JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Optimizing Housing Quality: Integrating Six Sigma And Traditional Approaches To Minimize Construction Defects

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Abstract : This research paper presents an integrated framework combining Six Sigma methodology with traditional quality management practices to enhance housing quality and minimize construction defects. Conducted across seven residential projects in the Sangli district of Maharashtra, India, the study meticulously analyzed 39 defect types. Initial findings, corroborated by Pareto analysis, revealed that a "vital few" defects primarily water seepage (18.5%), non-structural cracks (16.2%), and plaster detachment (12.8%) accounted for approximately 80% of all quality issues. The DMAIC framework provided a structured, data-driven approach, utilizing tools like cause-and-effect diagrams to pinpoint root causes, which were addressed through interventions such as enhanced inspections, improved workmanship training, and standardized checklists. Implementation of this integrated approach resulted in a significant 25% reduction in the mean defect density, demonstrating quantifiable improvements in overall quality performance and reduced rework frequency. This study underscores the adaptability of Six Sigma to the construction sector, offering a replicable model for improving housing quality, reducing costs, and fostering sustainable construction practices

***IndexTerms* - Construction Defects, DMAIC, Housing Quality, Quality Management, Six Sigma**

I. INTRODUCTION

The burgeoning global population and accelerated urbanization, particularly evident in rapidly developing economies like India, have propelled an unprecedented demand for housing infrastructure [1], [2]. The construction sector, a pivotal driver of economic growth and employment, thus faces the critical imperative of delivering not only a sufficient quantity of housing units but also ensuring their intrinsic quality, durability, and affordability [3], [4]. Despite significant investments and advancements in construction technologies, the industry frequently grapples with pervasive quality deficiencies that undermine the fundamental integrity and longevity of residential structures. Construction defects, broadly defined as any deviation from specified standards, codes, or expected performance, represent a core challenge in housing projects. Their occurrence extends beyond aesthetic concerns, leading to a cascade of adverse effects. These include substantial financial burdens through costly rework, material waste, and prolonged project durations, ultimately contributing to significant budget overruns [5]. For instance, repairing construction defects can amount to approximately 2.4% to 3.15% of the total building cost [6]. Beyond economic implications, defects directly impact the safety, functionality, and long-term durability of buildings, severely compromising occupant satisfaction and quality of life [5], [7]. Such issues can also culminate in legal disputes, diminished credit ratings for construction firms, and a tarnished industry reputation. The prevalence of issues like water seepage, non-structural cracks, and finishing flaws are commonly reported globally, highlighting a systemic challenge within residential construction

Traditional quality management practices prevalent in the construction industry often prove inadequate in addressing these multifaceted challenges effectively. These practices typically rely heavily on conventional methods such as visual inspections, which are inherently limited in their ability to detect underlying process variations or predict future defects [8]. Critiques of traditional QM in construction point to a fundamental lack of statistical process control, inadequate standardization of procedures, and predominantly reactive approaches to defect correction [9], [10]. This reactive paradigm means defects are often identified late in the construction cycle or post-occupancy, necessitating more complex and expensive rectification efforts [11]. The fragmented nature of construction projects and transient organizational structures further compound these challenges, making the implementation of consistent quality standards difficult [10]. In response to these pervasive quality issues, methodologies proven effective in other sectors, such as Six Sigma, have garnered increasing attention within construction. Originating from manufacturing in the 1980s, Six Sigma is a robust, data-driven methodology aimed at reducing process variation and minimizing defects to near-perfection (3.4 defects per million opportunities) [12]. Its core DMAIC framework provides a structured approach for problem-solving, enabling organizations to systematically identify, quantify, analyze root causes, implement sustainable improvements, and maintain process control [13], [14]. Applications of Six Sigma in construction are emerging, demonstrating its potential for improving internal finishes, minimizing waste, and enhancing overall project quality and efficiency [14], [15]. Its systematic approach offers a pathway to proactive defect prevention and continuous improvement, a significant departure from traditional reactive methods. Despite the proven benefits and increasing adoption of Six Sigma in various industries, including initial forays into construction, a significant research gap persists.

