Application of Six Sigma Methodology in Ethiopian Building Construction Projects: A case in Adama Andode Village Residential Building construction Projects

Genet Neguse Gezaw

A Thesis Submitted to the Department of Civil Engineering

College of Civil Engineering and Architecture

Presented in Partial Fulfilment of the Requirement for the Degree of Masters in Civil Engineering (Specialization in Construction Engineering and Management)

Office of Graduate Studies

Adama Science and Technology University

June, 2025

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DECLARATION

I hereby declare that this master thesis entitled **"Application of Six Sigma Methodology in Building Construction Sector: A Case in Adama Andode Village Residential Building Projects"** is my original work. That, it has not been submitted for the award of academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been dully acknowledged through citation. It is being submitted for the partial fulfilment of Master of Science in Construction Engineering and Management at Adama Science and Technology University College of Civil Engineering and Architecture.

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Name of student	Signature	Date

RECOMMENDATION

We, the advisors of this thesis, hereby certify that we have read the revised version of this thesis entitled **"Application of Six Sigma Methodologies in Building Construction Sectors: A Case in Adama Andode Village Residential Building Projects",** prepared under our guidance by Genet Neguse submitted in partial fulfilment of the requirement for the degree of masters of science in construction engineering and management. There for, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

______________________	______________	__________________
Major advisor	Signature	Date
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Co-advisor	Signature	Date

APPROVAL OF THE ADVISORS

We hereby certify that all the corrections and recommendations suggested by the board of examiners are incorporated in to the final thesis intitled **"Application of Six Sigma Methodology in Ethiopian Building Construction Sector: A Case in Adama Andode Village Residential Building Projects"** by Genet Neguse Gezaw.

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Co-advisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

We, the undersigned, member of the board of examiners of the thesis by Genet Neguse have read and evaluated the thesis entitled **"Application of Six Sigma Methodologies in Building Construction Sectors: A Case in Adama Andode Village Residential Building Projects"** and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of master of science in construction engineering and management.

Chairperson	Signature	Date
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Final approval and acceptance of the thesis is contingent up on submission of its final copy to the Office of Postgraduate Studies through the Department Graduate Council and School Graduate Committee.

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ACRONYM

DMAIC	Define, measure, analyze, improve and control
DMADV	Define, measure, analyze, design and validate
DPMO	Defect per million opportunity
FMEA	Failure mode and effect analysis
GDP	Gross domestic product
TQM	Total quality management
VSM	Value stream mapping

ABSTRACT

This study explores the application of Six Sigma methodology in Ethiopian building construction projects, with a specific focus on the Adama Andode Village residential building development. Despite global advancements in quality management, the Ethiopian construction sector continues to face persistent challenges related to defects, inefficiencies, and substandard project outcomes. To address these issues, this research applies the Six Sigma define, measure, analyze, improve, control framework to identify and reduce defects, improve process performance, and enhance construction quality. A mixed-methods approach was employed to collect and analyze data on construction defects before and after the implementation of improvement strategies. Results revealed a notable reduction in the total number of defects from 537 to 314 alongside an increase in yield by 12.47%. The calculated defects per million opportunities was 175,223.21, corresponding to a sigma level of approximately 2.46. While this demonstrates measurable improvements, the results remain below the industry benchmark of 3.0, signaling the need for continued process refinement. Further root cause analysis using fishbone diagrams identified key defect drivers such as inadequate supervision, poor communication, and weak management practices. These findings underscore the importance of addressing systemic organizational issues and enhancing stakeholder coordination. The framework developed is intended to guide contractors, consultants, and policymakers in systematically improving construction quality and reducing process inefficiencies. By integrating Six Sigma principles, the Ethiopian construction industry can advance toward achieving higher performance standards and sustainable project outcomes.

Key words: Building construction, Defect, Process improvement, Quality, Six sigma

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The construction industry is a cornerstone of economic development, playing a vital role in boosting national GDP and creating significant employment opportunities (Oladinrin et al., 2012). Despite its critical importance, the sector often grapples with inefficiencies, including cost overruns, delays, and quality defects (Bhuinyan et al., 2019). Attainment of acceptable levels of quality in construction has been a problem over the years (Ali & Wen, 2011). As a result, significant amount of resources both in terms of human resources and material are wasted each year (Ali & Wen, 2011). This greater wastage is mainly the result of insufficient and inefficient quality management procedures (Siddiqui et al., 2016) & (Stewart & Spencer, 2006). In response to these challenges, process improvement methodologies have gained prominence as tools for enhancing performance and ensuring sustainable growth.

Process improvement methodologies have been widely utilized across different industries to enhance efficiency and optimize performance (Aichouni et al., 2021). These process improvement methodologies include agile, lean manufacturing, six sigma, TQM, kaizen, kanban and 5s. Agile methodology is often applied to improve flexibility and adaptability in project management, while Lean Manufacturing focuses on eliminating non value adding activities to streamline workflows (Tenera & Pinto, 2014). Total Quality Management (TQM) fosters a culture of continuous improvement and customer satisfaction, as well as just in time ensures materials are delivered precisely when needed to minimize inventory costs (Lloréns-Montes & Molina, 2006). The Kaizen approach emphasizes incremental improvements through employee involvement. Methods like Process Mapping, Kanban, and the 5S framework target workflow visualization and workplace organization. Whereas Six Sigma is a data driven focus on defect reduction and process optimization using statistical tools to achieve near perfect quality. The increase in competition along with the never ending increase in demand for high quality is reportedly stressing construction practitioners to think out of the box (Siddiqui et al., 2016). Although each process improvement methodologies offer a unique strength, Six Sigma is the focus of this study as it has a quantifiable result of process improvement which makes it particularly effective for addressing process inefficiencies in construction industry.

Six sigma is a highly technical method used by engineers and statisticians to fine tune products, process & It is a goal near perfection in meeting customer requirement (Anbari & Kwak, 2004). Six Sigma is a statistical measure used to measure the performance of processes or products both qualitatively and quantitatively against customer requirements (Sui Pheng & Sze Hui, 2004). Six sigma is a business strategy that focuses on improving customer requirement by understanding business systems, productivity and financial performance. It is cultural belief system and management philosophy that guide the organization in repositioning itself towards world class business performance by increasing customer satisfaction considerably and enhancing bottom lines based on factual decision making (Sui Pheng & Sze Hui, 2004). The methodologies of Six Sigma are structured approaches designed to improve processes, eliminate defects, and enhance efficiency. The two primary Six Sigma methodologies are DMAIC and DMADV, which are applied based on the context of improvement or design. DMAIC is used for improving existing processes that are not meeting performance expectations while DMADV is used for designing new processes or products that meet customer requirements and achieve Six Sigma quality (Yilmaz, 2012). As the aim of this study improving the existing process in Adama, Ethiopian construction sector DMAIC methodology is used.

Process improvement using Six Sigma method should have four main advantages (Yilmaz, 2012): reducing of product cost (process cost), increasing the quality of final products, increasing the quantity of production and decreasing time taken by the process. This research focused on how six sigma can increase the quality of final product. However, its application and implementation in the construction industry, particularly in developing countries like Ethiopia haven't been explored. This research focuses on bridging this gap by assessing the integration of Six Sigma methodology into construction projects to address inefficiencies and defects. The study aims to assesses the application of Six Sigma in Andode village residential building construction project, with a specific focus on defects on HCB work and plastering work.

