. The importance of any element in the row (sayC_i) with respect to any element in the column (sayC_i) is determined by the element a_{ij}, where a_{ij} is the reciprocal of a_{ji} for non-diagonal element and all the diagonal elements are 1. In this study, the pairwise comparison matrix is prepared with the help of the responses received through a questionnaire. Thereafter, a normalization matrix is constructed to calculate the eigenvector. In AHP, the eigenvector represents the relative weights or priorities of the various criteria or alternatives involved in the decision-making process. They also help in consistency checks, where the principal eigenvalue indicates the reliability of judgments. A Consistency Ratio (CR) is used to ensure the comparisons are valid and consistent. The consistency index (CI) and CR is calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad ...1$$

Where, λ_{max} is principal eigen vector. Now the consistency ratio is given by:

$$CR = \frac{CI}{RI} \quad ...2$$

Where, RI is the random consistency index which is given as in Table 1.

Table 1: Random Consistency Index (RI)

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

The CR should be either 0 or less than 0.1.

3.1 Prioritization of Financial Risks using AHP

Prioritization is carried out to find out which phase of the project is more prone to financial risk and to rank the various risks prevailing in different phases of the project. Pair-wise construction phase matrix formed from the response and normalized matrix is shown in Table 2 and Table 3 respectively for one respondent.

Table 2: Pairwise Matrix for Construction Phase Comparison for Respondent

	P1	**P2**	**P3**	**P4**
P1	1.000	1.000	0.200	1.000
P2	1.000	1.000	0.333	3.000
P3	5.000	3.000	1.000	3.000
P4	1.000	0.333	0.333	1.000
Sum	8.000	5.333	1.867	8.000

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The different phases are named as follows to simplify: Initiation phase as P1, Planning Phase as P2, Execution, Monitoring and Control phase as P3 and Closure, O & M phase as P4.

Table 3: Normalization Matrix for Construction Phases

	P1	P2	P3	P4	Weights(W)	AW	λ
P1	0.125	0.187	0.107	0.125	0.136	0.580	4.262
P2	0.125	0.187	0.178	0.375	0.216	0.895	4.137
P3	0.625	0.562	0.535	0.375	0.524	2.223	4.238
P4	0.125	0.062	0.178	0.125	0.122	0.505	4.121
						λ_{max}	4.189
						CI	0.063
						CR	0.070

Once the consistency is checked for all the responses. The ranking is done based on the weight obtained as shown in Table 4.

Table 4: Weights and Rank for Construction Phases

	P1	P2	P3	P4
Mean	0.098	0.261	0.282	0.198
Ranking	4	2	1	3

Similar to the pairwise construction phase matrix, a pairwise construction risk matrix is also formed for all the respondents in different phases. Figure 3 and Figure 4 depict the final weights calculated for all the risks and their respective ranks in the form of a pie chart.

Figure 3: Weight and Ranks of Construction Phases

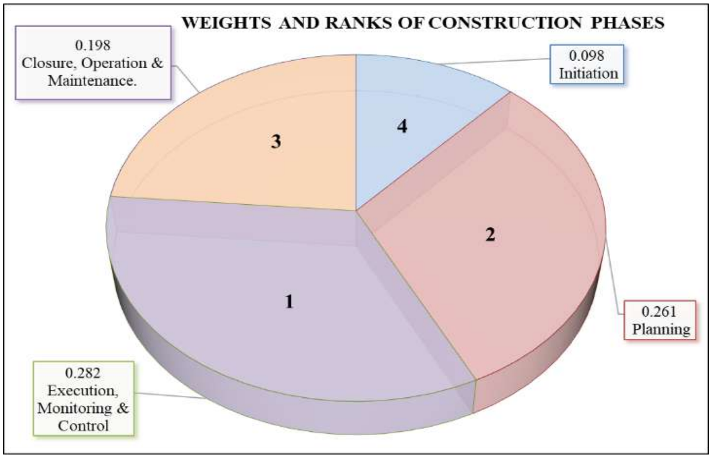

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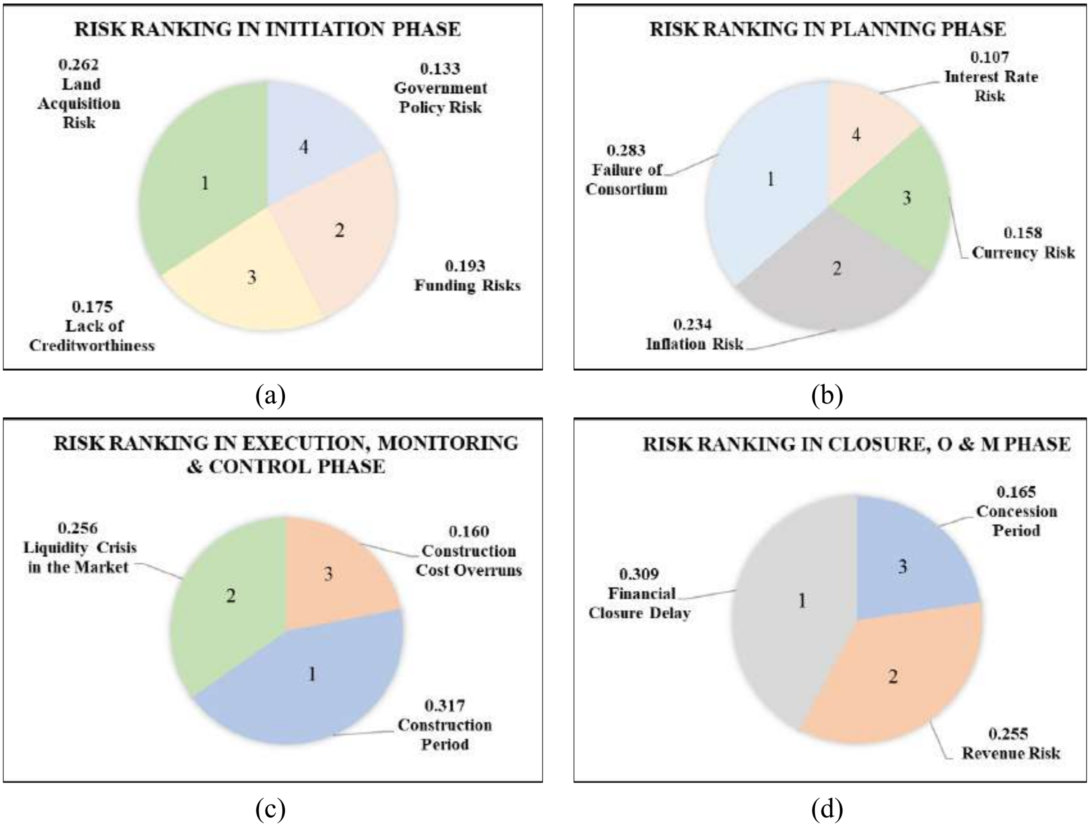
Figure 4: Ranking and Weight of Entire Phase



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3.2 Case study: Financial risk assessment in PPP projects

Three case projects have been assessed to evaluate financial risks in Public-Private Partnership (PPP) projects.

Project A: Hybrid Annuity Model (HAM) – Expressway Project in a Plain Region

Under this model, the government finances part of the project and the contractor finances the remaining part. The payment to the contractor is made in the form of an annuity over the operational phase of the project. This model reduces the financial burden on the contractor upfront but requires careful risk management over the long term. The project involves minimal geographical challenges. This can affect the construction phase as there are no complex terrains or environmental challenges but may increase risks related to land acquisition, local political issues, and the need for more extensive construction for a large-scale expressway. The financing model used is HAM, where the contractor bears a part of the capital expenditure but receives annuity payments from the government.

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The project duration is estimated to be 5 years for construction and 20 years for operation. Land acquisition is mostly free of issues due to the project being in a plain region. The contractor can secure financing with moderate risk, but the long operational phase requires monitoring over time to ensure a steady cash flow.

Project B: Build-Operate-Transfer (BOT) – Expressway Project in a Plain Area

In this model, the contractor builds the infrastructure, operates it for a specified period to recover costs and earn profit, and then transfers the asset back to the government. In this model the contractor is responsible for the initial capital investment and has to manage the operation and maintenance for the entire project lifecycle. Like Project A, this project is located in a plain region. However, the main difference lies in the funding model, as the contractor will bear the full cost of construction and operation for the project period. The project will involve full capital investment by the contractor, which means higher upfront financial exposure. The operation phase is expected to generate revenue from tolls or other sources, making the financial risk more tied to the traffic volume and public acceptance of the toll system. The duration of operation could range from 15 to 30 years, depending on the contractual agreement with the government.

Project C: Design-Build-Operate-Transfer (DBOT) – Expressway Project in a Plain Area

This model is similar to BOT, but with the added element that the contractor also handles the design of the project in addition to construction, operation, and transfer. This allows the contractor to have more control over the project but also increases the financial risk and design responsibility. Given that the contractor handles all aspects, they need to ensure quality control from design through to operation. The inclusion of the design phase adds additional time, costs, and complexity to the project. The contractor will take responsibility for both designing and building the infrastructure. The contractor's financial exposure is higher due to the requirement for greater capital for design, construction, and long-term operation. The operational revenue generation will depend on factors such as toll collection, traffic volume, and management of operation risks. This project will have the longest timeline among the three due to the added design phase (construction: 3 years, operation: 25 years).

The objective was to determine which project carries a higher potential for risk in each specific category. The methodology for assessing financial risks in the three project cases involved similar steps explained in section 3. In the Aggregation of expert opinions, the geometric mean of the risk weights assigned by all respondents was calculated to provide an overall weight for each risk category in each project case. Finally, the Final Risk-Based Ranking of Projects was determined by computing the total financial risk weightage for each project, where a higher risk weightage indicated a less preferred project, meaning projects with greater financial risk exposure were ranked lower in terms of preference. This analysis helps in systematically identifying the project that presents the least financial risk, assisting contractors in making more informed investment decisions. Table 5 and Table 6 show pairwise comparison matrix and normalized matrix for governmental risk.

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Table 5: Pairwise Comparison Matrix for Governmental Risk

	A	B	C
A	1.000	0.333	0.200
B	3.000	1.000	0.200
C	5.000	5.000	1.000
Sum	9.000	6.333	1.400

Source: Created by author

Table 6: Normalized Matrix for Governmental Risk

	A	B	C	Weights(W)	AW	λ
A	0.111	0.053	0.143	0.102	0.310	3.033
B	0.333	0.158	0.143	0.211	0.655	3.100
C	0.556	0.789	0.714	0.686	2.254	3.284

Source: Created by author

The weightage of all the risks in Project A, B, and C is shown in Table 7. The results show that Project B has the highest potential for financial risk among the three projects. Similarly, Project A has the least potential of having financial risk. Thus, the contractor should choose Project A which is a hybrid annuity model project. The final decision is ultimately taken by the higher authority which is very experienced and holds expertise. Figure shows the result graphically.

Table 7: Final Ranking of Projects

	Risks	**A**	**B**	**C**
1	Government Policy Risk	0.207	0.256	0.260
2	Funding Risks	0.232	0.191	0.326
3	Lack of Credit Worthiness	0.202	0.282	0.248
4	Land Acquisition Risk	0.272	0.124	0.415
5	Interest Rate Risk	0.125	0.356	0.352
6	Currency Risk	0.171	0.287	0.241
7	Inflation	0.208	0.254	0.240
8	Failure Of Consortium	0.323	0.210	0.193
9	Construction Cost Overruns	0.405	0.480	0.115
10	Construction Period	0.208	0.242	0.283
11	Liquidity Crisis in the Market	0.154	0.299	0.255
12	Concession Period	0.184	0.265	0.297
13	Revenue Risk	0.164	0.380	0.244
14	Financial Closure Delay	0.113	0.340	0.289
	Mean	**0.200**	**0.270**	**0.258**
	Rank	**3**	**1**	**2**
		Lowest Risk	**Highest Risk**	**Medium Risk**

Source: Created by author

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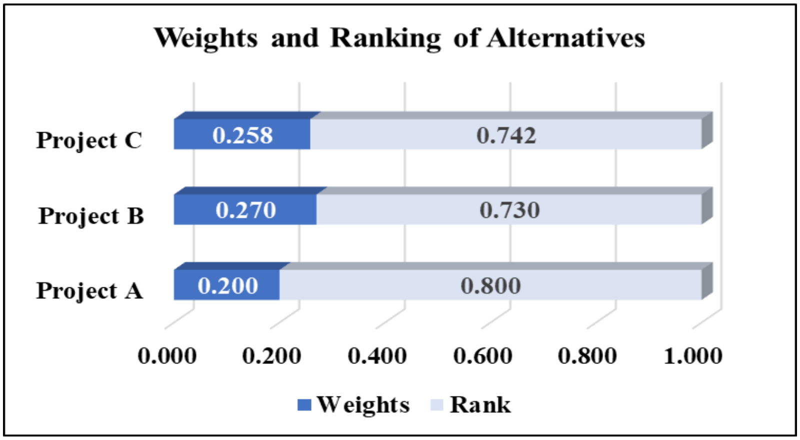
Figure 5: Weights and Rankings of Alternatives/Projects



Source Created by Author

4.0 Results and Interpretation

The AHP analysis for financial risk assessment in PPP projects highlights the Execution, Monitoring & Control phase as the most critical, followed by the Planning phase, Closure & O&M phase, and finally, the Initiation phase. The Execution phase ranks highest due to the direct financial impact of cost overruns and liquidity crises, which significantly affect the project's budget and timeline, leading to potential losses and delays. The Planning phase comes next, driven by interest rate fluctuations and currency risks, emphasizing the need for financial forecasting and stable funding, especially for projects involving international financing. The Closure & O&M phase ranks third, mainly due to financial closure delays and revenue risks, which affect the project's long-term financial sustainability. The Initiation phase holds the lowest priority, with government policy risk being the main concern. Although less frequent, policy changes still influence the project's foundation and feasibility.