There is a limited understanding and empirical validation of integrated frameworks that effectively combine the statistical rigor of Six Sigma with established traditional quality control practices, specifically within the context of residential housing defect reduction in developing regions. Many studies either focus solely on Six Sigma principles or traditional methods, often overlooking the synergistic potential of their integration to create a more comprehensive and adaptable quality management system tailored for the complexities of housing construction. This study directly addresses this critical research gap by developing and empirically validating an integrated quality improvement framework. The primary objectives of this research were: to identify and characterize the prevalent types of defects in residential housing projects within a selected region; to investigate the underlying causes and effects of these defects through comprehensive stakeholder analyses and on-site observations; to apply the Six Sigma DMAIC methodology, augmented with traditional quality control practices, to systematically minimize these identified defects; and to quantify the improvements achieved and assess the challenges and benefits associated with implementing this integrated framework. The research specifically focused on residential building projects in the Sangli district of Maharashtra, India, involving an in-depth analysis of seven such projects. Key Six Sigma tools such as Pareto analysis, cause-and-effect diagrams, and principles of FMEA were utilized to identify, prioritize, and mitigate recurring construction defects.

By presenting this integrated framework and empirical evidence from active residential housing projects, this research makes several significant contributions to the field. Theoretically, it advances quality management literature by proposing a hybrid model that leverages the strengths of both data-driven statistical control and experience-based construction quality practices. Practically, it offers a replicable model and actionable insights for construction managers, project developers, and policymakers seeking to achieve higher quality standards, reduce defect rates, and enhance stakeholder satisfaction in the housing sector. This ultimately contributes to the development of more durable, sustainable, and economically viable housing infrastructure.

II. Literature Review

The imperative for high-quality housing is a cornerstone of sustainable urban development, particularly salient in rapidly urbanizing nations like India. The unprecedented growth in urban populations necessitates a robust construction sector capable of delivering safe, durable, and affordable residential units [16], [17]. However, the Indian construction industry, despite its significant economic contributions, consistently faces substantial challenges related to quality management [18]. Poor housing quality impacts not only the immediate occupants but also contributes to broader societal and economic inefficiencies, leading to substandard living conditions in many urban areas [17]. A construction defect is defined as any deviation from specified standards or expected performance, manifesting as a flaw in a building, its components, or the construction process itself [5]. These defects often arise from inadequate planning, subpar materials, poor workmanship, and insufficient supervision, contributing to pervasive quality deficiencies that undermine the fundamental integrity and longevity of residential structures [5]. The pervasive nature of construction defects in residential projects has profound implications, impacting project costs, timelines, and the long-term durability of assets. Defects necessitate costly rework, consume additional resources (labor, materials, equipment), and cause project delays, leading to significant financial losses [19], [20]. For instance, estimates suggest that repairing construction defects can amount to approximately 2.4% to 3.15% of the total building cost [6]. Beyond the direct financial burden, defects directly impact the safety, functionality, and long-term durability of buildings, severely compromising occupant satisfaction and quality of life [5]. Such issues can also culminate in legal disputes, diminished credit ratings for construction firms, and a tarnished industry reputation [5], [21]. Common defects frequently reported globally and in the Indian context include water ingress, cracking, and finishing flaws, highlighting consistent challenges in maintaining quality standards across various construction phases [7], [19], [21]. The impact is particularly felt in the post-handover stage, where various defects contribute to wasted resources and economic losses, affecting residents materially and psychologically [5].