Efficient productivity in the construction industry, as defined by (Yilmaz, 2012), includes a consumer satisfying, sustainable and waste free final product. Although research and case studies over long years have shown some improvement, achieving this has been a challenge for the construction industry so far (Sui Pheng & Sze Hui, 2004). The construction industry is known to have a major impact on and provides the infrastructure of many other industries (Bhattarai, 2023). Therefore, any step forward in the construction industry results in a step forward in the associated businesses and industries depending on it (Bhattarai, 2023). For decades, and as mentioned before, inefficient handling of resources, pragmatic approaches to construction management and lack of systematic quality improvement methodologies specific to construction have continuously caused significant waste of a resource in the construction industry. (Siddiqui et al., 2016) further emphasize that the significant amount of material and human resource wastage within the nature of construction projects has lasted forever solely as a result of insufficient, inefficient and, in many cases non existent application of quality and process improvement management procedures. Increasing numbers of construction managers, academics and professionals have been storming the ramparts of conventional and traditional construction management methodologies in attempts to construct at a better value of money to owners while simultaneously maintaining profit and customer satisfaction (Yilmaz, 2012). To ensure this different research done in construction management strategies have resulted in many propositions such as just-in-time, lean construction, pull scheduling etc., are some more successful than others (Tenera & Pinto, 2014).

Most recently, one specific improvement strategy still undergoing research and relatively still in the concept phase is the integration of Six Sigma Principles as a quality initiative management strategy (Antony & Banuelas, 2002). Six Sigma based tools have emerged and have recently been applied to construction projects of varying complexities and sizes successfully (Dagne, 2023). As a general summary of what available literature provides on the benefits of Six Sigma in construction, real case studies show that projects implementing six sigma principles tend to be easier to manage, safer, more sustainable, cost less and most importantly, are of better quality (Coronado & Antony, 2002). Research studies tend to focus on six sigma as a quality improvement strategic methodology (Bhattarai, 2023). More efficient propagation is needed to allow for the increase in awareness to the effectiveness of six sigma and to enable construction firms to implement the methodology's principles willingly without worrying about potential risks that come with it (Bhattarai, 2023). From the perspective of a construction firm, survival in the industry and the potential to grow is not solely based on consumer satisfaction and quality of product delivery, it is actually more important to maintain project process performance and profitability (Anbari & Kwak, 2004).

1.2 Statement of the problem

The construction industry in Ethiopia faces persistent challenges related to cost overruns, quality and delay (Demissew & Abiy, 2023). Improving construction processes can lead to enhanced quality, which in turn can result in cost savings due to reduced rework and improved project outcomes (Times, 2021). Existing studies demonstrate the potential effect of six sigma methodology to significantly enhance process efficiency which leads to quality improvement and increase productivity time in various construction industries.

Chang et al., (2012) & Sui Pheng & Sze Hui, (2004) have applied Six Sigma to precast and plastering works of construction processes, achieving a reduction in production time and variability, proving its capability to streamline operations. These studies reveal Six Sigma's potential to transform construction processes through defect reduction & efficiency gains. However, there is a noticeable gap in understanding how Six Sigma can be systematically implemented in Ethiopia's construction industry, where inefficiencies, resource constraints and contextual challenges differ significantly from other countries. This study aims to address this gap by applying Six Sigma principles in Adama Andode village residential building project to assesses inefficiencies, calculate sigma levels and propose a framework for Six Sigma implementation in the Ethiopian construction industry.

1.3 Research question

1.What is the current level of defects and process inefficiencies in hollow concrete block (HCB) and internal plastering construction work?

2. How applicable and effective is six sigma methodology in improving the performance of construction projects in Ethiopia.

3. How can a tailored Six Sigma framework improve process efficiency?

1.4 Objective

1.4.1 General Objective

The general objective of this study is to investigate the application of Six Sigma methodology in Ethiopian building construction projects.

1.4.2 Specific Objectives

1. To assess the current defects level of process inefficiencies in HCB and internal plastering construction work.
2. To evaluate the applicability and effectiveness of Six Sigma methodologies in improving construction project performance.
3. To develop conceptual framework for implementing Six Sigma methodology in Ethiopian building construction sector.

1.5 Scope of the study

This research focuses on the application of Six Sigma methodology to enhance the quality products by minimizing defects in residential building project located in Andode Village, Adama, Ethiopia. The primary objective is to identify, analyze, and mitigate defects in the HCB and plastering work process, thereby improving overall construction quality and customer satisfaction. So the study is geographically limited to Adama in order to get different blocks done with the same budget and resource at one place which makes it more comfortable for six sigma implementations.

The study employed the DMAIC methodology to systematically assess the current HCB and Plastering work, quantify defects, determine root causes, implement improvements, and establish control measures to sustain quality enhancements but not included the DMAIV methodology. The research is limited to HCB and plastering work out of different work process in building construction due to time limitation of the research and also out of different phases in building it is limited to the construction phase.

1.6 Significance of the study

The research would contribute to the academic and practical understanding of Six Sigma's relevance and benefits in building construction projects of Ethiopia. The study demonstrates how implementing Six Sigma principles can lead to significant defect reduction and reducing waste, rework, and delays. This can benefit contractors, clients and End users in terms of reduced project costs and faster delivery. By developing a Six Sigma based framework tailored to the Ethiopian construction sector, the research provides stakeholders with tools to measure and manage construction processes more effectively, ensuring consistent quality and improved performance. This research would give direction for the future researchers on this area as the research touches the location that is better to be studied.

1.7 Organizational structure of the study

The study has five chapters as follows. Chapter 1- This chapter provides the introduction of the study, the statement of the problem, research objectives, research questions, scope & significance of the study. Chapter 2**:** This chapter reviews relevant literature on Six Sigma and its application in construction projects. Chapter 3: This chapter outlines the research design, data collection methods, and analysis techniques. Chapter 4**:** This chapter presents the result of an analysis of process inefficiencies, defects per million opportunities (DPMO), the calculated sigma level, critical defects through Pareto analysis, explores root causes using a Fishbone diagram, and evaluates the financial impact of rework. Chapter 5**:** Conclusion and Recommendations, This chapter summarizes the study's findings and highlights its contributions to the construction industry. It provides actionable recommendations for stakeholders to adopt Six Sigma methodology and suggests areas for future research to further enhance process efficiency and quality management in the Ethiopian construction sector.

CHAPTER TWO

LITERATURE REVIEW

2.1 Six Sigma

2.1.1 Definition of Six Sigma

Six Sigma is a methodology that provides businesses with the tools to improve the capability of business processes (Yang & Basem El-Haik, 2016). In Six Sigma, the purpose of method enhancement is to augment performance and minimize performance fluctuation (Coronado & Antony, 2002). This rise in performance and reduction in method variability leads to error minimization and improvement in profit. The title "Six Sigma" stems from statistical terms; Sigma (σ) signifies standard deviation. For normal distribution, the probability of falling within a ±6 sigma range around the mean is 0.9999966 (Yang & Basem El-Haik, 2016). In a production method, the six sigma means that the faultiness rate of the method will be 3.4 errors per million units (Tchidi et al., 2012). Clearly Six Sigma indicates a degree of extremely high consistency and extremely low variability (Bhattarai, 2023). In statistical terms, the purpose of Six Sigma is to reduce variation to achieve very small standard deviations (Yang & Basem El-Haik, 2016).