5.0 Recommendations

To effectively manage financial risks in PPP projects, key strategies include robust liquidity management with financial controls and contingency plans to handle cash flow issues. Hedging strategies and fixed-rate financing can mitigate interest rate risks during the planning phase. Real-time monitoring and cost-tracking systems help prevent construction cost overruns, while early regulatory compliance reduces government policy risks. Lastly, accurate revenue forecasting and flexible financial models ensure timely financial closure and manage revenue risks.

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CHAPTER 72

Green Construction: Legal Issues and Challenges

Pranav Bhunje[1], Kaustubh Deshmukh[1], Swapnil Sathe[1], Adish Thavare[1] and Yuvraj Patil[2]

ABSTRACT

Green construction refers to the philosophy and processes that minimize the built environment's negative impact on nature while promoting sustainability throughout a building's lifecycle. This study examines the legal challenges and regulatory frameworks associated with green construction in Pune, Maharashtra, India, focusing on compliance complexities, certification processes (LEED, IGBC, GRIHA), and contractual disputes. A qualitative research design was adopted, employing doctrinal and non-doctrinal methods, including interviews with five key industry experts and questionnaire-based surveys with 20 professionals, such as architects, engineers, and policymakers. The study identifies major legal challenges, including ambiguities in sustainability laws, high compliance costs, lack of streamlined certification procedures, and enforcement inconsistencies. Findings reveal that 72.7% of respondents cited high certification costs as a barrier, while 63.6% faced difficulties due to lack of expertise in green building regulations. Additionally, 77.3% stressed the need for simplified compliance processes, and 86.4% emphasized the necessity for clearer regulatory frameworks. Comparative insights from global best practices highlight the importance of government incentives, stricter legal enforcement, and public-private collaboration to improve sustainability adoption. The study recommends harmonized regulations, enhanced legal clarity, and targeted policy interventions to make green construction more accessible and legally feasible in Pune. By addressing these challenges, the research provides actionable recommendations to streamline green building compliance and accelerate sustainable urban development.

Keywords: Green construction; Certification processes; Legal framework; Regulatory challenges; Green building standards.

1.0 Introduction

Green construction integrates sustainability into the built environment by minimizing environmental impact, promoting energy efficiency, and ensuring resource conservation. The concept of green buildings has gained prominence in India since the establishment of the Indian Green Building Council (IGBC) in 2001, leading to increased adoption of sustainable construction practices (IGBC, n.d. 2025).

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"These buildings follow green rating systems such as LEED, IGBC, and GRIHA, which evaluate environmental performance based on energy efficiency, water conservation, material selection, and indoor air quality. The growth of green construction has been substantial, with numerous projects across residential, commercial, and industrial sectors" (World Economic Forum, 2024). Despite this progress, legal challenges remain a significant barrier to widespread adoption. Key issues include compliance complexities, certification disputes, regulatory ambiguities, and contractual conflicts related to sustainability requirements. Legal concerns also arise from disputes over third-party certification, discrepancies in energy efficiency claims, unfair competition allegations, and challenges in securing government incentives for green building initiatives (Build Your Future, n.d. 2025).

Furthermore, traditional contracts often lack provisions for green clauses, leading to legal uncertainties regarding sustainability obligations, maintenance responsibilities, and warranty claims for green technologies (U.S. Green Building Council, n.d. 2025). This study examines the legal aspects of green construction in Pune, India, focusing on regulatory frameworks, certification compliance, and contractual challenges. A comparative analysis with the United States, Germany, and Singapore provides insights into global best practices and their applicability to the Indian legal landscape. The scope of this study is limited to the legal aspects of green building certification, compliance challenges, and regulatory mechanisms in Pune. While a comparative review is included, the recommendations are specifically tailored to India's legal, environmental, and economic conditions. The paper is structured as follows: Section 2 presents a literature review, Section 3 outlines the research methodology, Section 4 discusses key findings, Section 5 provides policy recommendations, and Section 6 concludes with future research directions.

2.0 Legal Framework

2.1 Legal framework around green construction in India

Environment Protection Act (1986): This Act provides the legal foundation for environmental regulations, ensuring compliance with pollution control, energy efficiency, and sustainable resource management in construction. It mandates monitoring of air, water, and land pollution, ensuring that buildings integrate eco-friendly principles (Forest and Climate Change, 1986).

Energy Conservation Act (2001): The Act led to the establishment of the Bureau of Energy Efficiency (BEE) and introduced the Energy Conservation Building Code (ECBC). It promotes energy efficiency, optimized energy use, and renewable energy adoption, forming the legal basis for green building energy standards (EC Act, 2001). *National Building Code (NBC 2016), Part 11:* The NBC provides guidelines for sustainability, energy conservation, and eco-friendly building design. Part 11 focuses on natural ventilation, daylighting, and energy-efficient HVAC systems, influencing state and municipal building regulations (BISNBC, 2018).

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Energy Conservation Building Code (ECBC): Revised 2020: The ECBC establishes minimum energy efficiency requirements for commercial and residential buildings. It mandates efficiency in HVAC systems, lighting, water heating, and building envelope design, promoting low-energy designs (BEE-Buildings, 2020).

Environmental Impact Assessment (EIA) Notification (2006): This notification ensures environmental clearance for large-scale projects by assessing their impact on air, water, biodiversity, and land use. Developers must adopt sustainable construction practices to mitigate environmental risks (Ministry of Housing and Urban Affairs, Government of India, n.d. 2025).

Water (Prevention and Control of Pollution) Act (1974): This Act mandates wastewater treatment, rainwater harvesting, and sustainable drainage systems in construction. Compliance is essential for green building certification to reduce water wastage (Forest and Climate Change, 1986).

Air (Prevention and Control of Pollution) Act (1981): The Act enforces dust control measures, use of low-emission materials, and improved air circulation in construction projects. It supports indoor and outdoor air quality standards for sustainable buildings (Forest and Climate Change, 1986).

Solid Waste Management Rules (2016): These rules promote waste segregation, recycling, and reuse in construction projects. Green buildings must comply by adopting sustainable waste disposal methods to minimize landfill waste (BISNBC, 2018).

Construction and Demolition (C&D) Waste Management Rules (2016): These rules focus on construction debris recycling and sustainable waste management. Compliance requires prefabricated materials, waste reduction strategies, and eco-friendly disposal (BISNBC, 2018).

Occupational Safety, Health, and Working Conditions Code (2020) (OSH Code): The OSH Code ensures safe working conditions, health monitoring, and labor welfare at construction sites. It applies to contract, gig, and platform workers, ensuring better workplace standards (OSH Code, 2020).

Building and Other Construction Workers (Regulation of Employment and Conditions of Service) Act (1996): This Act protects construction workers' rights, fair wages, and welfare Provisions such as sanitation, clean water, and medical benefits. Green buildings must adhere to these standards for compliance (OSH Code, 2020).

2.2 Legal concerns and obstacles

- Difficulties in obtaining third-party certifications, leading to disputes over unmet requirements and loss of associated benefits.
- Variations between actual and projected energy efficiency, resulting in legal claims over unfulfilled sustainability targets.
- Claims of unfair competition in the green construction sector due to misleading statements or improper endorsements.

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- Disputes over government incentives and financial aid, stemming from compliance issues with third-party certification.
- Inadequacies in traditional contracts, making it challenging to address the legal complexities of green building standards.
- Conflicts over sustainability and green clauses, arising from differing interpretations and enforcement in construction contracts.
- Liability concerns regarding maintenance and warranties, questioning the effectiveness of implemented green technologies.

These legal issues underscore gaps in policy enforcement, compliance challenges, and the urgent need for standardized legal frameworks to facilitate the seamless adoption of green construction practices in Pune and across India.

3.0 Literature Review

The study examines the evolution and global progress of green building technology, analyzing key growth factors such as policies, financial benefits, certifications, technology, and user behavior. It highlights adoption challenges in countries like the U.S., U.K., Japan, and China while emphasizing economic drivers, policy strength, and evaluation methods. By identifying research gaps, it provides insights for academic and industry professionals. (Zhang *et al.*. 2019) The study examines legal aspects of green building, including risks and liabilities for owners, design professionals, contractors, and tenants.

It highlights liability bases such as contract breaches, fraud, and negligence while recommending risk mitigation through clear communication, proper documentation, and compliance with standards. (Bowers, 2009) This study examines various rewards and incentives promoting green building design and construction. It identifies nine government-provided incentives, emphasizing their voluntary nature. While this limits large-scale adoption, many professionals utilize them. The paper suggests adjusting incentives at different project stages to enhance effectiveness. (Saka, 2021)

This study analyzes legal and contractual risks in sustainable construction, surveying 95 professionals in Turkey from July 2015 to January 2016. Using a questionnaire and cause-and-effect analysis, it identifies 18 risk factors in four categories, highlighting professional liability concerns and legal challenges in developing countries to raise industry awareness. (Mohammadi, 2016) This study uses text mining and natural language processing to analyze construction legal cases, identifying dispute causes and contractual issues. It presents a data-driven framework, revealing patterns in seven key dispute areas, including delays, liquidated damages, and payment notices. The research highlights the importance of contract understanding to prevent disputes and demonstrates the potential of AI-driven legal analysis.(Lee, 2021) This study examines challenges hindering green building adoption in India, identifying 20 key obstacles grouped into policy issues, financial difficulties, lack of awareness,

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and management problems. The biggest barrier is insufficient knowledge, with limited training and unclear eco-friendly material labeling. Weak policies, poor enforcement, and financial constraints further slow adoption. The research highlights the need for stronger policies, education initiatives, and financial incentives while addressing internal resistance and leadership gaps. A clear strategic framework is essential to enhance awareness, policy execution, and economic support for green construction.(Abraham, 2018)

This study examines factors influencing sustainable construction adoption in the U.S., highlighting energy conservation, indoor air quality, resource efficiency, and waste reduction as key drivers. Barriers include high costs, long payback periods, industry resistance, and lack of expertise, slowing green building adoption.(Ahn, 2013)

The study explores challenges in developing green homes in Malaysia, analyzing public acceptance and developer obstacles through case studies and interviews. Findings highlight uncertainties about acceptance and high costs as major hurdles. The research emphasizes the need for awareness and education to promote green housing adoption. (Alias, 2010) The study examines the growth of green building practices in India, emphasizing sustainability to reduce environmental harm and conserve resources. It highlights IGBC's role in promoting green construction but notes slow adoption due to high costs and low awareness. The research recommends public education and demand-driven strategies to accelerate growth (Singh, 2020)

The study explores green building from business and legal perspectives, highlighting environmental responsibility, cost savings, and market competitiveness as key drivers. It also examines legal risks like certification failures, regulatory challenges, and liability issues. To mitigate these risks, the research suggests strategies for legal compliance and smoother implementation of sustainability goals (Kelly, 2010)

The study examines the link between urbanization, industrialization, and environmental degradation in India, highlighting the government's efforts to promote sustainability through GRIHA, IGBC, and BEE. However, multiple regulations create confusion among stakeholders, leading to inconsistent implementation. The research emphasizes the need for strong local oversight and policy simplification to ensure energy-efficient and sustainable buildings. (Tiwari, 2023) The study examines barriers to green building adoption in India's commercial sector, categorizing them into economic, governmental, organizational, and technological factors. Key challenges include high costs, weak policy enforcement, lack of awareness, and material uncertainties. The research highlights the need for region-specific strategies to overcome these obstacles and promote sustainable construction. (Saha, 2021)

The study examines contractual and legal risks in green construction, highlighting disputes over ambiguous specifications, performance guarantees, and regulatory compliance. Financial risks, including high upfront costs and budget conflicts, further complicate adoption. Traditional dispute resolution may be inadequate for sustainability-related issues. The research recommends clear contracts, stakeholder education, and open communication to mitigate risks and ensure smoother project execution. (Riazi & Mohamad, 2022)

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This study examines legal and contractual challenges in green building projects, emphasizing gaps in sustainability clauses, performance standards, and environmental liabilities. Case studies show disputes arise from unclear certification requirements and financial liabilities. The research recommends contract standardization, legal training, and stronger regulations to improve clarity and reduce conflicts. (Chen *et al.*, 2021) This study explores government policies in green construction, focusing on regulatory incentives, financial subsidies, and compliance facilitation. While initiatives like tax rebates and expedited approvals promote sustainability, bureaucratic delays, inconsistent enforcement, and legal uncertainties hinder effectiveness. The research recommends streamlining approvals, strengthening legal support, and standardizing compliance frameworks to address these challenges. (Kumar & Williams. 2020)

4.0 Methodology

This study adopts a qualitative research design to explore the legal challenges in green construction. Purposive sampling was used to select participants with relevant expertise, including architects, engineers, consultants, developers, and environmental experts. Data collection involved five in-depth interviews with key industry professionals and a questionnaire-based survey administered to 20 professionals to gather both qualitative and quantitative insights on regulatory issues, certification processes, and legal concerns.