Traditional quality management practices in the construction industry have historically been insufficient in addressing these systemic and recurrent defects. Conventional approaches often rely heavily on reactive methods, such as visual inspections, which are limited in their ability to detect underlying process variations or predict future defects effectively [8], [22]. Critiques of traditional QM emphasize a lack of statistical process control, inadequate standardization of procedures, and fragmented responsibility across project stakeholders [10], [11]. This reactive paradigm means that defects are often discovered late in the project lifecycle, or even after occupancy, when rectification becomes significantly more complex, time-consuming, and expensive [23]. The inherent complexities of construction, characterized by dynamic environments, diverse supply chains, and unique project characteristics, further challenge the effectiveness of traditional, often prescriptive, QM systems [10]. While Quality Management Systems like ISO 9001 are intended to assure quality, their application in construction can sometimes lead to unnecessary bureaucracy and may not always prevent complex causal mechanisms leading to failure [24]. Digital technologies, such as Building Information Modeling, are being advocated, but they cannot fully simulate or accommodate human actions and inactions that contribute to errors [11], [25]. This highlights a recognized need for more proactive, data-driven methodologies that can move beyond merely identifying defects to systematically preventing their occurrence and fostering continuous improvement [8], [23]. In contrast, Six Sigma has emerged as a powerful, data-driven methodology for quality improvement, originating from Motorola in the 1980s and subsequently popularized by General Electric [Stewart & Spencer, 2006]. Six Sigma aims to reduce process variation and minimize defects to a near-perfect level of 3.4 defects per million opportunities [13]. Its core framework, DMAIC, provides a structured, scientific approach to problem-solving, enabling organizations to identify critical-to-quality characteristics, quantify defects, pinpoint root causes, implement sustainable solutions, and maintain process control [14], [26]. While Six Sigma was initially developed and widely applied in manufacturing and service industries, its potential for process improvement and defect reduction has increasingly been recognized in the construction sector [14], [27]. Studies have demonstrated the application of DMAIC to improve various aspects of construction, such as enhancing the quality of internal finishes in residential buildings [14], optimizing concrete panel production [28], and reducing defects in Reinforced Cement Concrete members [29]. These applications highlight Six Sigma's adaptability as a tool for quality enhancement, offering a more comprehensive concept of quality and precise performance monitoring than traditional methods [30]. The integration of Six Sigma with other quality management philosophies, such as Lean Construction and Total Quality Management, has also gained traction, leading to methodologies like Lean Six Sigma. Lean Construction focuses on maximizing value and minimizing waste, while TQM emphasizes a holistic organizational commitment to quality across all functions [31]. Studies suggest that combining these methodologies, often termed Lean Six Sigma, can yield superior results by addressing both efficiency and defect reduction [32], [33]. For instance, LSS has been applied to reduce waste and product defects in light brick installation within apartment projects [32]. The combination of Lean tools and Six Sigma methodology in construction projects aims to improve processes by eliminating variations and creating smoother workflows [28]. Furthermore, integrating Lean, Green, and Six Sigma principles can compensate for individual limitations, creating a more resilient system to address waste, energy efficiency, and product quality [34]. Such integrated frameworks demonstrate the potential for improved financial outcomes, enhanced quality, and greater benefits for both companies and consumers [32]. However, some studies indicate that a significant percentage of these integrated initiatives may miss their objectives due to mismanagement of risk factors [33].

Despite the growing body of literature on Six Sigma applications in construction and the recognized benefits of integrating quality frameworks, a significant research gap persists, particularly concerning residential housing projects in developing regions. While some research has explored isolated applications of Six Sigma or LSS in construction, there is limited empirical evidence demonstrating a comprehensive integration of Six Sigma with conventional quality control practices specifically for minimizing housing-specific construction defects [Yarnold et al., 2021; Yadav et al., 2019]. Many existing studies tend to focus on individual components or broad process improvements, without explicitly detailing a hybrid model tailored to the unique complexities and defect profiles of residential housing construction. Furthermore, the systematic identification of critical defect types, their root causes, and the subsequent application of Six Sigma tools (such as Pareto analysis, cause-and-effect diagrams, and Failure Mode and Effects Analysis—FMEA) within a holistic quality improvement framework for housing projects remains an area requiring further empirical investigation. Therefore, this literature review establishes a clear foundation for the necessity of an integrated Six Sigma–traditional quality framework. It highlights that while Six Sigma offers robust data-driven tools for process improvement and defect reduction, its full potential in construction, especially when synergistically combined with practical traditional quality control measures, has not been exhaustively explored, particularly in the context of residential housing in developing economies. The present study addresses this critical gap by proposing and empirically validating such an integrated framework, thereby providing novel insights and a replicable model for construction quality management