Compared with other quality initiatives, the key difference of Six Sigma is that it applies not only to product quality but also to all aspects of business operation by improving key process (Yang & Basem El-Haik, 2016). For example, Six Sigma may help to develop well designed, highly reliable, and consistent customer billing systems, cost control systems and project management systems (Swami & Kadiwal, 2020). This shows six sigma can extend the scope of quality from the product quality alone to the quality of all aspects of business operation. Therefore, the Do the right things & do things right all the time strategy have to be applied in construction industry and it is an approach for business excellence (Yang & Basem El-Haik, 2016).

Six sigma is a project driven management approach to improve the organization's products, services, and processes by continually reducing defects in the organization (Heon Han et al., 2008). It is a business strategy that focuses on improving customer requirements understanding, business systems, productivity, and financial performance (Coronado & Antony, 2002). Dating back to the mid1980s, applications of the six sigma methods allowed many organizations to sustain their competitive advantage by integrating their knowledge of the process with statistics, engineering, and project management (Kwak & Anbari, 2006). The technical concept of Six Sigma is to measure current performance and to determine how many sigma exists which is measured from the current average before customer dissatisfaction occurs (Bhattarai, 2023). When customer dissatisfaction occurs, a defect is defined as any event that does not meet the requirements (Sui Pheng & Sze Hui, 2004).

2.1.2 The Evolution of Six Sigma

Six sigma was initially ignited by Motorola in 1998 as a six step quality improvement technique and has recently evolved to become a game-changing quality management methodology (Sui Pheng & Sze Hui, 2004) & (Yang & Basem El-Haik, 2016). Some early research has defined the phenomenon as a business strategy with the goal of enhancing customer satisfaction, increasing productivity and, hence overall performance of the organization (Kwak & Anbari, 2006). As a history records, six sigma can be traced all the way back to Carl Friedrich Gauss in 1809 where the phenomenon of the normal curve was initiated (Linderman et al., 2003). More than a century later, in the early 1930s, Walter Shewhart proved that three sigma from any mean defines a point where a process or processes requires rectification (Morales et al., 2016). As mentioned before, by 1998 Motorola was using six sigma as a quality initiative business strategy to change the culture of the business in order to enable higher quality output, expansion of employee's skills and reduce errors and anomalies in work processes (Bhattarai, 2023). Six sigma was also used in and is currently still being used in the American, multinational electronic provider corporation, General Electric (Henderson & Evans, 2000). Six sigma executioners can become qualified experts who are specifically trained in applying its principles to multiple disciplines. The eventually become qualified enough to be called six sigma black belts (Yang & Basem El-Haik, 2016). These experts are knowledgeable to the use of measurement analysis, analysis of variance, supply chain management and many more (Stewart & Spencer, 2006).

Six Sigma is the quickest growing business administration system in industry today. It has been credited with conserving billions of dollars for companies since the early 1990s. Devised by Motorola in the mid-1980s, the technique became well known only after Jack Welch from GE made it a central focus of his business plan in 1995 (Yang & Basem El-Haik, 2016). After these achievements, many books and papers have been published. Some of these studies defined Six Sigma regarding their own perspectives: "A disciplined method of using extremely rigorous data gathering and statistical analysis to pinpoint sources of errors and ways of eliminating them" (Kaming et al., 1997). "A strategic approach that works across all processes, products, company functions and industries"(Snee, 2000). "A business strategy and a systematic methodology, use of which leads to break through quantum gains in product/service quality, customer satisfaction and productivity"(Coronado & Antony, 2002).

"A business strategy that focuses on improving customer requirements understanding, business systems, productivity, and financial performance" (Anbari & Kwak, 2004). "A cultural and belief system and a management philosophy that guide the organization in repositioning itself towards world class business performance by increasing customer satisfaction considerably and enhancing bottom lines based on factual decision making" (Sui Pheng & Sze Hui, 2004). "A business strategy with the goal of enhancing customer satisfaction, increasing productivity and, hence, overall performance of the organization" (Kwak & Anbari, 2006).

Six Sigma originally associated with manufacturing industry is increasingly welcomed in construction industry due to the alarming under performance of construction especially in developing countries (Henderson & Evans, 2000) along with that the increasing quality demand is also stressing construction practitioners to think out of the box (Chin et al., 2024). This drives the research for implementation of Six Sigma in construction. In the construction industry, the use of Six Sigma principle for performance assessments, particularly aimed at high quality and variability control, first appeared when Buggie introduced the Six Sigma principle as one of the approaches to augmenting productivity by reducing defects or errors engaged in the processes (Thomas et al., 2009). (Hussain et al., 2019) explained how Six Sigma and lean principles can be combined and used in a beneficial way to achieve outstanding performance. Six Sigma was also implemented in construction sector to update the process of neutralizing chemical agents, in national telecommunication projects to help enhance the administration of schedules and cost (Tenera & Pinto, 2014). Bechtel Corporation reported saving a handsome amount by using Six Sigma program to identify and prevent rework and defects from design to construction (Kwak & Anbari, 2006). For the construction sector, Six Sigma techniques are not about being thorough or having all procedures and items at Six Sigma levels of execution (Linderman et al., 2003), but they aim at improving the processes resulting into cost reduction. (Ã, 2009) have pointed out that the target of Six Sigma is to create a higher supposed value of the services of company in the eyes of customers.

2.1.3 Six Sigma Methodologies

Six Sigma is a methodology for enhancing process efficiency across various industries, including construction management. It operates on a disciplined framework known as DMAIC (Define, Measure, Analyze, Improve, Control), which uses a structured process to ensure specific deliverables before progressing. Unlike traditional quality programs focused on error detection, Six Sigma emphasizes reducing process variability to eliminate defects proactively, achieving up to 3.4 defects per million opportunities (DPMO). It is both a business strategy aimed at profitability and customer satisfaction and a statistical concept of minimizing process variation (Stewart & Spencer, 2006).

According to (Anbari & Kwak, 2004) & (Shibani et al., 2021), Six Sigma has two key methods. DMAIC process (Define, measure, analyze, improve, control) & DFSS methodology (Design for Six Sigma). DMAIC is for improving existing processes which requires significant improvement for being below expected quality specification. DFSS as a systematic methodology is for designing new products and/or process at Six Sigma quality levels (Kwak & Anbari, 2006). DMAIC methodology and its main steps are explained and summarized below as stated by (Yilmaz, 2012), (Kwak & Anbari, 2006), (Anbari & Kwak, 2004), (Samman & Graham, 2007), (Ugr & Canatan, 2015), (Siddiqui et al., 2016) & (Shibani et al., 2021).