The questionnaire was structured with both closed-ended and open-ended questions, covering topics such as awareness of green building laws, certification challenges, compliance issues, and government policies. It was distributed through online surveys and direct interactions to ensure a diverse range of responses. A mixed-method approach was used for data collection, combining interviews for in-depth insights and surveys for statistical analysis. For data analysis, thematic analysis was applied to interview responses, identifying common legal and regulatory challenges, while survey responses were statistically analyzed to determine trends, percentages, and industry viewpoints. Data visualization techniques, such as bar charts and pie charts, were employed to present findings effectively, ensuring a comprehensive understanding of legal barriers in green construction projects in Pune.

5.0 Results and Discussion

Legal complexities in green construction stem from sustainability mandates, certification processes, environmental compliance, and unclear contractual responsibilities. While 45% of respondents reported no legal issues, 30% faced disputes, with 15% related to certifications and 10% to contractual conflicts. The biggest challenge, cited by 72.7%, is high costs, including certification fees and compliance expenses. Lack of expertise in green building regulations affects 63.6% of respondents, while 50% face regulatory hurdles due to complex approval processes and inconsistent guidelines. These challenges create legal and financial barriers for businesses seeking green certification.

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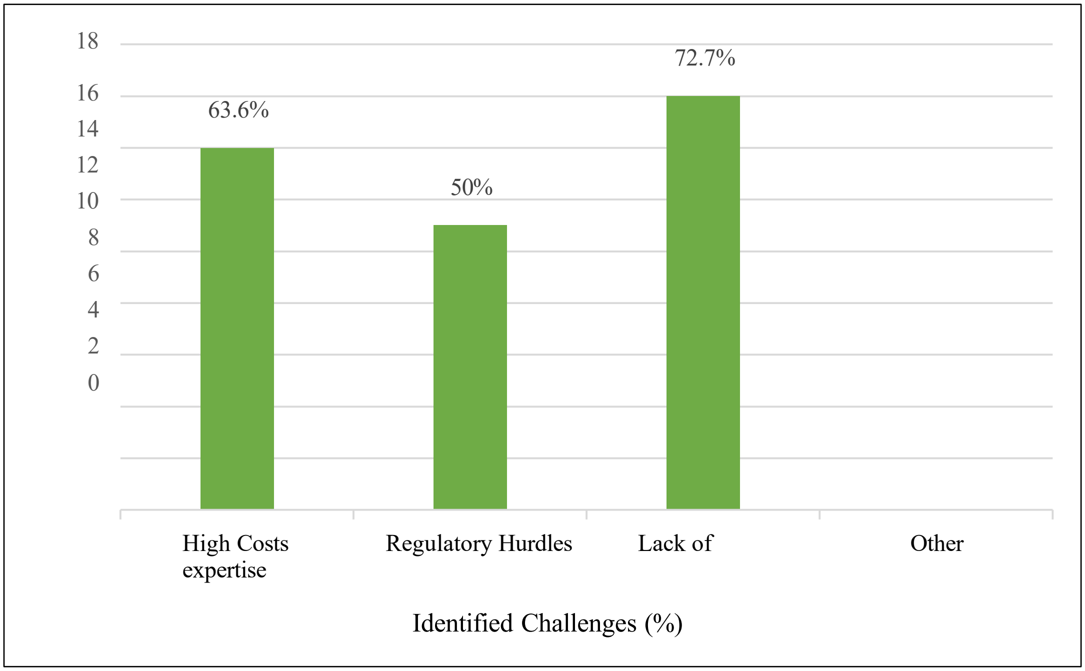
Figure 1: Identified Challenges in Green Building Certification



Delays and ambiguities in certification approvals for LEED, GRIHA, and IGBC were a major legal concern, with 15% of respondents facing compliance issues due to unclear or evolving standards. Some projects experienced rejections or delays despite following guidelines, while inconsistent interpretations of energy efficiency benchmarks led to disputes. Failure to meet sustainability targets post-certification also resulted in legal claims against developers. The biggest challenge, cited by 81.8%, is the lengthy review process, followed by complex compliance requirements (77.3%) and high certification costs (36.4%). A small 4.5% noted lack of support from authorities. These findings highlight the need for streamlined approvals, clearer guidelines, and financial incentives to facilitate green construction in Pune.

Contractual disputes are a major legal challenge in green construction, with 10% of respondents noting that contracts often lack clarity on compliance responsibilities, causing conflicts between developers, contractors, and certification agencies. Poorly drafted agreements due to legal professionals' limited expertise further complicate sustainability obligations. Performance guarantees also create disputes when energy savings or environmental targets are not met. Additionally, tenant-landlord conflicts over sustainability upgrade costs add to legal complexities. 81.8% of respondents believe green certifications increase contractual obligations, while 59.1% say they introduce new liabilities, and 54.5% find them complex to negotiate. These findings highlight the significant legal impact of green certifications on contracts.

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Figure 2: Identified Challenges Faced by Developers

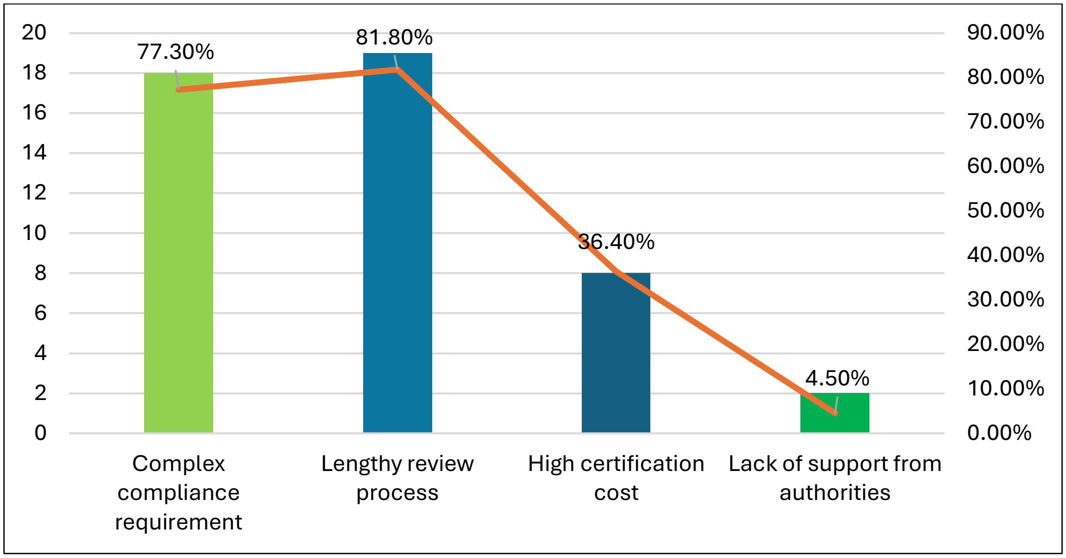
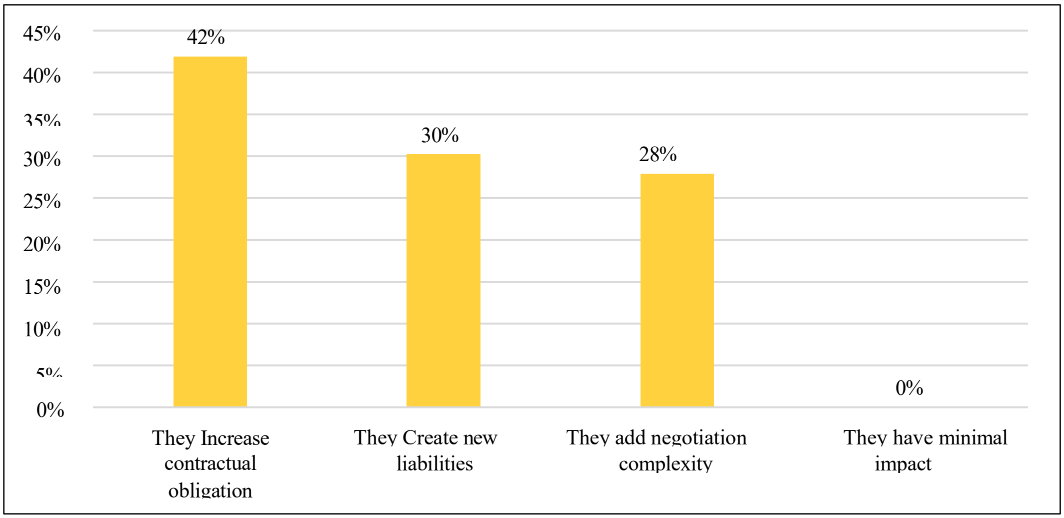


Figure 3: Impact of Green Building Certifications on Contractual Agreements



Government-issued tenders for green construction pose legal challenges for 10% of respondents, as outdated clauses and unclear compliance requirements create confusion regarding sustainability benchmarks, financial obligations, and legal responsibilities. Some contractors report that regulatory bodies lack technical expertise, leading to inconsistent

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approvals and arbitrary legal rulings. 50% of respondents find Pune's legal framework insufficient, while 45.5% believe it requires modifications, indicating weak enforcement. 86.4% support financial incentives as the most effective government intervention, followed by stricter regulations (54.5%) and expedited approvals (40.9%).

Figure 4: Preferred Government Interventions for Green Construction

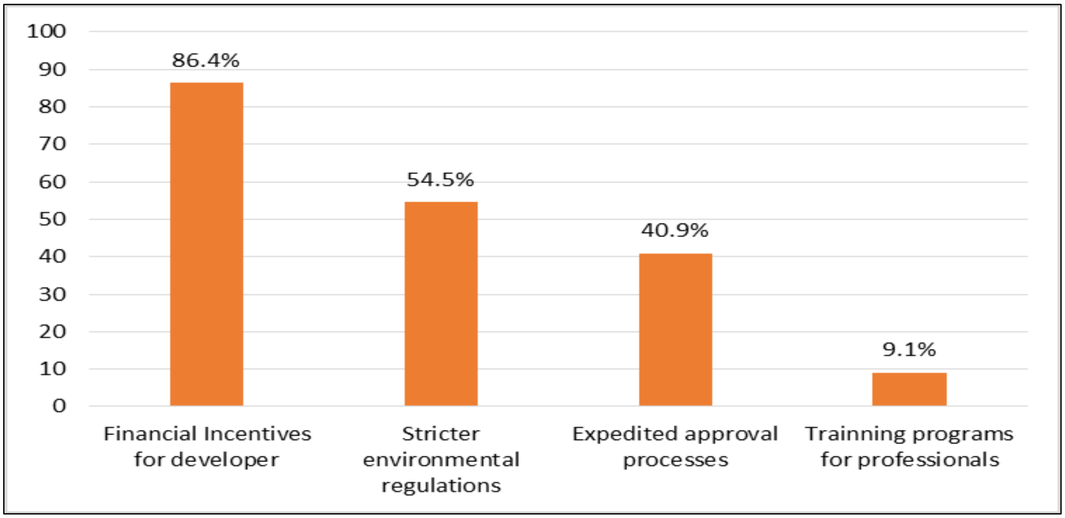
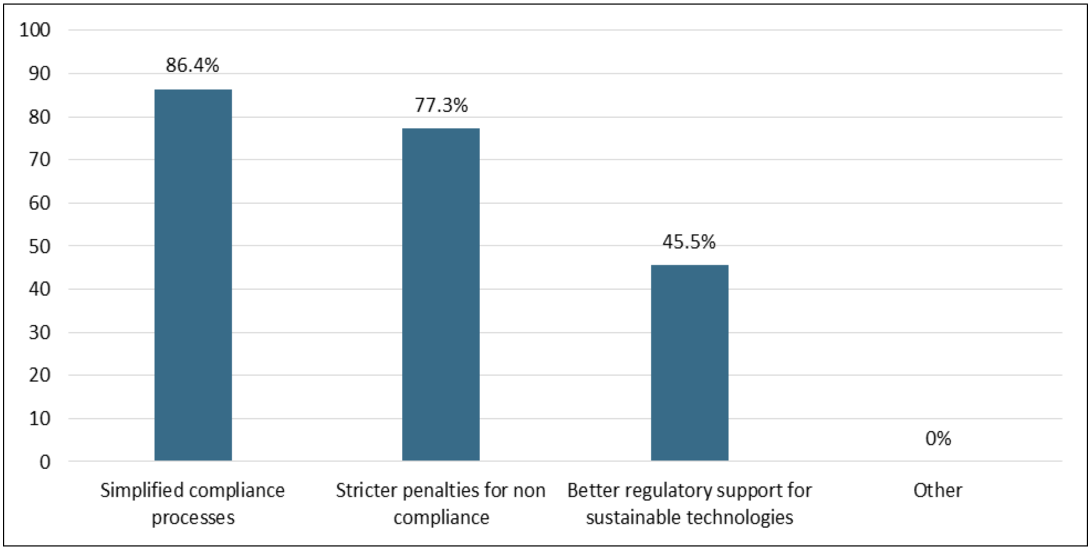


Figure 5: Preferred Legal Reforms for Green Construction in Pune



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Training programs (9.1%) were the least prioritized, emphasizing that financial and regulatory support are key to promoting green construction in Pune. Developers in Pune primarily integrate sustainable technologies by hiring legal experts (86.4%) to navigate compliance challenges and thoroughly reviewing contracts (63.6%) to ensure legal and sustainability obligations are met. However, only 9.1% favor collaborating with the government, indicating weak public-private engagement. The findings highlight the need for stronger cooperation with regulatory authorities to streamline legal compliance in sustainable construction.