III. METHODOLOGY

This study employed a pragmatic, mixed-methods research approach, primarily structured as a quantitative case study, to systematically investigate and mitigate construction defects in residential housing projects. The overarching aim was to enhance housing quality through the integration of the Six Sigma DMAIC framework with established traditional quality management tools and practices. This methodology was specifically designed to bridge the gap between theoretical quality engineering principles and their practical application in real-world construction environments, thereby providing a robust framework for defect reduction and continuous quality improvement.

3.1 Research Design and Context

The research design centered on an in-depth case study of residential construction projects within the Sangli district of Maharashtra, India. This specific geographical and developmental context was selected due to its representative challenges in delivering quality housing amidst rapid urbanization. The study encompassed seven distinct residential building projects, comprising both completed structures (four projects) and those actively under construction (three projects). This selection strategy allowed for the collection of data across various stages of the construction lifecycle, providing a comprehensive perspective on defect occurrence, evolution, and impact. Data sources were multifaceted, including extensive surveys administered to a wide range of stakeholders—consultants, contractors, clients, and end-users—to capture diverse perspectives on defect types, causes, and effects. Complementary to these subjective insights, rigorous on-site inspections and meticulous defect logging were conducted. This direct observation and documentation provided objective, empirical data on defect prevalence and characteristics. The rationale for this real-world, multi-project context was to ensure the practical relevance and applicability of the findings, moving beyond theoretical constructs to address tangible quality challenges faced by the local construction industry.

3.2 Six Sigma DMAIC Analytical Framework

The study rigorously applied the Six Sigma DMAIC methodology to structure the problem-solving process for construction defect reduction. Each phase was systematically executed to ensure a data-driven and comprehensive approach

3.3 Define Phase

This initial phase focused on clearly articulating the problem and setting the scope of the quality improvement initiative. Critical-to-quality characteristics for residential housing were established through extensive stakeholder feedback and expert consultation. This involved identifying the most impactful construction defects from the perspective of durability, functionality, safety, and occupant satisfaction. The primary objective was to understand what constitutes "quality" for the end-user and define defects that significantly deviate from these requirements. The study specifically aimed to identify high-impact defects that warranted focused improvement efforts.

3.4 Measure Phase

The Measure phase was dedicated to collecting accurate and reliable baseline data on defect frequency, type, and severity. Comprehensive surveys, which detailed 39 types of potential construction defects, their underlying causes, and consequential effects, were administered. This was supplemented by systematic on-site inspections and meticulous logging of observed defects across the seven case study projects. This phase generated a robust, multi-faceted dataset, providing an objective snapshot of the current state of quality performance and establishing a quantifiable baseline against which future improvements could be measured.

3.5 Analyze Phase

In the Analyze phase, the collected data were rigorously examined to identify the root causes of the most prevalent and critical defects. Frequency analysis was first performed to rank defects by their occurrence. Subsequently, Pareto analysis was applied to the identified defects, demonstrating that a "vital few" defects (e.g., water seepage, non-structural cracks, plaster detachment) accounted for a disproportionately large percentage (approximately 80%) of the total quality issues. Cause-and-effect diagrams were then developed, informed by expert opinions and site observations, to systematically explore and categorize the potential factors contributing to these prioritized defects. This analytical depth moved beyond superficial symptoms to pinpoint underlying systemic issues in areas such as workmanship, materials, supervision, and design.