Define -is for team forming, determining the responsibilities of team members, establishing team goals and review the process steps (Morales et al., 2016). In this phase, customer needs, requirements, standards are identified in accordance to the unsatisfactory performance (Henderson & Evans, 2000). A few questions are answered in this phase: What is the problem, Who is involved and what are the requirements? (Shibani et al., 2021) & (Yilmaz, 2012)

Measure, second stage of DMAIC, is for having a plan for data collection, preparing a sufficient data sample and preliminary analysis of this sample (Shibani et al., 2021). In this stage, Six Sigma team analyzes current performance through valid data in order to understand improvement opportunities and identify KPIV (Key process input variables) (Yang & Basem El-Haik, 2016). It includes measurement of the current performance of the process and the collection of all relevant data for the process (Shibani et al., 2021) & (Yilmaz, 2012)

Analyze, thirds stages of DMAIC is for finding the root causes of defects, right approach styles to data and improvement opportunities (Andersson & Pardillo-Baez, 2020). The root cause of the problem is identified through the creation of cause and effect diagrams and fishbone diagram (Yang & Basem El-Haik, 2016). Defects per million Opportunities (DPMO) are calculated and the current sigma performance level is revealed (Shibani et al., 2021). A new target performance level is set and possible solutions are then listed (Yilmaz, 2012).

Improve, fourth stages of DMAIC, is for designing, implementing and validating the improvements (Shibani et al., 2021). This stage includes FMEA (Failure Mode and Effect Analysis), a preliminary cost/benefit analysis and preparation of necessary actions. In the improve phase, cost/benefit analysis is performed to facilitate a final improvement solution which is then implemented so that the process's performance satisfies the performance requirement(Samman & Graham, 2007).

Control, last stage of DMAIC, is for the institutionalization of process/product improvements and following performance (Shibani et al., 2021). This is a transition phase of process from Six Sigma team to original executers under detailed control plan (Yang & Basem El-Haik, 2016). the improvement is maintained to ensure the gains in performance remain in the long term(Samman & Graham, 2007).

DFSS is a method more than a universal methodology and is used for designing and redesigning processes and has no universally acknowledged procedure for implementation (Shibani et al., 2021). A logic explanation for this would that nearly every organization designs and redesigns in a unique way to meet company requirements and follow company policies (Samman & Graham, 2007). DFSS can be successful on new products/process developments and meet customer expectations for performance, quality, reliability and cost (Dagne, 2023).

2.1.5 Statistical Theory Behind Six Sigma

Six Sigma metrics measures defects rate without considering the complexity of the products and processes (Oguz et al., 2012). Sigma concept as an international quality measurement technique was started by Motorola and better processes with few defects rates have higher sigma values (Pheng and Hui, 2004). Table 2.1 shows the conversion of six sigma from calculated DPMO (Yilmaz, 2012) and (Sui Pheng & Sze Hui, 2004)

Table 2.1 Six sigma conversion table

Basic sigma conversion table		
Yield=Percentage of items without defects	Defects per million opportunities (DPMO)	Sigma Level
30.9	690 000	1
69.2	380 000	2
93.3	66 800	3
99.4	6 210	4
99.98	320	5
99,9997	3.4	6

For example; three sigma level means that product satisfies requirements at 93.3% of the time and products numbers with defects are 66800.

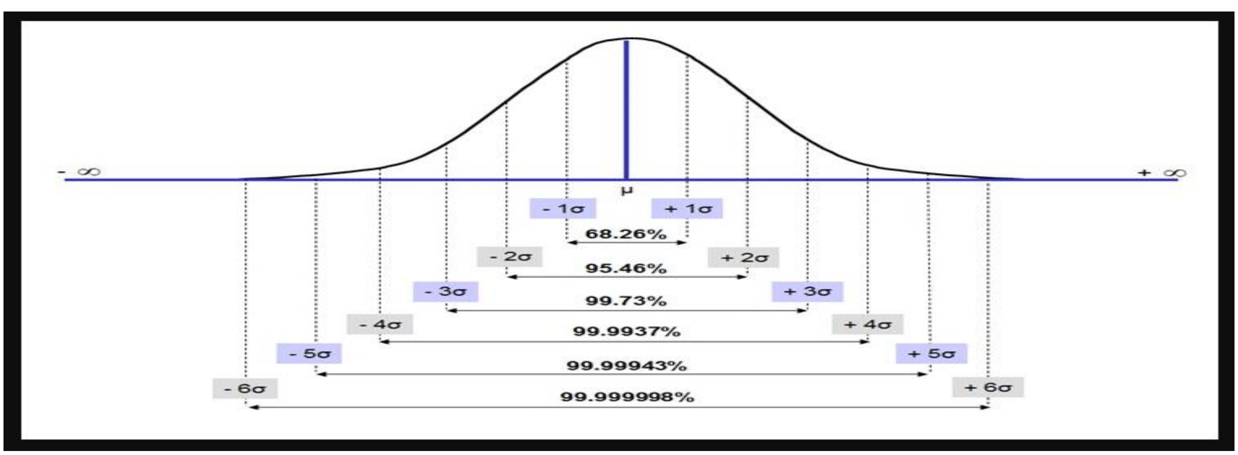

Figure 2.1 Six sigma bell curve

The symmetrical bell shaped normal distribution curve, derived by mathematician Carl Friedrich gauss what six sigma is based on the curve represents the component at measure (product, process etc.), or in statistical terms, represents the whole population by the infinite series of segments in both directions (Yang & Basem El-Haik, 2016). The inflexion point in the curve marks the mean (μ) of the population and each segment is called sigma and represents a deviation from the mean (Dagne, 2023). Although the graph continues to infinity on both sides, usual representations of this graph only show the area between -6σ and +6σ (Ugr & Canatan, 2015). On the other hand, using 6σ is much more effective as it covers 99.9997% data meaning only 0.0003% of the data are out of range (Yilmaz, 2012). Figure 1 shows that with 3σ being customer specification, there is a 31% probability that customer requirements will not be satisfied with a defect rate of 308,000 defects per million defect opportunities (DPMO) whereas with six sigma this percentage is reduced to 0.00033% with only 3.4 DPMO.

2.1.6 Process improvement by Six Sigma

Six Sigma is a technique centered on processes for enhancement. The main characteristic is enhancing a single process at a time. The process in this context can be a manufacturing system, a client invoicing system, or the product itself (Yang & Basem El-Haik, 2016). Researchers describes it as an ongoing sequence of activities, occurring or conducted in a specific manner, and resulting in the completion of a certain outcome; a continuous operation or set of operations (Yang & Basem El-Haik, 2016). It can be also defined as a chain of actions that takes an input, adds worth to it, and generates an output for a client or generates a valuable product.