6.0 Conclusion

This study highlights the legal and regulatory challenges in Pune's green construction sector, including certification hurdles, contractual disputes, regulatory inconsistencies, and financial barriers. Legal conflicts arise when developers fail to implement pre-certification recommendations, leading to disputes during final audits. Marketing properties based on pre-certification without achieving final certification also results in legal battles. Contractual issues, such as vague agreements and lack of legal expertise, further complicate sustainability commitments. Government-issued tenders often contain outdated clauses, creating compliance difficulties. Data analysis shows 86.4% of respondents support simplified compliance processes, 77.3% favor stricter penalties for non-compliance, and 45.5% advocate for stronger regulatory support for green technologies. The findings emphasize the need for clear legal frameworks, improved contract enforcement, and structured tendering processes. Government intervention through financial incentives, policy standardization, and stricter enforcement is essential for promoting green construction. A collaborative effort between developers and regulatory bodies is crucial to ensuring transparency and accountability in sustainable construction. By adopting best practices, enhancing compliance mechanisms, and strengthening regulatory enforcement, Pune can lead in sustainable urban development.

6.1 Recommendation

1. Simplify compliance processes: Regulatory bodies should streamline the approval mechanisms for green building certifications by reducing bureaucratic delays, ensuring consistency in assessment criteria, and providing clear guidelines to developers and contractors.
2. Enhance contract enforcement and legal clarity: Contracts should explicitly define sustainability obligations to prevent disputes. Legal professionals involved in drafting agreements should have specialized knowledge of green construction laws to ensure enforceability and clarity.
3. Improve accountability in certification processes: Developers must be held responsible for meeting sustainability commitments made during the pre-certification stage. Legal

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provisions should protect buyers and investors in cases where final certification is not achieved.

4. Introduce financial incentives: The government should provide tax benefits, subsidies, and low-interest loans to offset the high initial costs of sustainable materials and certification fees, encouraging wider adoption of green construction.
5. Expedite approval processes: Fast-track clearances should be introduced for projects that meet predefined green criteria, incentivizing developers to integrate sustainability from the early stages.
6. Revise tendering practices for public projects: Government agencies should develop structured frameworks for drafting tenders specific to green construction, ensuring updated, project-specific requirements rather than relying on outdated templates.
7. Promote legal awareness and capacity building: Training programs, workshops, and awareness campaigns should be conducted by government agencies, certification bodies, and professional organizations to educate stakeholders about evolving green building regulations and best practices.
8. Strengthen collaboration between regulators and industry professionals: Improved coordination between policymakers, developers, and certification bodies can bridge gaps in policy implementation and regulatory compliance.
9. Mandate independent compliance audits: Regular sustainability audits should be conducted at different stages of construction to verify adherence to green building standards and prevent legal conflicts.
10. Implement stricter penalties for non-compliance: Developers failing to meet sustainability benchmarks after obtaining pre-certification should face legal consequences, ensuring greater accountability in the green construction sector.

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CHAPTER 73

Identification of Success Factors and Analysis of Barriers in the Implementation of Safety Management System (SMS) in the Construction Industry

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ABSTRACT

Despite being a key driver of economic growth, the construction industry remains one of the most dangerous, accounting for 16.4% of all occupational deaths worldwide. In India, where most construction workers are untrained and work in hazardous environments, implementing efficient Safety Management Systems (SMS) is essential to lowering risks and enhancing worker safety. However, there are several obstacles to SMS adoption, such as cultural barriers, high implementation costs, and inadequate safety awareness. These challenges result in fewer accidents, monetary loss, and lower employee morale. This study aims to analyze the obstacles to SMS deployment in the Indian construction sector and to pinpoint essential success factors. A thorough literature review and a structured questionnaire survey were components of the methodical research technique. 384 professionals received the survey; 112 valid responses were examined for stakeholder alignment using Spearman's coefficient and the Relative Importance Index (RII). High safety investment costs, constrained project timelines, a lack of safety expertise, and a preference for output over safety are some of the main obstacles found. The critical success elements were introducing early warning systems, enhanced safety culture, appropriate authority distribution, and safety education and training. Stakeholder viewpoints differ significantly despite the broad consensus regarding many obstacles and success criteria. The findings highlight the need for stronger regulatory frameworks, enhanced stakeholder collaboration, and targeted training programs. Addressing these barriers and leveraging success factors can help improve safety performance, reduce accidents, and align the Indian construction industry with global safety standards.

Keywords: Safety management systems (SMS); Barriers; Construction industry; Critical success factors; Safety awareness.

1.0 Introduction

After agriculture, the construction sector is India's second-largest economic sector.

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It includes building and civil work projects, contributing significantly to infrastructure and economic growth. The Indian government has spent ₹23 lakh crore on infrastructure in the last three years, with capital spending doubling as a percentage of GDP. However, there is a considerable risk of accidents in the construction sector.

Although they represent approximately 7.5% of the global labor force, construction workers in India are responsible for 16.4% of workplace fatalities worldwide. Most unskilled workers work under tough conditions, leading to a high accident rate—nearly three times higher than other industries.

The need for safety in construction is crucial. The Silkyara-Barkot tunnel collapse in 2023 highlighted the lack of proper safety management. Safety Management Systems (SMS) were introduced in the 1980s in Europe and later adopted in India to improve workplace safety. The National Safety Council was established in 1966, and March 4 is celebrated as National Safety Day.

Despite improvements, implementing safety measures faces challenges. Effective safety management requires policies, training, and proper risk control. A well-structured SMS can reduce accidents, improve worker morale, and minimize financial losses, making construction sites safer.

2.0 Literature Review

Because construction is a high-risk sector, safety is a major concern. Risky tasks, including working at heights, operating large gear, and coming into contact with toxic materials, are all part of construction sites, leading to many workplace accidents and injuries. The construction industry contributes substantially to the economy but remains one of the most accident-prone sectors worldwide.

To mitigate these risks, a well-implemented Safety Management System (SMS) can help reduce workplace hazards, accidents, and financial losses. SMS is a structured framework that integrates policies, procedures, and practices to manage workplace safety effectively. It includes hazard identification, risk assessment, employee training, incident reporting, and compliance with regulatory standards. A successful SMS ensures safety measures are in place, actively followed, and improved. However, despite the recognized benefits of SMS, several barriers hinder its successful adoption. These barriers range from financial constraints and resistance to change to inadequate enforcement of safety regulations and a lack of awareness among construction workers.

Therefore, examining the key success factors and challenges in implementing SMS in the construction industry is essential. A thorough examination of research articles from respectable publications found twenty success factors and twenty hurdles, offering important new perspectives on the challenges of SMS adoption in the Indian construction industry. Tables 1 and 2 depict the barriers mentioned above and the success factors.

3.0 Research Methodology

The study followed a structured methodology, including questionnaire formulation, respondent profiling, sample selection, survey execution, data collection, and analysis. Based on a literature review, a questionnaire was created and validated by piloting it with ten safety experts with five or more years of experience.

Table 1: Barriers in the Implementation of SMS

Sr. No.	Barriers	References
1	Workers Under the Influence of Drugs or Alcohol	(Maliha *et al.*, 2021; Pereira *et al.*, 2018)
2	Poor equipment and lack of various machine and equipment	(Maliha *et al.*, 2021; Pereira *et al.*, 2018; Rivera *et al.*, 2021)
3	Safety Investment and operational cost	(Rivera *et al.*, 2021)
4	Lack of Safety Standards	(Al-Otaibi & Kineber, 2023; Buniya *et al.*, 2021)
5	Lack of safety knowledge to implement proper safety measures as required	(Maliha *et al.*, 2021)
6	Operational Cost	(Okonkwo *et al.*, 2023)
7	Lack of analysis of accidents and injuries	(Kineber *et al.*, 2023)
8	Prioritising production over safety and health	(Kineber *et al.*, 2023)
9	Lack of proficiency	Jeong *et al.*,2021.
10	Organizational Complexity	(Gao *et al.*, 2018)
11	Language barriers among project participants	(Gao *et al.*, 2018)
12	Tough projects (e.g. tight budget, complex design, tight schedule and long construction period.	(Gao *et al.*, 2018)
13	Putting safety as a lower priority due to cultural differences in organizations	(Yiu *et al.*, 2019)
14	Inactive participation for the SMS implementation by the project team member	(Yiu *et al.*, 2019)
15	Lack of motivation by project team or sub-contractors	(Yiu *et al.*, 2019)
16	The disparity between the number of workers and qualified trainers in the industry	(van der Ham & Opdenakker, 2023)
17	Use of low-engagement training approaches (e.g., trainer centric with limited discussion)	(Kashmiri *et al.*, 2020)
18	Poor planning and safety risks	(Azil & Jabar, 2022)
19	General workers taking shortcuts or ignoring safety rules and regulations	(Azil & Jabar, 2022)
20	Attitude and Behaviour	(Mohammadi *et al.*, 2018)

Source: Compiled by authors

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Based on their feedback, necessary modifications were made. Three sections make up the final questionnaire: (1) background information about the respondents, (2) implementation difficulties for SMS, and (3) success factors. On a 5-point Likert scale, respondents scored success factors and impediments from 1-strongly disagree to 5-strongly agree. The target group included professionals like architects, engineers, project managers, safety officers, contractors, laborers, etc. 384 surveys were disseminated via social media and email using convenience sampling. The response rate was calculated, and data was analyzed using the Relative Importance Index (RII) to rank barriers and success factors. The degree of agreement between the various professionals regarding the corresponding ranks was assessed using Spearman's rank correlation.

Table 2: Success Factors in the Implementation of SMS

Sr. No.	Success Factors	References
1	Emergency Planning	(Pereira *et al.*, 2018)
2	Management team's priority with safety over schedule and cost	(Pereira *et al.*, 2018)
3	Safety Budget	(Pereira *et al.*, 2018)
4	Appropriate plant and equipment for carrying the work safely	(Yiu *et al.*, 2019)
5	Personal attitude	(Buniya *et al.*, 2021)
6	Intensive Collaboration with all Stakeholders	(van der Ham & Opdenakker, 2023)
7	Idea and Promotion of Safety Culture	(Guo *et al.*, 2023)
8	Safety Education and Training	(Guo *et al.*, 2023; Ajslev & Nimb, 2022)
9	Adequate Time to complete the Assigned Job Task Safely	(Gao *et al.*, 2018)
10	Contribution of some external experts in supervision works	(Maliha *et al.*, 2021)
11	Allocation Of Authority and Responsibility	(Othman *et al.*, 2020)
12	Early Warning System	(Phinias, 2023)
13	Increase compliance with H&S legislations	(Phinias, 2023)
14	Organization commitment	(Xu *et al.*, 2023)
15	Client, designer and contractor engagement	(Xu *et al.*, 2023)
16	Safety Legislation	(Rashid *et al.*, 2023)
17	Daily safety meetings	(Engler Bridi *et al.*, 2021).
18	Safety inspections carried out by external evaluators	(Engler Bridi *et al.*, 2021).
19	Improved safety culture	(Yiu *et al.*, 2019)
20	Improvement in accident investigations and analyses	(Yiu *et al.*, 2019)