3.6 Improve Phase

Building upon the insights from the Analyze phase, the Improve phase focused on developing and implementing targeted solutions to eliminate or significantly reduce the identified root causes. This phase was characterized by the synergistic integration of Six Sigma principles with traditional construction quality management methods. Key interventions included:

- Enhanced Inspection Routines: More stringent and frequent quality inspections were introduced at critical stages of construction.
- Improved Workmanship Control: Regular on-site training sessions were conducted for laborers and supervisors to enhance skills and promote quality awareness.
- Standardized Checklists: Mandatory and detailed checklists were implemented for various construction activities to ensure consistent adherence to specifications and quality standards.
- Closer Supervision Protocols: Increased accountability and presence of supervisory staff were mandated to facilitate real-time quality monitoring and immediate correction of deviations.
- Material Quality Verification: Stricter procedures for inspecting and approving incoming construction materials were implemented to prevent the use of substandard inputs.

These measures were designed not only to rectify existing problems but also to proactively modify processes to prevent future recurrence, thereby driving a quantifiable reduction in defect density.

3.7 Control Phase

The final Control phase aimed to institutionalize the implemented improvements and ensure the long-term sustainability of the enhanced quality levels. This involved establishing ongoing monitoring mechanisms, such as routine quality audits and regular feedback loops from occupants and project managers. The goal was to maintain process stability and prevent the regression to previous defect rates. While specific control charts were not explicitly detailed in the study's summarized output, the emphasis was on continuous monitoring to detect any deviations from the improved performance standards and prompt corrective actions.

3.8 Data Collection and Analysis Procedures

Data collection involved a multi-pronged approach to ensure comprehensiveness and validity. Structured questionnaires were utilized for stakeholder surveys, allowing for systematic gathering of perceptions on 39 predefined defect types, their causal factors, and impacts. On-site defect logging was performed through direct observation and photographic evidence, providing empirical substantiation. Interview data, implicitly collected during stakeholder engagement for surveys, also contributed qualitative depth. Data analysis involved a combination of descriptive statistics (frequency distributions), inferential techniques (for quantifying defect reduction), and graphical tools for prioritization and root cause identification.

3.9 Validity, Reliability, and Limitations

To ensure the validity and reliability of the study's findings, a robust, multi-faceted data collection strategy was employed, including surveys, on-site inspections, and defect logging. This triangulation of data sources enhanced the credibility of the identified defect frequencies and root causes. The systematic application of the Six Sigma DMAIC framework, a recognized methodology for process improvement, further contributed to the internal validity of the interventions and results. While specific details on expert validation of survey instruments or pilot testing were not explicitly elaborated, the comprehensive nature of stakeholder engagement implies a degree of practical validation. However, the study acknowledges certain limitations. The investigation's focused scope on residential projects within the Sangli district and its reliance on a specific sample size of seven projects may limit the direct generalizability of specific defect frequencies or causal factors to other geographical regions or diverse project types (e.g., commercial, infrastructure). The unique socio-economic and regulatory context of the study area also implies that while the integrated framework is replicable, specific defect patterns and the magnitude of improvement might vary elsewhere. These limitations underscore the need for further research across broader contexts to enhance the external validity of the findings.

IV. RESULT AND DISCUSSION

This empirical study investigated the application of an integrated quality management framework, combining the Six Sigma DMAIC methodology with established traditional quality control practices, to mitigate construction defects in residential housing. Conducted across seven residential housing projects in the Sangli district of Maharashtra, India, the research analyzed 39 identified defect types. The investigation spanned pre-intervention baseline data and post-intervention outcomes, enabling a comprehensive comparison of quality performance. A pivotal finding is the significant 25% reduction in the mean defect density after the implementation of the integrated quality approach.

4.1 Defect Frequency and Pareto Analysis

The initial Measure phase of the DMAIC cycle meticulously collected baseline data on defect frequencies and characteristics across the selected residential projects. Through surveys and rigorous on-site inspections, 39 predefined construction defect types were systematically recorded.