The aim of process improvement in construction is to produce something of equal or better worth, at a lower cost (Mohamed Hassan et al., 2023). In the procurement of projects, leading clients are increasingly demanding a high quality product at a low cost, which is also reliable and delivered on the date required (Bhuinyan et al., 2019). The major feature of construction processes is that they are notorious for their complexity and changes during the construction process (Stewart & Spencer, 2006). The absence of clear guidelines as meant that improvements are often isolated and benefits cannot be coordinated or repeated (Ugr & Canatan, 2015). Industry's inability to assess construction processes, prioritize process improvements and direct resources appropriately (Bhuinyan et al., 2019). Subsequently, the concept of process improvement varies for construction firms, unlike in manufacturing, where variation can be eliminated because the standards by which it is measured are themselves invariant (Yang & Basem El-Haik, 2016). In construction, clients inevitably have variability in their requirements; consequently variation cannot be totally eliminated, but it can be managed (Stewart & Spencer, 2006). Six Sigma, derived from TQM and SPC, combines data driven methods with a structured framework, making it more effective for addressing process variability and improving efficiency in dynamic industries like construction (Lloréns-Montes & Molina, 2006). Among these, Six Sigma is highlighted as the most adaptable and impactful approach for achieving process improvement in complex environments (Stewart & Spencer, 2006).

Process improvement or continuous improvement process (CIP), is the practice of optimizing existing business processes to meet the current industry standards and improve customer satisfaction (Henderson & Evans, 2000). Which means the aims of process improvement is identifying, analyzing, and improving workflows. Processes can either be modified or complemented with sub processes, or even eliminated for the ultimate goal of improvement (i.e., minimizing errors, reducing waste, improving productivity, and streamlining efficiency) (Bhuinyan et al., 2019). The common methodology types for process improvement are- Agile methodology, Six sigma, Lean manufacturing, Total quality management (TQM), Just in time, Kaizen, Process mapping, Kanban & 5S method (Stewart & Spencer, 2006).

Process improvement methodologies have been widely utilized across industries to enhance efficiency, reduce waste, and optimize performance. Agile methodology is often applied to improve flexibility and adaptability in project management, while Lean Manufacturing focuses on eliminating non-value-adding activities to streamline workflows. Total Quality Management (TQM) fosters a culture of continuous improvement and customer satisfaction, whereas Just-in-Time ensures materials are delivered precisely when needed to minimize inventory costs. The Kaizen approach emphasizes incremental improvements through employee involvement, and the PDCA (Plan-Do-Check-Act) model is used for iterative problem-solving. Similarly, methods like Process Mapping, Kanban, and the 5S framework target workflow visualization and workplace organization. Tools such as SIPOC analysis and Value Stream Mapping (VSM) provide detailed insights into processes, helping identify bottlenecks and inefficiencies. However, Six Sigma stands out with its data-driven focus on defect reduction and process optimization, using statistical tools to achieve near perfect quality. Each methodology offers unique strengths, yet Six Sigma's systematic approach and quantifiable results make it particularly effective for addressing inefficiencies in complex industries like construction. As referred different research on six sigma its difference from other process improvement techniques is summarized in the Table 2.2 below (Siddiqui et al., 2016), (Andersson & Pardillo-Baez, 2020), (Yilmaz, 2012), (Anbari & Kwak, 2004) &(Yang & Basem El-Haik, 2016) shows the comparison of six sigma with traditional process improvement techniques.

Table 2.2 Comparison of six sigma with other process improvement techniques

Aspect	Traditional approach	Six sigma approach
Deciding	Trial and error	Resistant design
Analysis	Experience	Data
Focus	Product	Process
Time	Reactive	Proactive
Planning	Short term	Long term
Control	External control	Self control
Employee relation	Low confidence personal management	high confidence, human resource management

2.2 Defects and Rework challenges in Building construction projects

Building is essential to human life, providing shelter and supporting various social, economic, religious, and recreational activities. In today's world, it is difficult to imagine life without buildings. To accommodate different needs and ensure user safety, countries implement distinct building construction policies and regulations (Imafidon & Ogbu, 2020). Construction process involves multiple stages, including initial preparation and conceptual design, design development, technical detailing, on-site construction, project handover, and eventual usage. Every phase of building planning, from architectural design to construction and maintenance, requires thorough supervision and high-quality input from professionals and stakeholders in the construction industry (Messay et al., 2021).

A defect is any deviation from the required standard, specification, or quality in a product, service, or process. In construction, defects refer to flaws, errors, or imperfections in materials, workmanship, or design that affect the performance, durability, or safety of a structure. Construction defects often arise during the execution of construction activities and are linked to various challenges encountered throughout the process (Njonge, 2023). Studies indicate that such issues contribute to approximately 95% of all reported defects, highlighting the importance of addressing and minimizing them to enhance construction efficiency and achieve better financial results (Njonge, 2023). Among these defects, improper installation is the most prevalent, accounting for 24.29% of total construction errors (Forcada et al., 2016) .Construction defects are generally defined as faults in materials, systems, or workmanship that compromise a building's intended functionality and performance (Gatlin, 2013). Improper installation occurs when materials, components, or systems are incorrectly positioned or fail to meet project specifications, leading to structural deficiencies and reduced performance (Forcada et al., 2016); (Ahzahar et al., 2011).

2.2.1 Overview & Definition of Construction Defects

A construction defect is a flaw in the building process (design, materials, or workmanship) that results in a failure of the structure, causing harm to people or property. The problem originates from poor design, faulty materials, or improper workmanship. The deficiency leads to a breakdown or malfunction in the built structure. The failure causes harm, which can be physical injury, property damage, or financial loss. Defects can range from minor issues (not meeting expectations) to major problems (structural flaws). The consequences of a defect depend on its cause and severity. Construction defects are a common challenge in the industry, often reducing a structure’s overall value. Addressing these defects in a timely manner ensures that projects are completed on schedule (Njonge, 2023). Proper classification of construction defects is essential for their accurate identification and prevention, particularly in residential buildings. Identifying the sources and categorizing defects is the first step toward effective mitigation. Understanding how defects arise allows for the development of targeted prevention strategies (Ali & Wen, 2011). Therefore, categorizing construction defects is crucial, not only by type but also based on performance indicators (Bhattarai, 2023).

Construction projects often have flaws, ranging from small, harmless issues to serious defects that can endanger people or property. The difficulty is that these problems usually surface after the work is finished. Whether the defect is big or small, dealing with these claims is always complex and costly. Construction defects refer to any flaws arising from deficiencies in design, planning, supervision, inspection, or execution that result in substandard work or prevent the structure from functioning as expected (Njonge, 2023). Several classification methods exist, including categorization based on severity, construction phase, defect type, and cause (Forcada et al., 2016).

Construction defects are increasingly prevalent, particularly in projects with inadequate management and supervision. These defects diminish a building's value and lead to significant rework costs. Common causes include faulty design, substandard workmanship, deviations from the design plans, unforeseen environmental factors, and poor oversight. Beyond lowering property value, defects can cause project delays and cost overruns, impacting the project's timeline and budget (Nawade et al., 2022). Construction defects have significant repercussions beyond individual projects. They pose safety risks to the public, leading to direct repair costs, increased maintenance expenses, disputes, and even building loss. These defects drive up overall building costs, regardless of who bears the financial burden, and can even result in structural collapse. While the construction industry is advancing with technology, defects still severely hinder project success, negatively impacting budgets, timelines, productivity, sustainability, and ultimately, customer satisfaction (Nawade et al., 2022).