Source: Compiled by authors

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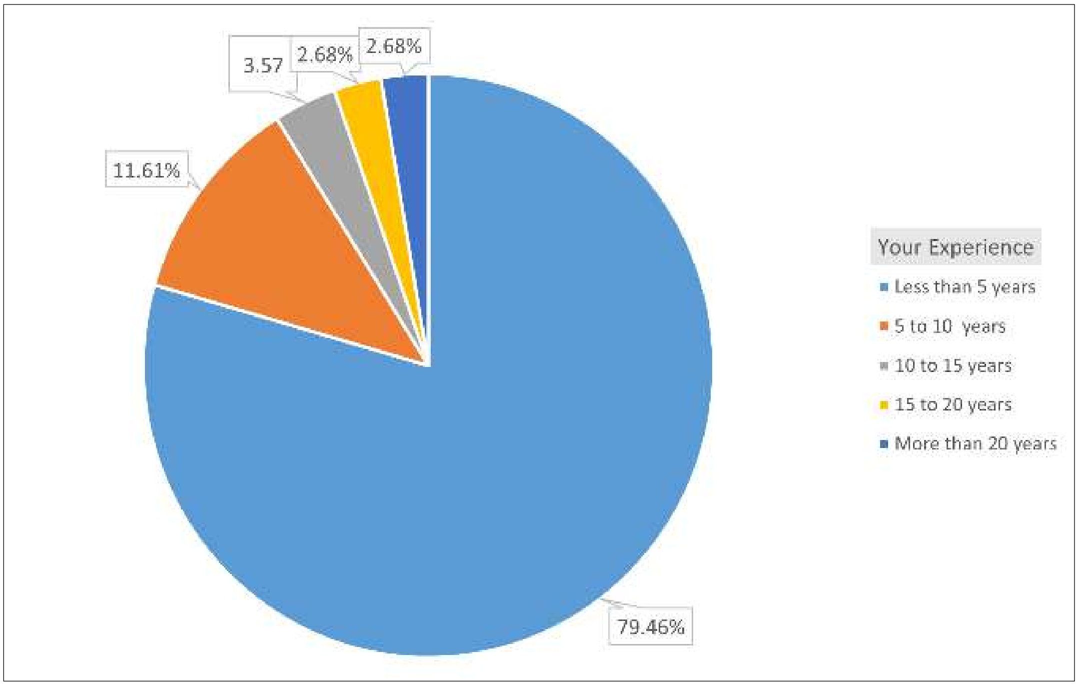
4.0 Results and Discussions

A structured questionnaire survey was conducted to gain insights into the barriers and success factors associated with implementing Safety Management Systems (SMS) in the construction industry. The survey targeted professionals across various organizational roles and work backgrounds, with 384 Surveys. After careful screening and validation, 112 of the 123 received responses were legitimate. This resulted in a response rate of approximately 29.2%, which ensures statistical significance for reliable analysis. The respondents' profiles are shown in Figures 1 to 4. They were categorized based on work experience, qualifications, organizational role, and primary work experience sector.

Figure 1: Experience of the Respondents



Source: Compiled by authors

As illustrated in Figure 1, the majority, i.e., 89 out of 112 (79.46%) of respondents had up to five years of experience in the construction sector, while 20.54% had more than five years of experience. This distribution reflects the perspectives of both early-career and experienced professionals regarding SMS implementation.

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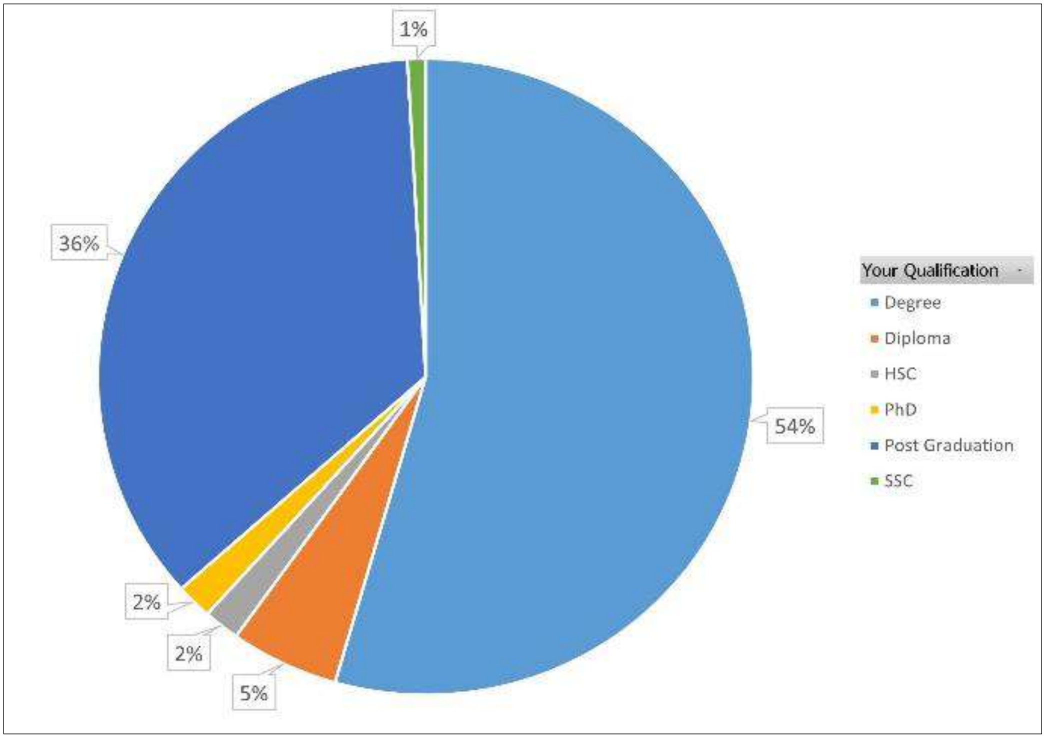
Figure 2: Qualification of the Respondents



Source: Compiled by authors

Figure 2 presents the distribution of respondents based on their qualifications. Approximately 54.46% of the participants held an undergraduate degree, while 35.71% possessed a postgraduate qualification. The respondents' educational background indicates high expertise and understanding of construction safety practices.

Figure 3 displays the respondent stakeholder groups. Among the respondents, 40.17% were employed by contractors, 23.21% by consultants, 14.28% by client companies, and 9.82% by developers. This diverse representation ensures a balanced perspective on SMS implementation challenges and success factors.

As depicted in Figure 4, 63.39% of respondents worked in the building sector, while 12.50% were involved in roads and bridges. The remaining respondents were distributed across other infrastructure projects. This distribution highlights the prominence of building sector professionals in the study. RII values and final rank for different barriers and success factors are shown in Table 3 & Table 4.

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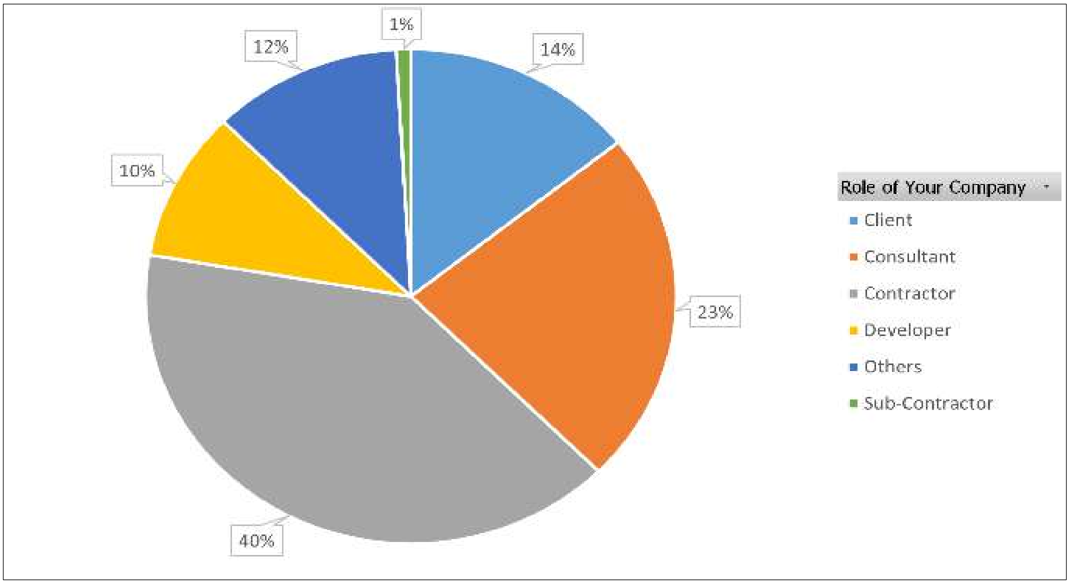
Figure 3: Role of Company of the Respondents



Source: Compiled by authors

Figure 4: Major Experience Sector of the Respondents

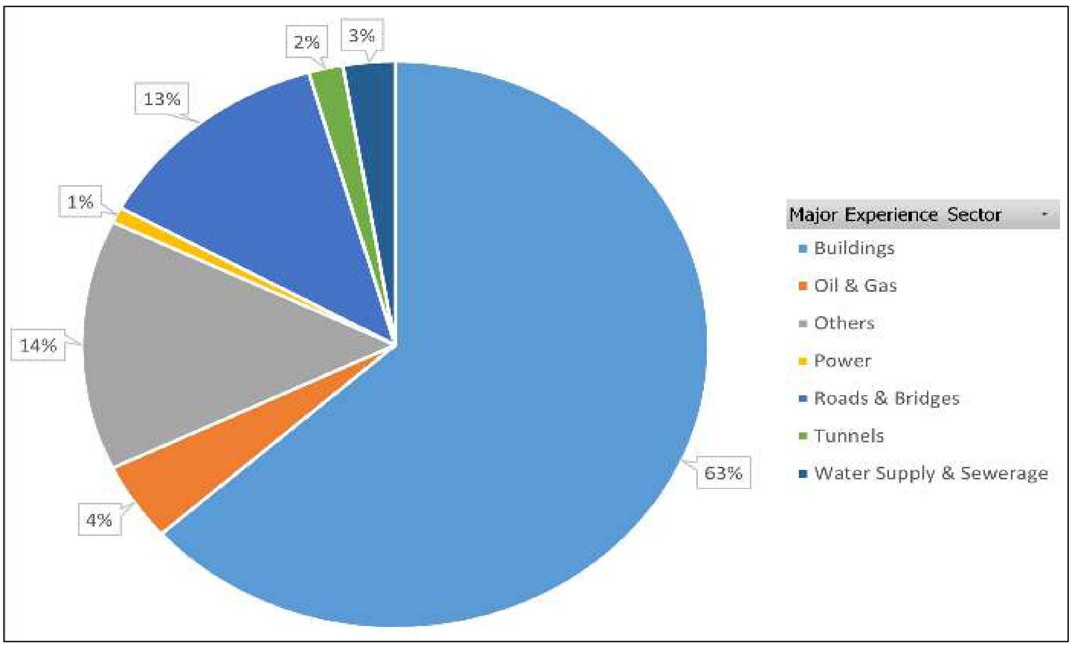


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Table 3: RII Score & Ranking for Barriers

	Barriers in the implementation of SMS	Overall	
Code	**Name**	**RII Score**	**Rank**
B3	Safety Investment and operational cost	0.763	1
B12	Tough projects (e.g. tight budget, complex design, tight schedule and long construction period.)	0.718	2
B20	Attitude and Behaviour	0.716	3
B8	Prioritising production over safety and health	0.702	4
B6	Operational Cost	0.693	5
B5	Lack of safety knowledge to implement proper safety measures as required	0.691	6
B16	The disparity between the number of workers and qualified trainers in the industry	0.689	7
B19	General workers taking shortcuts or ignoring safety rules and regulations	0.679	8
B11	Language barriers among project participants	0.666	9
B7	Lack of analysis of accidents and injuries	0.655	10
B4	Lack of Safety Standards	0.654	11
B18	Poor planning and safety risks	0.646	12
B9	Lack of proficiency	0.643	13
B10	Organizational Complexity	0.643	13
B14	Inactive participation for the SMS implementation by the project team member	0.643	13
B15	Lack of motivation by project team or sub-contractors	0.636	16
B17	Use of low-engagement training approaches (e.g., trainer centric with limited discussion)	0.634	17
B13	Putting safety as a lower priority due to cultural differences in organizations	0.625	18
B2	Poor equipment and lack of various machine and equipment	0.607	19
B1	Workers Under the Influence of Drugs or Alcohol	0.580	20

Source: Compiled by authors

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Table 4: RII Score & Ranking for Barriers

	Success Factors in the implementation of SMS	Overall	
Code	Name	RII Score	Rank
S8	Safety Education and Training	0.823	1
S11	Allocation Of Authority And Responsibility	0.800	2
S12	Early Warning System	0.800	2
S19	Improved safety culture	0.800	2
S15	Client, designer and contractor engagement	0.796	5
S20	Improvement in accident investigations and analyses	0.796	5
S14	Organization commitment	0.795	7
S7	Idea and Promotion Of Safety Culture	0.791	8
S18	Safety inspections carried out by external evaluators	0.789	9
S4	Appropriate plant and equipment for carrying the work safely	0.782	10
S16	Safety Legislation	0.779	11
S9	Adequate Time to complete the Assigned Job Task Safely	0.773	12
S3	Safety Budget	0.771	13
S10	Contribution of some external experts in supervision works	0.770	14
S1	Emergency Planning	0.763	15
S5	Personal attitude	0.757	16
S13	Increase compliance with H&S legislations	0.757	16
S17	Daily safety meetings	0.754	18
S2	Management team's priority with safety over schedule and cost	0.752	19
S6	Intensive Collaboration with all Stakeholders	0.752	19

Source: Compiled by authors

The degree of agreement or disagreement with the ranks derived from the responses of different parties was measured using Spearman's rank correlation coefficient. The Spearman correlation analysis indicated varying levels of agreement among stakeholders regarding prioritizing these factors. Contractors and other groups showed the highest agreement (0.64) in ranking barriers, whereas contractors and subcontractors had the lowest agreement (0.22).