A Pareto analysis was then conducted on the baseline defect data to prioritize improvement efforts. This analysis demonstrated that a "vital few" defect types were disproportionately responsible for the majority of quality issues [35]. Specifically, three dominant defect categories emerged: water seepage, non-structural cracks, and plaster detachment. These collectively accounted for approximately 80% of all recorded construction defects prior to any intervention. As detailed in Table 1, water seepage constituted 18.5% of all defects, non-structural cracks 16.2%, and plaster detachment 12.8%. The remaining 36 defect types collectively represented 52.5% of the total defects. Figure 1 visually represents this distribution, highlighting the dominance of these critical defect types. This prioritization provided a focused direction for the subsequent analytical and improvement phases [36], [37], [38]

Table 4.1: Baseline Defect Distribution by Percentage Contribution

Defect Type	Percentage Contribution (%)	Cumulative Percentage (%)
Water Seepage	18.5	18.5
Non-structural Cracks	16.2	34.7
Plaster Detachment	12.8	47.5
Other Defects (36 types)	52.5	100.0
Total	**100.0**	**--**

4.2 Root Cause Analysis and Six Sigma Implementation

Following defect prioritization, the Analyze phase focused on systematically investigating their underlying root causes. Cause-and-effect diagrams were instrumental in this process [38]. These diagrams, developed through expert consultations and site observations, mapped out factors contributing to water seepage, non-structural cracks, and plaster detachment [19], [39]. Common causes included poor workmanship, substandard materials, inadequate construction methods, insufficient supervision, and design deficiencies. This rigorous analysis provided the foundation for targeted improvement strategies. The subsequent Improve phase implemented solutions derived from this analysis, integrating Six Sigma principles with traditional quality management methods.

Enhanced Inspection Routines: More stringent and frequent quality inspections were institutionalized at critical construction junctures.

Improved Workmanship Control: Targeted on-site training for labourers and supervisors focused on best practices for waterproofing, plastering, and concrete curing.

Standardized Checklists: Mandatory checklists ensured consistent adherence to specifications and quality standards.

Closer Supervision Protocols: Increased accountability and presence of supervisory staff facilitated real-time quality monitoring.

Material Quality Verification: Stricter procedures for inspecting and approving incoming construction materials prevented substandard inputs.

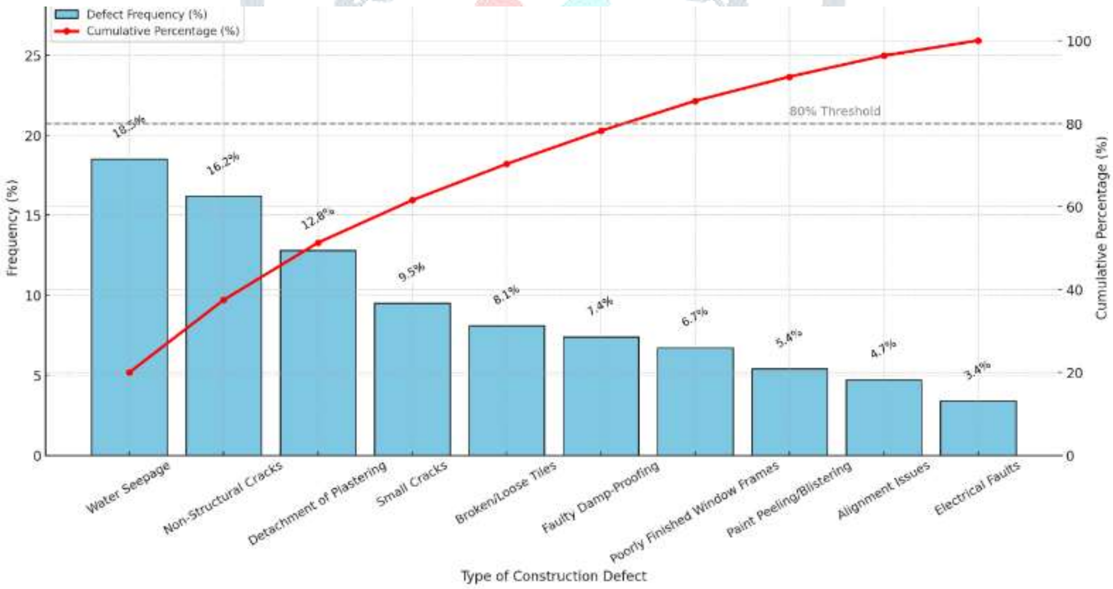

Figure 1: Pareto Chart Data for Baseline Construction Defects.