2.2.2 Classification of Construction Defects in Buildings

Research findings indicate that most defects occurring during construction are technical in nature. Several studies have classified construction defects based on their source or impact. For instance, according to (Njonge, 2023), grouped defects into eight categories according to their causes: water-related issues, surface appearance problems, fractured elements, abrasion, separation, improper fitting, missing components, and surface cracks. Other studies have identified defects related to materials, design, and geotechnical conditions. (Ali & Wen, 2011) categorized defects into seven groups, including technological implementation issues, structural component defects, and construction technology utilization. Furthermore, classifying defects based on different construction phases has been widely accepted in studies conducted by (Ali & Wen, 2011). According to (Nawade et al., 2022) types of defects are classified as structural defect, material defects, workmanship defects, electrical defects, plumbing defects, supervision defect & design defects.

One approach to categorizing construction defects is based on time of occurrence when they become apparent. Two main types in this classification are latent and patent defects (Njonge, 2023).

2.2.2.1 Patent Defects

Patent defects are flaws in a structure that can be identified during or shortly after construction, typically before or during the defect liability period. These defects, often caused by construction workers, are visible and easily detectable (Act, 1990). Examples include cracks in building exteriors, stairways lacking railings, window fractures, water leaks, and electrical or plumbing issues. Because construction undergoes regular inspections, patent defects are frequently addressed during the building process.

Contractors are responsible for identifying and rectifying patent defects as they arise. However, clients also have a contractual obligation to report defects, ensuring they are repaired within a reasonable period. Any patent defects identified during inspections or within the defect liability period must be corrected by the contractor (Garg & Misra, 2021). Due to the frequent inspections conducted during construction, these defects are identified and addressed more often. While contractors are generally responsible for detecting and fixing defects as they progress with the work, the client also has a contractual obligation to notify the contractor of any issues (Njonge, 2023). Upon notification, the contractor is expected to rectify the defect within a reasonable period. Additionally, contractors are usually required to repair any patent defects found during construction and must complete these corrections within the specified defect liability timeframe (Act, 1990)

2.2.2.2 Latent defect

Latent defects are hidden flaws in construction that may remain undetected for many years. These defects often become noticeable only after damage has already occurred due to construction activities (Njonge, 2023). Similarly, they are typically identified through in depth investigations into their specific effects. latent defects refer to concealed faults that only become apparent once a building is in use. Addressing latent defects in construction is particularly challenging, as most issues emerge during the occupancy phase. Additionally, collecting data on these defects in occupied buildings can be difficult. Design errors are a primary cause of latent defects, and they can be mitigated by improving the design process (Act, 1990). These defects often go u nnoticed by the general public unless they are severe enough to prompt residents to report them to authorities. Various factors, such as design errors, contribute to latent defects in residential structures. Since these defects may not become evident until long after project completion beyond the defect liability period.

Research has also been conducted on measuring defects and inefficiencies in construction. A study by (Yarnold et al., 2023) used six sigma tools, particularly DPMO and Pareto Analysis, to identify the most frequent construction defects in structural, architectural, and mechanical works. Their findings showed that poor workmanship and inadequate supervision were the primary causes of rework. Different researches have implemented Six Sigma in a high rise building project, where Fishbone diagrams were used to determine root causes of inefficiencies, including poor material handling and labor productivity issues. These studies provide empirical evidence that Six Sigma tools can effectively analyze and address construction inefficiencies. Despite these contributions, most studies have focused on general construction defects without considering Ethiopian construction projects unique challenges. Therefore, further empirical investigation is required to apply these methodologies in Ethiopian construction sector.

Rework is one of the major cost drivers in construction projects, and several empirical studies have quantified its financial impact. (Love et al., 2011)conducted a cost analysis of rework in construction projects, finding that rework accounts for 5-15% of total project costs. Their study utilized historical project data and Six Sigma cost estimation techniques to determine the financial burden of inefficiencies.

2.3 Application and Effectiveness of Six Sigma in Building Construction Industry

The increase in competition along with the never ending increase in demand for high quality is reportedly stressing construction practitioners to think out of the box (Siddiqui et al., 2016). In light of this, there exists research regarding the implementation of six sigma principles within the construction industry (Swami & Kadiwal, 2020). Buggie, was the first to introduce the six sigma ideology for the construction industry where he proposed that implementing it could allow the organizations within the industry to perform assessments which aid in controlling quality and reduce variability, which are two issues nearly every construction project in the world encounters (Chang et al., 2012). Bechtel, one of the largest construction and civil engineering firm in the United States, reported saving of eye watering amounts of money due to the use of a program designed in accordance to six sigma principles which aided in the avoidance of rework, defects and errors from initial design phases to final construction phase (Kwak & Anbari, 2006). A case study on the implementation process of a Six Sigma program by the Housing and Development Board of Singapore has presented, Improvement measures taken by a contractor helped to raise the sigma from 2.66s to 3.95s for quality of internal finishes (Sui Pheng & Sze Hui, 2004). This is not a small number of defect, it is improved from 148,995 DPMO to 9,240 DPMO.

According to (Mohamed Hassan et al., 2023) construction industry is often considered high risk due to its complexity and strategic importance. It involves numerous internal and external stakeholders, creating an environment filled with potential hazards. Compared to other sectors, construction has a weaker reputation for risk analysis, as very few projects are entirely risk free. A project is deemed successful when it is completed on schedule and within budget. However, cost adjustments and overruns are common in infrastructure projects. According to Indians Ministry of Statistics and Program implementation (MOSPI) monitors infrastructure projects valued at over 225 billion birr. Out of 1,670 projects, 432 experienced cost overruns. The initial estimated cost for these projects was 30,872,899.89M birr, but the final expenditure is projected to reach 39,309,899.5M birr. This reflects an overall cost increase of 6,436,999.62M birr, accounting for the increase of 20.85% of the initial budget. Project execution involves multiple phases, including conception, planning, construction, handover, utilization, and closure. This study primarily examines risk assessment throughout the project's lifecycle.

Six Sigma is used to increase sustainability, productivity, and project quality, and decrease life cycle cost, manage project delays, and reduce waste (Siddiqui et al., 2016). Over the last decades, improving environmental quality and productivity and reducing waste have been considered challenges in the construction industry (Taner, 2013). Furthermore, high productivity has been recognized as a driving force towards increasing the competitive advantage of business organization (Hussain et al., 2019). Six Sigma recognizes that business quality is the highest when costs of delivering products and services to meet customer requirements are at the absolute lowest for both the producer and the consumer (Taner, 2013)

Six Sigma has been considered as a powerful business strategy that employs a well structured continuous improvement methodology to reduce process variability and drive out waste within the business process using effective application of statistical tools and techniques. It is a quality philosophy at the highest level, relating to all processes, and a quality measure at the lowest level (Stewart & Spencer, 2006). Its programs improve operational performance in order to enhance customer satisfaction with a company's product and services (Yang & Basem El-Haik, 2016). The objective of Six Sigma programs is to create a higher perceived value of the company's product and services in the eyes of customers (Meadows, 1990). Six Sigma programs have performance metrics and measurements based on cost, quality, and schedules (Tchidi et al., 2012). Companies with profitable Six Sigma strategies are successful because they maintain effective infrastructures for selecting, supporting and executing projects (Yilmaz, 2012). They do so by thinking of their infrastructures as ongoing processes that are continually improved and revisited through executive planning (Meadows, 1990).