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Similarly, the highest agreement on success factors was between clients and contractors (0.63), while developers and subcontractors showed a negative correlation (-0.52). The findings highlight the need for improved safety investments, better project planning, and stronger stakeholder collaboration to enhance SMS implementation in construction projects.

5.0 Conclusion and Recommendations

Despite being a vital component of economic growth, the construction business is nevertheless one of the riskiest because of its high level of danger. This study highlights the crucial role of Safety Management Systems (SMS) in minimizing workplace hazards, reducing accidents, and ensuring worker safety. Despite growing awareness and regulatory measures, effective SMS implementation still faces considerable challenges. Through research and analysis, this study identifies key success factors and barriers hindering SMS adoption in the construction sector.

The study findings indicate that financial constraints, organizational complexities, and weak safety culture are the primary barriers to SMS implementation. Conversely, safety education, management commitment, and proactive risk assessment are critical success factors in enhancing safety performance. A strong safety culture protects workers, improves project efficiency, and reduces long-term costs. Collaboration among stakeholders, i.e., clients, contractors, and regulatory agencies, is crucial to guaranteeing SMS uptake.

Using a structured questionnaire survey, the study examined the success factors and obstacles affecting the construction industry's implementation of Safety Management Systems (SMS). Out of 384 distributed surveys, 112 valid responses were received, ensuring a Statistically significant sample. The survey included respondents from various roles, including contractors (40.17%), consultants (23.21%), clients (14.28%), and developers (9.82%), with most having up to five years of experience.

Furthermore, the adoption of advanced technology can significantly enhance safety practices. Artificial intelligence, IoT-based monitoring systems, and wearable safety devices can help predict and prevent potential hazards, thereby reducing risks on construction sites. Another vital aspect is fostering stakeholder collaboration, where active participation from all levels, including workers, supervisors, clients, contractors, and regulatory authorities, is encouraged to create a strong safety culture within the industry.

Future research should focus on developing innovative safety solutions, addressing financial and behavioral challenges, and exploring comparative studies across different regions or countries. These kinds of studies can offer insightful information on best practices that can be modified to improve construction safety performance in India. By implementing specific safety-related measures and cultivating a safety culture, the construction industry may improve worker well-being, increase productivity, and lessen workplace accidents' overall financial and social effects.

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CHAPTER 74

Identifying and Controlling Real Estate Projects Delays: A Pune Region Study with SPSS

Kolhe[1], Hemendra Wani[2], Raja Udandarao[2] and Harshit Gupta[2]

ABSTRACT

The real estate sector in India is a cornerstone of urban growth and economic progress. The conditions in the Pune real estate sector are expanding continuously. However, project delays have become a prevalent problem, causing financial losses and reducing stakeholder trust. These delays often stem from issues like inefficiencies in planning, communication breakdowns, and logistical hurdles, making it difficult to meet project timelines. To address these issues, this study adopts a systematic approach by collecting data through structured questionnaire surveys and interviews with key construction industry stakeholders, including contractors, engineers, and consultants. Advanced statistical analysis was employed to identify and prioritize the critical factors contributing to schedule delays. The findings of this research emphasize the need for adopting modern project management strategies that focus on improving planning accuracy, enhancing collaboration among stakeholders, and streamlining processes. These insights lay the groundwork for developing actionable recommendations to minimize delays and ensure timely project delivery in dynamic real estate sector.

Keywords: Real estate delays; Pune construction; Delay mitigation; SPSS.

1.0 Introduction

The real estate sector is a cornerstone of urban development and economic growth in India. Pune, being one of the fastest growing cities in the country, has witnessed a surge in real estate projects. However, delays in these projects have become a significant concern, leading to financial losses, legal disputes, and a decline in stakeholder confidence. Delays in construction projects can be attributed to various factors, including inadequate planning, poor site management, financial constraints, and regulatory hurdles. This study focuses on identifying the key factors causing delays in real estate projects in the Pune region and proposes mitigation strategies to control these delays. By analyzing the responses from industry stakeholders using advanced statistical tools like SPSS and the Relative Importance Index (RII), this research aims to provide actionable insights for improving project management practices and ensuring timely project completion.

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Extensive research has been conducted on construction delays globally and in India, but there is a lack of region-specific studies that quantitatively analyze Pune's real estate delays. While previous studies have identified delay factors qualitatively, few have ranked them using Relative Importance Index (RII) or analyzed interdependencies using Principal Component Analysis (PCA).

2.0 Literature Review

Construction delays in real estate projects are a global issue, leading to cost overruns, legal disputes, and inefficiencies. Various studies have analyzed the causes of delays and suggested mitigation strategies using methodologies like the Relative Importance Index (RII) and Principal Component Analysis (PCA) to identify critical factors. Delays are often classified into categories such as contractor-related issues, consultant inefficiencies, material shortages, labor challenges, external influences, and design errors (Edison & Singla, 2020). Additional contributing factors include delays in approvals, frequent design revisions, labor incompetence, unrealistic planning, and inadequate project monitoring (Kalkani & Malek, 2016). Financial constraints, particularly delayed payments and cash flow problems, significantly impact project timelines (Prasad & Vasugi, 2018; Ferreira, 2024).

Regulatory inefficiencies, such as slow land acquisition, approval delays, and contract mismanagement, further hinder progress (Nallatiga, 2017). Corruption in procurement and contract awards exacerbates delays (Le *et al.*, 2014). Changes in project scope and poor planning also contribute to schedule disruptions (Sampatha *et al.*, 2024). Modern construction technologies can mitigate delays, but slow adoption of tools like Building Information Modelling (BIM) and real-time tracking remains an issue (Tayal & Yadav, 2024). Studies using RII have identified financial constraints, poor contractor performance, and bureaucratic delays as critical factors (Nallatiga, 2017; Bhavsar *et al.*, 2024). PCA helps simplify complex datasets, grouping delay factors into key components for better analysis (Edison & Singla, 2020; Gupta & Vyas, 2024). Combining RII and PCA provides a robust approach to prioritizing delay factors and formulating mitigation strategies. Recommended solutions include improved financial management, streamlined approval processes, enhanced stakeholder coordination, and the adoption of Industry 4.0 technologies (Ferreira, 2024; Nallatiga, 2017; Tayal & Yadav, 2024; Arantes & Ferreira, 2020).

3.0 Research Methodology

This approach involves gathering insights from a variety of construction stakeholders—contractors, engineers, consultants, supervisors, draftsmen, and workers—using structured questionnaire surveys. By employing the Relative Importance Index (RII), we assess the severity of each delay cause identified, ranking them according to their impact. This allows

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stakeholders to concentrate their efforts on the most pressing issues. With this data, we can create specific recommendations to address these delays, encouraging proactive steps to enhance project management and minimize disruptions. This framework not only helps in understanding the complexities of real estate construction delays but also emphasizes the importance of using analytical methods like RII to improve project outcomes and reduce risks.

Figure 1: Process Flowchart

Questionnaire Survey: Data was collected through structured questionnaires, which were designed after a thorough review of existing literature. These questionnaires, featuring 20 questions on a Likert scale, targeted various stakeholders, including contractors, engineers, and clients, with the aim of pinpointing the factors behind project delays. This methodical approach ensured a comprehensive gathering of insights, crucial for identifying and addressing the root causes of delays in construction projects. The questionnaire was distributed among clients, contractors, and consultants to capture a broad spectrum of perspectives.

RII Calculation: The data was analyzed using SPSS to uncover patterns and calculate the Relative Importance Index (RII), which helped prioritize the causes of delays based on their significance as perceived by the respondents. This analysis facilitated a more targeted approach in addressing the most critical issues affecting project timelines.

Principle Component Analysis: Principal Component Analysis (PCA) was applied to simplify the data, grouping related delay factors and focusing on the major contributors to project delays. This statistical technique helped to reduce the complexity of the data set, making it easier to identify and address the most impactful issues.

Recommendations: From our findings, we suggest practical strategies to reduce delays, emphasizing better planning, enhanced communication among stakeholders, and efficient resource management to ensure projects stay on track.

4.0 Results and Discussion

4.1 RII results

The comprehensive analysis of Relative Importance Index (RII) values across various charts heatmap, bar chart, and radar chart provides a detailed perspective on the factors

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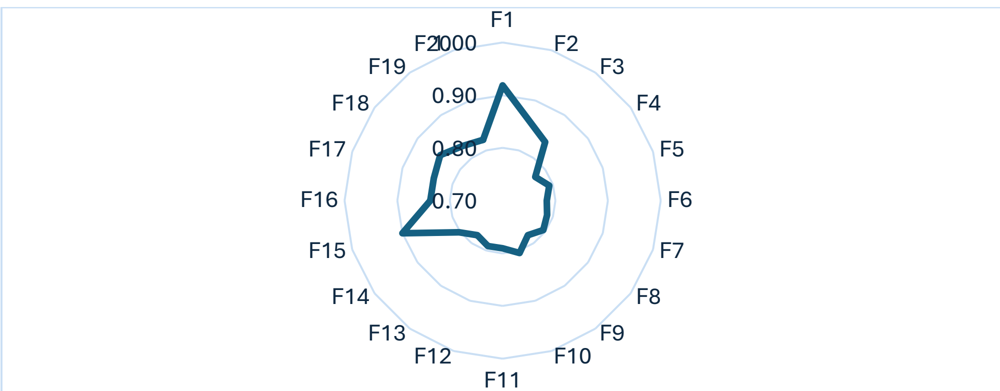
contributing to delays in real estate projects. These visual tools reinforce and clarify the impact of specific challenges, with inadequate project planning and scheduling (F1) consistently identified as the most critical factor. This is depicted through its top ranking across all charts with an RII value of 0.9186, strongly emphasizing the paramount importance of robust planning and effective scheduling in project management.

Figure 2: RII Heat Map

F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
0.92	0.86	0.84	0.78	0.79	0.78	0.79	0.80	0.78	0.80	0.79	0.79	0.78	0.80	0.90	0.84	0.84	0.85	0.83	0.82

Financial constraints faced by contractors, represented by F4, are another key factor highlighted in the analysis. With an RII of 0.7767, it underscores the critical need for financial management and stability to ensure that projects are not hindered by monetary issues. This comprehensive evaluation through different analytical charts not only points out the most pressing concerns but also serves as a guide for prioritizing interventions and resources to address these pivotal issues effectively, ultimately aiming to enhance project efficiency and reduce the likelihood of delays in the dynamic environment of real estate construction.

Figure 3: RII Radar Chart



4.2 Principle component analysis

The analysis of the data using SPSS and the Principal Component Analysis (PCA) method provides valuable insights into the factors contributing to delays in real estate projects in the Pune region. The following matrices explain the underlying structure of the data and the relationships between the variables. Below are the inferences drawn from these matrices.

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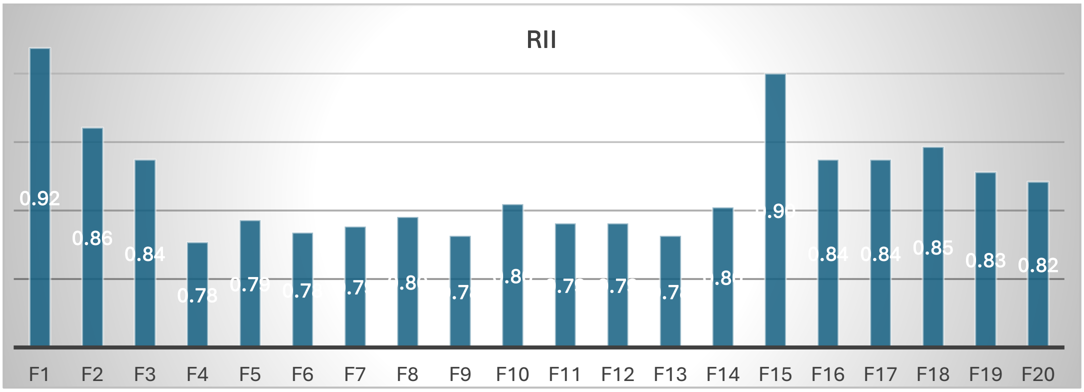
Figure 4: RII Bar Chart



4.2.1. Correlation matrix

The correlation matrix reveals the strength and direction of the relationships between the 20 identified factors causing delays in real estate projects. The matrix shows both positive and negative correlations, indicating how these factors interact with each other. Inadequate Project Planning and Scheduling shows a strong negative correlation with Frequent Changes in Government Policies Affecting Construction (-0.427), suggesting that better planning can mitigate the impact of policy changes. Poor Site Management by Contractors is positively correlated with Delays in Decision-Making by Project Stakeholders (0.408), indicating that ineffective site management often coincides with delays in decision-making. Financial Difficulties Faced by the Contractor are positively correlated with Delays in Payments from Clients (0.097) and Equipment Breakdowns Causing Delays (0.319), highlighting the cascading effect of financial constraints on project timelines.