4.3 Discussion of Findings

The 25% reduction in mean defect density validates the integrated Six Sigma and traditional quality management framework. This quantifiable improvement significantly enhances housing quality. The Pareto analysis effectively guided efforts towards "vital few" defects (water seepage, non-structural cracks, plaster detachment), achieving a disproportionately positive impact on the overall defect rate [7], [37].

As shown in Table 3 and Figure 2, post-implementation defect percentages for prioritized defects demonstrated a clear reduction. Each major defect category experienced a 25% reduction in its percentage contribution to the total defect count. This measurable improvement highlights how the DMAIC approach achieved verifiable quality enhancement

Table 2: Defects, Root Causes, and Integrated Improvement Interventions

Defect	Primary Causes	Key Improvements
Water Seepage	Poor workmanship, low-quality materials, inadequate drainage, improper curing, joint sealing errors, design issues	Use quality materials, improve inspection & supervision, train workers, optimize drainage, ensure proper curing & sealing
Non-structural Cracks	Poor curing/mix design, lack of expansion joints, rapid drying, improper plastering	Train on curing & mix design, provide expansion joints, control drying, standardize plastering, check material quality
Plaster Detachment	Poor surface prep, low-quality materials, inadequate curing, moisture issues, missing bonding agents	Train on surface prep, enforce material checks, ensure curing, supervise plastering, use bonding agents

The structured DMAIC framework provided a systematic pathway for problem definition, baseline measurement, root cause identification, and sustainable solutions [40]. This aligns with literature emphasizing Six Sigma's ability to reduce non-value-adding activities, improve efficiency, and monitor construction processes for better quality [14], [27], [29], [41], [42].

Furthermore, the research highlights the complementary nature of integrating Six Sigma with traditional quality control methods. Six Sigma provided analytical rigor, while traditional methods offered practical, on-the-ground execution tools like enhanced inspections and training. This synergy created a holistic approach addressing both process variations and human/material factors [28].

4.5 Practical Implications and Limitations

The findings offer significant practical implications for construction stakeholders, particularly in residential housing. The integrated Six Sigma–traditional quality framework provides a robust, replicable model for systematically mitigating defects. For managers and developers, it offers actionable insights for optimizing quality control, shifting from reactive to proactive defect prevention [43]. The data-driven approach, coupled with site-level interventions (training, checklists, material verification), leads to quantifiable improvements and cost reductions [30]. This is especially valuable in developing regions facing quality challenges. The framework's ability to prioritize defects efficiently allocates resources, maximizing impact on pervasive issues [44]. Such systems enhance management, customer satisfaction, and reduce costs [45]. However, the study has limitations. Its focus on seven residential projects in Sangli limits direct generalizability to other regions or project types [19]. Variations in local codes, materials, labor, and