Six sigma's structured and systematic framework, combined with the employment of statistical techniques, makes it an excellent tool for process diagnostics, which is an integral task of modern construction managers (Stewart & Spencer, 2006). The methodology has led to significant improvements in the manufacturing sector and it is believed that it should also assist construction firms to deliver projects on time, at the right cost and of superior quality (Love et al., 2011). (Linderman et al., 2003) proposed that unlike the manufacturing industry, where six sigma techniques require thoroughness and full adherence to its technicalities in all processes of production, the construction industry needs only to apply six sigma principles where process improvements will see reductions in costs and increased quality. In other words, since the nature of the industry provides for the motive of reducing costs to increase profitability, implementing six sigma principles would be most effective in improving the performance of processes which are cost demanding (Linderman et al., 2003).

In construction and engineering, Six Sigma adapts to the sector's unique needs by not striving for defect free processes universally but prioritizing improvements based on the strategic importance of processes and their cost benefit balance. The methodology requires top down implementation, involving experts known as "black belts" trained in techniques like process mapping, measurement analysis, and supply chain management. These leaders drive process improvement projects by applying Six Sigma principles to address sector specific challenges and enhance operational efficiency (Stewart & Spencer, 2006). The versatility of Six Sigma lies in its adaptability to different industries while maintaining its core principles of data driven improvement. For the construction sector, it provides a systematic approach to process optimization without necessarily adhering strictly to manufacturing level defect standards, ensuring practical and cost effective application.

Six Sigma is used to increase sustainability, productivity, and project quality, and decrease life cycle cost, manage project delays, and reduce waste (Schroeder et al., 2008). Over the last decades, improving environmental quality and productivity and reducing waste have been considered challenges in the construction industry (Yang & Basem El-Haik, 2016). Furthermore, high productivity has been recognized as a driving force towards increasing the competitive advantage of business organization (Hussain et al., 2019). The purpose of project quality management is to ensure that the project meets its requirements by applying the theories of Six Sigma, which does not consists not having defect, but pursues the perfection (Chang et al., 2012). It has a fixed position, a production flow, various structures, various quality requirements, various construction methods, high integrity and long construction cycle (Tchidi et al., 2012).

Six Sigma recognizes that business quality is the highest when costs of delivering products and services to meet customer requirements are at the absolute lowest for both the producer and the consumer (Ugr & Canatan, 2015). For the construction sector, Six Sigma improvement methods are not about being totally defect free or having all processes and products at Six Sigma levels of performance (Schroeder et al., 2008). Instead, the appropriate level will depend on the strategic importance of the process and the cost of its improvement relative to the benefit (Yang &

Basem El-Haik, 2016). The objective of Six Sigma is to create a higher perceived value of the company's products and services in the eyes of customers. Essential features of Six Sigma include a clear set of objectives for the delivery process, aimed at maximizing performance for the customer at the project level, concurrent design, construction and the application of project control throughout the life cycle of the project from design to delivery (Swami & Kadiwal, 2020).

2.3.1 Implementation of six sigma in construction industry

Several studies have examined the application of Six Sigma in construction process management. (Rodgers & Antony, 2019) conducted a case study on Six Sigma's impact on quality control and waste reduction in construction projects, showing that defining critical defects and applying the DMAIC (Define, Measure, Analyze, Improve, Control) framework led to a 35% reduction in defects. Similarly, (Andersson & Pardillo-Baez, 2020) analyzed Six Sigma applications in building construction processes, highlighting its role in minimizing process inefficiencies and rework costs. However, these studies primarily focused on Six Sigma applications in developed economies with well established quality management systems, leaving a gap in research on developing countries like Ethiopia, where construction inefficiencies are prevalent. For the implementation of six sigma the following points should be followed.

Create and Agree on Strategic Business Objectives: This initial step sets the foundation for the entire Six Sigma initiative. It involves aligning Six Sigma goals with the organization's overall strategic objectives. Agreement among key stakeholders is crucial to ensure buy in and commitment. Essentially, what are the goals of the company, and how will six sigma help achieve them?

Identify Key Customers, Core, Key Sub and Enabling Processes, and Owners of These Processes: This step focuses on understanding the organization's ecosystem. Key customers, Core processes, Key sub-processes, Enabling processes & Process owners. By defining these elements, the organization gains clarity on where to focus its improvement efforts.

Define Customer Requirements: This step emphasizes the importance of understanding customer needs and expectations. It involves gathering data on customer requirements, such as quality, delivery, and cost. These requirements serve as the basis for measuring process performance and identifying areas for improvement. What does the customer consider a quality product or service?

Measure Current Performance: This step involves collecting data on the current performance of the identified processes. Metrics are used to quantify process performance and identify areas of variability and defects. This data provides a baseline for measuring the impact of improvement efforts. How well are the processes performing now?

Prioritize, Analyze, and Implement Improvements: This step involves analyzing the data collected in the previous step to identify root causes of problems. Prioritization is essential to focus on the most critical issues. Improvement solutions are developed and implemented, and their effectiveness is monitored. This is the meat of the six sigma process. Using data to make changes that improve the process.

Expand and Integrate the Six Sigma System: This step focuses on institutionalizing Six Sigma within the organization. It involves expanding the use of Six Sigma to other processes and departments. Integration with existing management systems ensures sustainability and continuous improvement. Make the six sigma process a part of the company culture.

2.3.2 Key factors for implementing a successful six sigma program

According to (Antony & Banuelas, 2002) and (Coronado & Antony, 2002), the successful implementation of a Six Sigma program hinges upon several key factors. Paramount among these is strong management commitment and active involvement, which are essential for driving the initiative forward. Equally important is a comprehensive understanding of Six Sigma methodology, tools, and techniques among organizational members. Furthermore, aligning Six Sigma initiatives with the broader business strategy and ensuring they are customer-focused are crucial for their effectiveness. The process of selecting appropriate projects, conducting regular reviews, and monitoring progress also plays a vital role. Establishing a robust organizational infrastructure and fostering a culture conducive to change are necessary for sustained success. Additionally, developing project management skills within the organization and integrating Six Sigma practices with suppliers can enhance overall performance. Training and development are fundamental to build internal expertise, while linking Six Sigma initiatives with human resource strategies ensures ongoing support and alignment. (Kwak & Anbari, 2006) further emphasize the importance of sustained and visible management commitment, continuous education and training for managers and team members, and setting clear expectations. They also highlight the significance of carefully selecting project leaders based on their leadership capabilities and choosing strategically important projects to maximize impact.