4.2.2 KMO and Bartlett's test

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is 0.565, which is above the threshold of 0.5, indicating that the data is suitable for factor analysis. Bartlett's Test of Sphericity is significant ($p < 0.001$), confirming that the correlation matrix is not an identity matrix and that the variables are sufficiently correlated for factor analysis. This validates the appropriateness of using PCA to reduce the dimensionality of the data and identify underlying factors.

4.2.3 Total variance explained

The analysis reveals that the first eight components together account for about 68.04% of the total variance in the data, showing a significant chunk of the information is captured by these initial factors. The first component is particularly striking as it alone explains 20.46% of the variance, highlighting its importance. The second and third components also hold substantial

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weight, explaining 8.57% and 8.36%, respectively. This pattern indicates that these early components are critical in influencing project delays, with subsequent factors contributing less significantly, thus providing diminishing returns in their ability to explain further variability.

4.2.4 Scree plot (Eigen values vs. component number)

The screen plot, which plots eigenvalues against component numbers, helps in determining the optimal number of components to retain. The plot shows a sharp decline in eigenvalues after the first few components, followed by a gradual leveling off. This "elbow" point typically indicates the number of components to retain. In this case, the plot suggests retaining the first eight components, as they explain a substantial portion of the variance (68.04%), while the remaining components contribute minimally.

Figure 5: Scree Plot

4.2.5 Component matrix

The Component Matrix from the Principal Component Analysis (PCA) is a crucial tool that unveils the relationship between original variables and the principal components derived during the analysis. This matrix helps in understanding the underlying structure of the data by displaying how each original variable contributes to the principal components. Factor loadings within the matrix indicate the strength and direction of these relationships, with higher absolute values showing a significant association with a particular component.

Component 1 Site Management Issues: Poor site management is identified as a primary cause of project delays. Implementing Lean Construction Methods, such as Just in Time (JIT)

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inventory systems, can significantly reduce material waste and site congestion, thus enhancing on-site efficiency (Ansari, 2020). Additionally, real-time monitoring with drones and IoT sensors can track worker productivity and pinpoint inefficiencies (Arantes & Ferreira, 2020). Employing digital tools like Procore and PlanGrid facilitates better documentation and stakeholder communication, crucial for timely project execution.

Component 2 Project Planning & Scheduling Issues: Inadequate planning and scheduling are critical issues, as revealed by PCA. AI-based scheduling software, such as Primavera P6 and Microsoft Project, creates adaptable project timelines that reflect real-time progress and resource availability (Kalkani & Malek, 2016). Early Contractor Involvement (ECI) ensures that contractors are part of the planning and design phases, reducing the need for later redesigns (Ansari, 2020). Including penalty clauses in contracts can also enforce schedule adherence (Sampath & Abeysooriya, 2024).

Component 3 Equipment Related Delays: Equipment reliability is a significant factor. Using RFID and GPS-based tracking systems helps monitor and optimize equipment usage, preventing delays caused by unavailability or malfunctions (Ansari, 2020). AI-driven predictive maintenance can anticipate and prevent equipment failures, thereby reducing project downtime (Arantes & Ferreira, 2020).

Component 4 Regulatory & Approval Delays: Delays due to regulatory processes can be mitigated by adopting streamlined approval systems such as a single-window clearance, which reduces approval times by up to 40% (Sampath & Abeysooriya, 2024). Public-private partnerships and government liaison officers can also expedite these processes, minimizing bureaucratic red tape.

Component 5 Design & Documentation Errors: Errors in design and documentation significantly impact project timelines. Building Information Modeling (BIM) can help prevent such errors by aligning architectural, structural, and MEP models early in the design process, reducing rework and delays (Ansari, 2020). Cloud-based document management systems ensure that all stakeholders have access to the latest design versions, further reducing errors (Kalkani & Malek, 2016).

Component 6 Communication Gaps: Effective communication is essential for project success. Cloud-based collaboration tools like Microsoft Teams and Asana improve real-time communication and coordination among project teams, helping to align project goals and reduce miscommunication (Ansari, 2020).

Component 7 Slow Decision-Making Processes: Slow decision-making can stall projects significantly. Implementing AI-powered project dashboards provides real-time financial tracking and construction progress updates, facilitating quicker and more informed decision-making (Sampath & Abeysooriya, 2024). Establishing clear decision hierarchies allows project managers to handle routine approvals, speeding up the process (Arantes & Ferreira, 2020).

Component 8 Contractor & Subcontractor Issues: The selection and management of contractors and subcontractors are crucial. Pre-qualifying contractors based on their

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performance and financial stability can prevent delays (Ansari, 2020). Performance-based contracts encourage timely completion and hold contractors accountable for delays (Arantes & Ferreira, 2020).

By strategically implementing these mitigation strategies in response to the specific challenges identified through PCA, real estate construction projects can achieve more efficient management, reduced delays, and better overall project outcomes. These targeted approaches, supported by the cited research, provide a robust framework for enhancing project efficiency and effectiveness in the construction industry.

4.2.6 Component correlation matrix

Table 3: Component Correlation Matrix

Component	1	2	3	4	5	6	7	8
1	1.000	-0.137	-0.155	0.141	0.198	-0.017	0.167	0.048
2	-0.137	1.000	0.063	-0.069	-0.077	0.093	-0.126	-0.113
3	-0.155	0.063	1.000	-0.058	-0.116	0.005	-0.130	-0.154
4	0.141	-0.069	-0.058	1.000	0.120	0.014	0.111	0.032
5	0.198	-0.077	-0.116	0.120	1.000	-0.063	0.076	0.075
6	-0.017	0.093	0.005	0.014	-0.063	1.000	0.011	-0.085
7	0.167	-0.126	-0.130	0.111	0.076	0.011	1.000	0.050
8	0.048	-0.113	-0.154	0.032	0.075	-0.085	0.050	1.000

The Component Correlation Matrix serves as a key analytical tool to understand how Principal Components (PCs) relate to one another within a dataset. Each value in the matrix represents a correlation coefficient, indicating the degree of linear association between two components. This is essential for determining whether the components explain distinct aspects of the data or share overlapping variance.

In this matrix, the diagonal values are always 1.0, signifying perfect self-correlation. The off-diagonal values provide insight into the relationships between different components. Values near zero suggest that the components are largely independent, each capturing unique variance within the dataset. A positive correlation above 0.3 indicates a moderate degree of shared information between components, while negative correlations below -0.3 reflect inverse relationships where an increase in one component typically aligns with a decrease in another.

4.3 Observations from the correlation matrix

A moderate correlation is observed between Component 1 (Site Management Issues) and Component 5 (Design & Documentation Errors) with a coefficient of 0.198, suggesting that there may be some overlap in how these issues influence project delays. However, most of the

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other relationships across components are weak or negligible. For instance, Component 1 shows a weak negative correlation with Component 2 (Planning & Scheduling Issues) and Component 3 (Equipment-Related Delays), indicating they capture slightly different patterns of variance. Similarly, Component 2 and Component 3 are mostly independent, with only a very slight correlation (0.063), and minor negative relationships with other components like Component 4 (Regulatory & Approval Delays) and Component 5. These small coefficients suggest that the issues associated with planning, equipment, and regulatory delays operate relatively independently in real-world scenarios. Other components, such as Component 6 (Communication Gaps), Component 7 (Slow Decision-Making Processes), and Component 8 (Contractor & Subcontractor Issues), also show only minimal or weak correlations with the rest—indicating that they represent unique challenges within project management. For example, Component 8 displays very weak correlation with Component 1 and a slight negative correlation with Component 3, further confirming its distinct nature. Overall, the weak inter-component correlations confirm that PCA has successfully differentiated between various dimensions of delay. This reinforces the model's effectiveness in simplifying complex project data while retaining meaningful distinctions between contributing factors, enabling targeted and data-driven interventions in construction project management.

5.0 Conclusion

This study identifies inadequate project planning and ineffective communication among stakeholders as the leading causes of delays in Pune's real estate projects, supported by high Relative Importance Index (RII) scores. Poor scheduling, lack of contingency planning, and fragmented coordination often lead to inefficiencies and work disruptions. Regulatory hurdles, financial constraints, and contractual disputes also significantly impact timelines, underscoring the need for streamlined approvals, better financial management, and clearer contracts.

Through Principal Component Analysis (PCA), the research highlights eight core delay factors ranging from site management to equipment reliability explaining over 68% of data variance. To mitigate these delays, the study recommends integrating advanced tools such as AI-driven schedulers, real-time monitoring systems, BIM, and digital collaboration platforms. Performance-based contracts and contractor prequalification are also emphasized as critical strategies. Technology adoption, particularly in predictive maintenance, digital twin simulations, and blockchain-enabled smart contracts, shows strong potential in enhancing project efficiency. Future research should explore regional variations and the evolving role of emerging technologies in construction project management across India.

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CHAPTER 75

Impact of Digital Marketing in Real Estate

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ABSTRACT

The study explores the effects of digital marketing on the real estate sector in Pune, focusing on its role in enhancing brand awareness, generating leads, and fostering customer engagement. The main aim of the study is to explore how digital marketing techniques impact customer decision-making and contribute to real estate sales. Information was collected from purchasers and specialists in the area through a combination of statistical and descriptive approaches. The data indicates a clear relationship between digital marketing efforts and the rise in profits for businesses. According to key results, social media, SEO, and online property listings play a crucial role in attracting potential buyers and streamlining the sales process. It emphasizes the increasing significance of digital marketing platforms compared to traditional methods, demonstrating their ability to connect with a larger audience and build consumer trust. In conclusion, digital marketing plays a vital role in achieving success in the current Pune real estate market. To enhance marketing strategies and consumer experiences, future studies should focus on advancing technologies like virtual reality and artificial intelligence. The results of the study can assist real estate agents and brokers in adapting to emerging digital standards and sustaining a competitive advantage in an ever-evolving industry.

Keywords: Digital marketing; Real estate; Social media; SEO; Consumer engagement.

1.0 Introduction

Due to digital marketing, 92% of homebuyers now turn to the internet to search for a property. This is significantly transforming the real estate industry. To remain competitive in the current economy, leveraging digital tools is essential. To succeed in the **"**real estate (RE)**"** industry, it is necessitated to implement a well-structured digital marketing campaign. Digital marketing can enhance the complete sales process, spanning from lead generation to closing deals (Rabby *et al.*, 2022). Real estate companies can leverage digital marketing to broaden their customer reach, engage with clients more effectively, and enhance their sales strategies.

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1.1 Impact of digital marketing of real estate

Internet advertising has revolutionized the real estate industry, altering how homes are showcased, bought, and leased. Digital tools are rapidly taking the place of long-standing techniques, such as public displays& print ads, due to their reach, efficiency, and ability to be tailored to individual needs.

1.2 Social media and its impact on real estate in Pune

In Pune, the real estate sector heavily depends on social media to enhance its marketing and sales strategies. Social media is becoming more prevalent in the RE sector, allowing for easier access to that audience on platforms such as “Facebook, Instagram, and LinkedIn”. The foundation of the text is notably dynamic, allowing real estate professionals to expand their reach by leveraging technological platforms for streaming virtual tours and live presentations featuring high-quality images and videos.

2.0 Challenges Encountered

The growing significance of digital platforms in the real estate sector, especially as consumer behavior increasingly shifts towards online research and transactions. To engage today’s tech-savvy consumers, conventional marketing methods are proving inadequate. To effectively respond to the evolving market dynamics, real estate developers can gain insights from this study’s analysis of digital marketing strategies designed to enhance sales, lead generation, and customer engagement (Kaur, 2022).

3.0 Literature Review

Kumar & Rao, (2024) analysed that digital marketing has undoubtedly transformed the RE sector in Pune. This was achievable through mass media and SEO, along with virtual tours that provided clients with real-time views of the properties. As a result, the market saw an increase in the availability of consumer goods that are also budget friendly. Additionally, the virtualization of providers was essential for effective integration. The digitization of the sales process was essential for the large-scale manufacturing of consumer products (Kumar, 2014). Patel (2024) examined that social media is considered as the most effective method of advertising property in Pune. The builders succeeded in luring the prospective buyers to social media, consequently leading to a boost in the sales of their properties and creating a bond of trust with their customers. The social media platforms that were used are Instagram, Facebook, and LinkedIn (Patel, 2024).

4.0 Research Methodology

The research design employed a descriptive and exploratory approach to understand digital marketing strategies within the real estate industry. The questionnaire, serving as the

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primary instrument, addressed topics concerning digital marketing strategies, brand recognition, lead generation, consumer decision processes, buying behavior, digital marketing platforms, real estate transactions, and customer engagement. The data sources employed comprised both primary and secondary types.