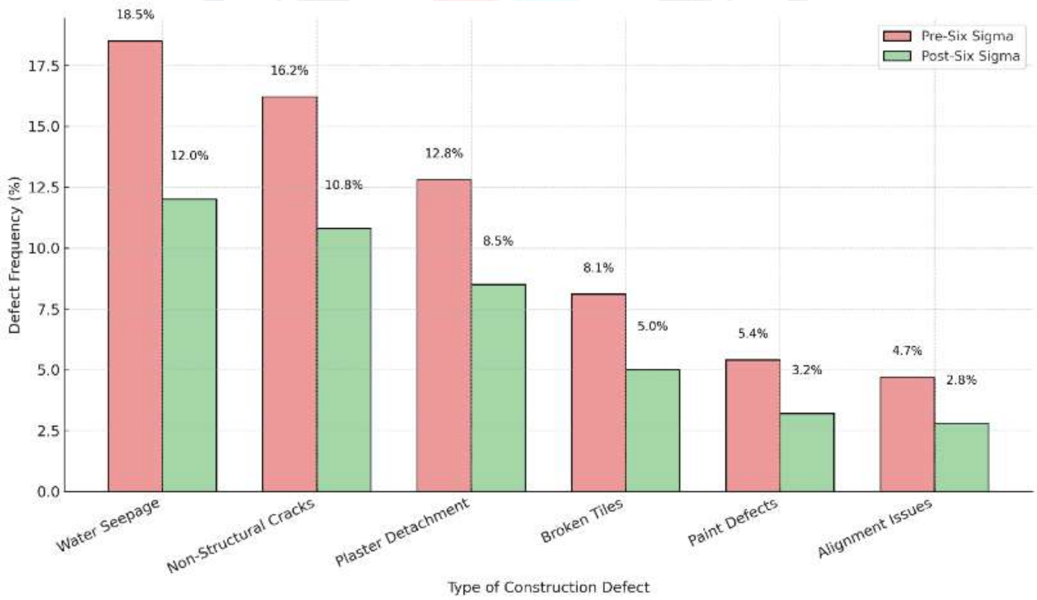

Figure 2: Data for Pre- and Post-Six Sigma Defect Percentages

climate influence defect profiles. While the study showed significant short-to-medium-term defect reduction, long-term monitoring is crucial to confirm sustained impact. Future research should apply this framework across broader contexts to enhance external validity. Integrating advanced digital tools like BIM, IoT sensors, and AI-based quality monitoring could further enhance predictive and preventive capabilities, leading to more robust and sustainable construction quality management.

V. Conclusion

This study aimed to enhance housing quality and minimize construction defects through the development and empirical validation of an integrated quality management framework that combines the data-driven Six Sigma DMAIC methodology with traditional quality control practices. Conducted across seven residential projects in the Sangli district of Maharashtra, India, the research provides a representative evaluation of quality challenges in emerging urban contexts. A comprehensive analysis of 39 construction defect types identified water seepage (18.5%), non-structural cracks (16.2%), and plaster detachment (12.8%) as the dominant issues, collectively contributing to approximately 80% of total defects. The systematic application of the Six Sigma DMAIC process resulted in measurable improvement, achieving a 25% reduction in mean defect density post-intervention. This quantifiable enhancement reflects significant gains in process stability, workmanship quality, and defect prevention, validating the framework's practical effectiveness. The DMAIC methodology proved pivotal in achieving these outcomes. The Define and Measure phases established precise performance baselines, while the Analyze phase employed cause-and-effect techniques to isolate root causes related to workmanship, materials, and supervision. The Improve phase translated these analytical insights into targeted interventions, including enhanced inspections, worker training, standardized checklists, and stricter material quality verification.

The Control phase institutionalized these gains through continuous monitoring and feedback systems, ensuring sustained quality performance and reduced defect recurrence. This research contributes to the advancement of construction quality management in three key ways. First, it introduces a validated hybrid Six Sigma–traditional quality model tailored for residential construction, bridging the gap between analytical rigor and field practicality. Second, it empirically demonstrates the model's replicability and adaptability in a developing regional context. Third, it provides a structured, data-driven framework that facilitates proactive, continuous improvement transitioning the industry from reactive correction to preventive quality management. the implications of this research extend to multiple stakeholders. Developers and contractors benefit from measurable cost savings and improved efficiency through reduced rework, while policymakers gain a replicable model for standardizing quality benchmarks in the housing sector. By promoting durable, defect-free construction, the framework supports sustainable housing development and improved occupant satisfaction, aligning with long-term urban sustainability goals. While the results are promising, the study's focus on seven projects within the Sangli region limits the generalizability of specific defect patterns. Future research should expand this framework across varied project types, regions, and socio-economic conditions. Integrating advanced digital technologies such as Building Information Modeling (BIM), IoT-based defect tracking, and AI-driven predictive analytics can further enhance the precision and real-time responsiveness of construction quality control systems

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