4.1 Research objectives

- To analyze the role of digital marketing strategies in enhancing brand visibility and lead generation for real estate businesses.
- To examine the impact of digital marketing on consumer decision-making and buying behavior in the real estate sector.
- To assess the effectiveness of digital marketing channels in real estate sales and customer engagement.

Figure 1: Depecting Influence of Online Marketing in Order to Close Sales

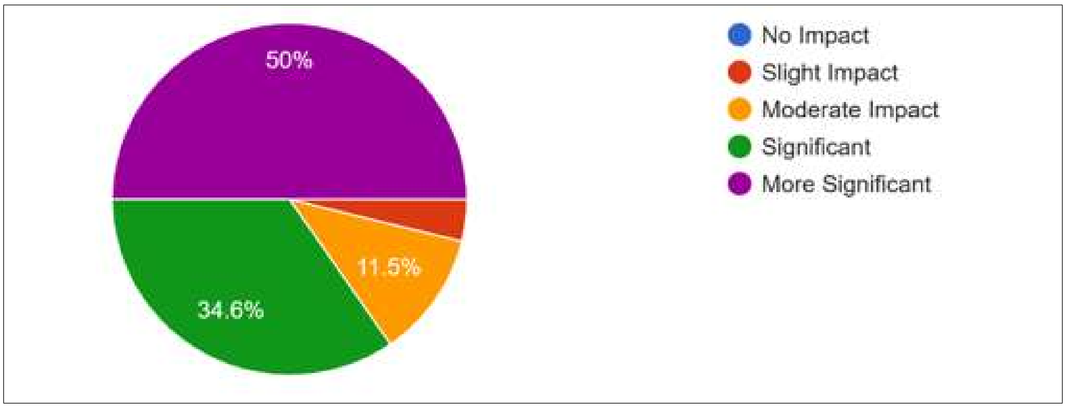
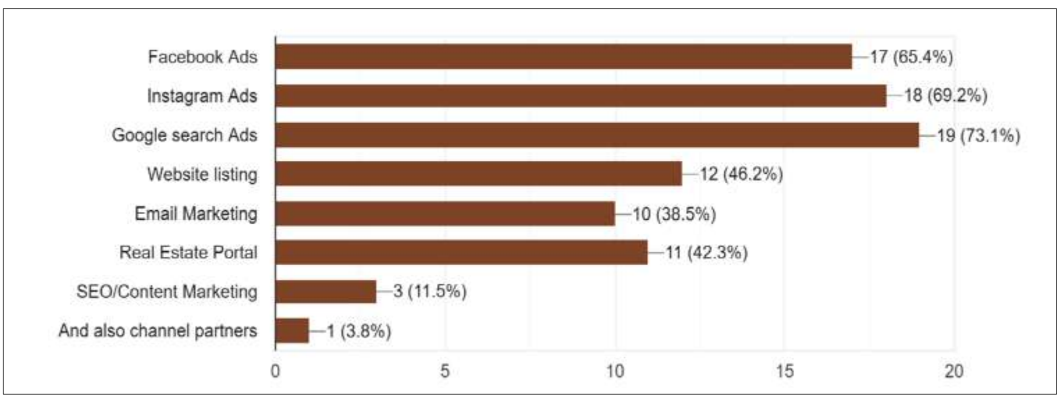


Figure 2: Depicting the Effectiveness of Various Online Marketing Channels for Generating Leads for Real Estate Companies



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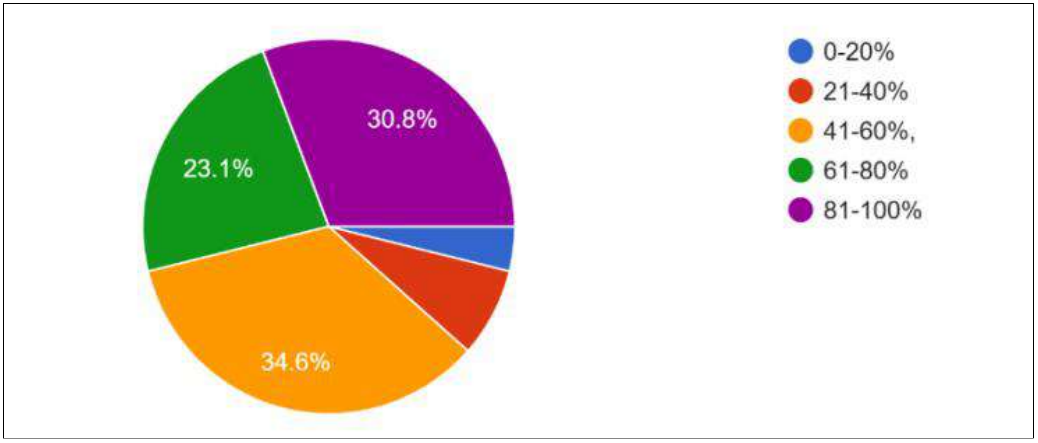
5.0 Results

The chart highlights the perceived effectiveness of online marketing in driving sales. This strongly suggests that digital marketing is a powerful tool in the real estate sector.

Figure 3: Examining, Lead Pool Generated from Online Marketing in Reference to Real Estate Marketing Team



This strongly suggests online marketing is seen as a valuable tool for providing information and building client understanding.

Figure 4: Interpretating Follow up of the Leads by the Company Generated through Online Marketing

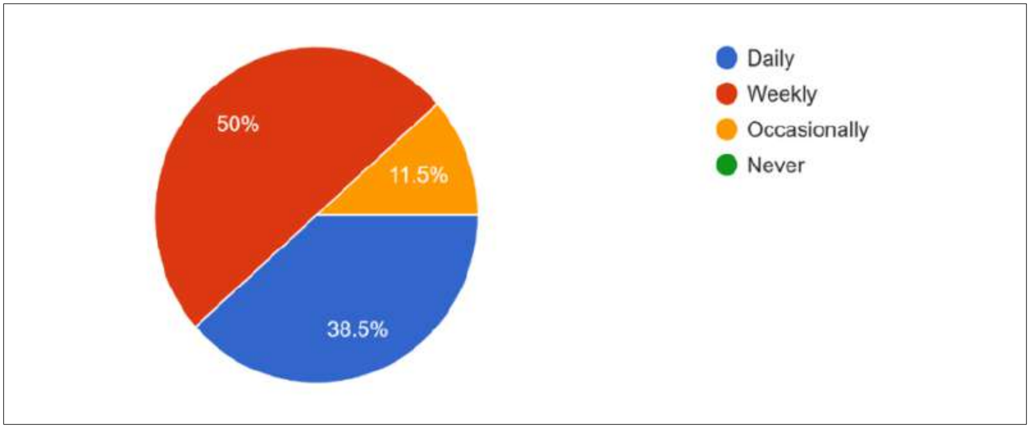


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Figure 5: Depicting Leads Generated from Online Marketing are as Qualified as those from Traditional Methods (referrals, walk-ins, etc.)

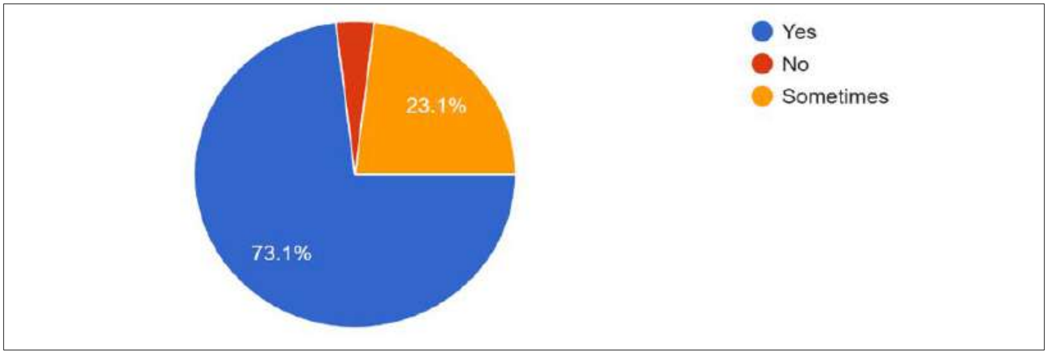

Table 1: T-Test

Test	t	Df	Sig. (2-tailed)	Mean Difference	Lower Confidence Interval	Upper Confidence Interval
Impact of Digital Marketing on Closing Sales	10.81665	13	7.18E-08	1.5	4.200411	4.799589
Effectiveness of Marketing Channels for generating leads	2.280351	13	0.040093	0.857143	3.045099	4.669187
Lead Pool generated from Digital Marketing	6.276459	13	2.85E-05	1.428571	3.936855	4.920288
Follow-up of Leads	10.21219	13	1.41E-07	1.357143	4.070042	4.644244
Online Leads vs Traditional Leads	13	13	7.96E-09	1.857143	4.548519	5.165767

Table 2: Demographic

Sr no	Demographic Variables		Frequency	%
1	Age group	18-25	36	24%
		26-30	41	27.33%
		31-35	48	32%
		Above 45 Years	25	16.66%
2	Gender	Female	67	44.66%
		Male	83	55.33%
3	Education Level	Bachelor’s degree	32	21.33%
		Master’s degree	29	19.33%
		Other	53	35.33%
		PhD	36	24%
4	Income level	Less than 30000	50	33.33%
		30000- 60000	45	30%
		60000- 100000	28	18.66%

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		More than 100000	27	18%
5	Location	Rural	41	27.33%
		Semi-urban	45	30%
		Urban	64	42.66%
6	Occupation	Other	34	22.66%
		Unemployed	26	17.33%
		Self employed	39	26%
		Employed full time	51	34%
7	Technological Savviness	Novice	36	24%
		Intermediate	80	53.33%
		Advanced	34	22.66%

Obj. 1: To analyze the role of digital marketing strategies in enhancing brand visibility and lead generation for real estate businesses.

H1: Digital marketing strategies significantly enhance brand visibility and lead generation for real estate businesses.

Table 3: Regression Analysis

Hypothesis	Regression Weights	Beta Coefficient	R2	F	t-value	p-value	Hypothesis Result
H1	Digital marketing strategies > Brand visibility and lead generation	.321	0.103	17.012	4.125	0.000	Supported

The findings of this study validate that H1 is significantly influenced by digital marketing, particularly regarding its role in enhancing brand visibility and attracting potential leads within the housing sector.

Obj. 2: To examine the impact of digital marketing on consumer decision-making and buying behavior in the real estate sector.

H2: Digital marketing significantly influences consumer decision-making and buying behavior in the real estate sector.

Table 4: Regression Analysis

Hypothesis	Regression Weights	Beta Coefficient	R2	F	t-value	p-value	Hypothesis Result
H2	Digital marketing strategies > Consumer decision-making and buying behavior	.326	0.106	17.573	4.192	0.000	Supported

Therefore, Hypothesis H2 is supported, indicating that internet advertising methods use a considerable impact on shaping consumer decisions and influencing their buying behavior in the RE market.

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Obj. 3: To assess the effectiveness of digital marketing channels in real estate sales and customer engagement.
H3: Digital marketing channels significantly impact real estate sales and customer engagement.

Table 5: Regression Analysis

Hypothesis	Regression Weights	Beta Coefficient	R2	F	t-value	p-value	Hypothesis Result
H3	Digital marketing channels > Real estate sales and customer engagement	.321	0.103	17.012	4.125	0.000	Supported

These findings support, Hypothesis H3 is supported, highlighting the efficacy of online advertising channels in driving sales and enhancing customer engagement within the real estate industry.

6.0 Findings and Discussion

Digital marketing strategies serve as the initial phase in shaping the brand image and attracting several new customers, influencing their preferences and perceptions towards real estate agents and firms. The relationship between the variables (digital marketing outcomes) and the digital marketing investment in regression analysis is notably strong and positive. The primary hypothesis of this study was that the volume of leads and brand recognition would significantly increase due to online advertising initiatives. Furthermore, the study finds that internet advertisements have a significantly positive impact on client spending behavior and decision-making, highlighting their essential role in shaping client preferences. The research has shown that sites of social media and webpages among other channels of digital marketing can significantly contribute to sales and improve the levels of interaction with clients.

7.0 Conclusion

Recent advancements in technology, changes in legislation, and evolving consumer perspectives could lead to significant progress in the property market in India. Pune is expected to have a crucial role in this matter due to its robust infrastructure and strategic positioning. The line direction is barely connected with also the sustainability, eco-friendliness, and technological utilization practices. The Indian real estate potential enablers will be better than ever in the setting up and the development of future cities by promoting these innovative trends will be more successful in the country. Keeping up with the market demand as well as the newest technologies in order to secure a competitive edge is very much necessary and provides the

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insight and market perspective for previously discussed the report to be successful. Moreover, the focus on customer satisfaction highlighted in the previously discussed report is essential. In the property industry in India, online contact has become an integral aspect of daily operations, and Pune's impressive digital marketing strategies ensure smooth functioning. To attract more clients, real estate brokers need to actively participate in web marketing within a competitive landscape.

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