Successful Six Sigma implementation relies on several key elements (Dagne, 2023), (Anbari & Kwak, 2004), and (Schroeder et al., 2008). Management commitment and active involvement are essential, as demonstrated by leaders like Jack Welch at General Electric, who helped reshape attitudes and allocate resources. Establishing a strong organizational infrastructure with well-trained personnel is also crucial. Projects should be carefully selected based on feasibility, customer focus, and potential organizational and financial benefits, with ongoing reviews to track progress and lessons learned. Cultivating a culture open to change requires effective communication, motivation, and education for all stakeholders, including employees, managers, and customers. Continuous training is vital, with a structured belt system (Master, Black, Green, Yellow) ensuring skill development and effective project execution. Training should be tailored to individual roles, and organizations must stay current with new techniques beyond Six Sigma. Additionally, top management should drive performance through regular reporting and active project championing. Overall, integrating these elements fosters a successful Six Sigma program that aligns with organizational goals and customer needs.

2.3.3 Obstacles and challenges of six sigma method

Implementing Six Sigma often encounters several significant obstacles that can hinder its success. One primary challenge is resistance to change within the organization. Employees and managers who are accustomed to traditional processes may be hesitant or resistant to adopt new methods, tools, and cultural shifts required by Six Sigma(Stewart & Spencer, 2006). This resistance can stem from fear of the unknown, concerns about job security, or skepticism regarding the effectiveness of the methodology. Without strong leadership and effective change management strategies, such resistance can slow down or derail Six Sigma initiatives.

Another critical obstacle is the lack of top management support and commitment. Successful Six Sigma deployment requires visible and sustained leadership involvement, including resource allocation, strategic alignment, and ongoing communication(Schroeder et al., 2008). When leadership is not fully committed or fails to prioritize Six Sigma projects, initiatives often lack the necessary authority and resources, leading to poor project selection, insufficient training, and low employee engagement. Additionally, organizations may face difficulties in integrating Six Sigma with existing processes and systems, leading to fragmented efforts and inconsistent results. These integration issues can create confusion and reduce the overall effectiveness of the methodology. Overcoming these obstacles requires a comprehensive strategy that includes strong leadership, effective communication, and a culture that embraces continuous improvement.

Cultural Challenge is one of the most challenging point to implement new process improvement techniques in the construction sector (Siddiqui et al., 2016). Integrating quality into organizational culture is fundamental, shifting from merely monitoring quality at the manufacturing level to embedding quality into planning and decision-making processes. Addressing cultural resistance and fostering a mindset that prioritizes quality are critical. Superficial efforts that focus only on easy-to-correct issues or claim quick successes can be misleading. Effective Six Sigma deployment requires comprehensive change management, with strong leadership and commitment from senior management. Without such support, organizations are unlikely to overcome cultural barriers or sustain the initiative, and adopting Six Sigma may not be advisable.

Training and skill development is also a vital success factor for Six Sigma projects and should be integrated into the organization's broader development strategy. The Six Sigma belt program must be supported from the top leadership and applied organization wide. Training curricula should be tailored to organizational needs, emphasizing both qualitative and quantitative measures, leadership, and project management skills. Participants must stay updated on the latest tools, techniques, and data analysis practices. Proper selection of personnel for belt levels is crucial; assigning less capable employees to critical roles such as Black Belts can hinder project success and pose significant challenges. Therefore, investing in comprehensive, customized training and selecting skilled individuals are essential for the effective implementation of Six Sigma initiatives.

2.4 Developing a Framework for Implementing Six Sigma in the Construction Sector

The application of Six Sigma in construction has gained momentum worldwide due to its structured methodology for reducing defects, improving process efficiency, and ensuring quality outcomes (Garg & Misra, 2021). However, despite its proven success in manufacturing and in some advanced construction markets, the development and contextual adaptation of Six Sigma implementation frameworks tailored to local industry needs particularly in developing countries remains under researched (Antony & Banuelas, 2002) & (Kwak & Anbari, 2006).

This review synthesizes global literature on Six Sigma frameworks and implementation strategies in construction, identifies key framework components and highlights the critical contextual factors necessary for successful application in the Ethiopian building construction context. A conceptual framework serves as a structured guide to apply theoretical methods to practical challenges. In the context of Six Sigma, frameworks typically align with the DMAIC (Define, Measure, Analyze, Improve, Control) methodology, supported by organizational readiness, training, and leadership structures(Snee, 2000). An effective Six Sigma framework should define: clear project goals and process boundaries, process mapping and defect definition, measurement strategies (e.g., DPMO, sigma level), root cause analysis tools (e.g., Pareto charts, Fishbone diagrams), implementation and control mechanisms(Snee, 2000).

Research by (Coronado & Antony, 2002) outlines critical success factors for Six Sigma frameworks, including top management commitment, proper selection of projects, employee involvement, and a strong training infrastructure. These components must be customized based on industry needs, organizational culture, and regional challenges. The construction industry presents unique challenges for Six Sigma implementation due to its dynamic environments, high variability, and project-based nature. Unlike manufacturing, where processes are repetitive, construction activities are diverse and influenced by external factors like labor skill, site conditions, and material variability (Stewart & Spencer, 2006).

To address these challenges, researchers have developed construction specific Six Sigma frameworks: (Sui Pheng & Sze Hui, 2004) applied six sigma to plastering works in Singapore and found that a tailored approach led to a rise in sigma level from 2.66 to 3.95. (Heon Han et al., 2008) proposed a model integrating Six Sigma with simulation tools to improve performance in reinforcement bar assembly operations. These studies emphasize that a construction based six sigma frameworks should not seek to eliminate all variability but manage it effectively. The implementation must be strategic, focusing on high impact processes and adopting a gradual approach to cultural and operational change.

2.4.1 Challenges in Developing Countries and the Ethiopian Context

Developing countries face particular constraints when applying advanced quality management techniques. These include limited awareness, skill gaps, resource constraints, and lack of supporting institutional infrastructure(Dagne, 2023). Ethiopia's construction sector is further challenged by fragmented project delivery systems, inconsistent supervision, and limited integration of quality management systems(Demissew & Abiy, 2023). Thus, a Six Sigma framework for Ethiopia must be simple and appropriate for organizations with limited resources. Focused on human factors such as emphasizing training, supervise on, and communication (Forcada et al., 2016). Rooted in local context using defect types and causes common in Ethiopian construction (e.g., plaster cracks, HCB misalignment). There is also a lack of empirical studies and performance metrics such as DPMO and sigma levels, in Ethiopian projects, which are essential for establishing baseline performance and monitoring improvement.

2.5 Research Gap

Based on the reviewed literature, several significant gaps have been identified:There is no a research concerning the application of Six Sigma within the Ethiopian construction industry. Most existing studies predominantly focus on developed countries, thereby lacking context specific insights pertinent to the Ethiopian region. Currently, there is no comprehensive dataset available regarding defect rates, DPMO (Defects Per Million Opportunities) calculations, and rework costs associated with construction projects in the local context. Additionally, there exists an absence of a structured framework tailored to guide the implementation of Six Sigma in Ethiopia. While prior research provides general strategies for Six Sigma adoption, a context specific framework that facilitates practical and effective implementation within the Ethiopian construction sector remains undeveloped. This study aims to address these identified gaps by collecting real time data on inefficiencies, calculating sigma levels, and developing a tailored Six Sigma framework suitable for application in Ethiopian construction projects. Table 2.3 below shows research gaps collected from different articles

Table 2.3 Research gap

Author	Objective	Methodology	Result	Gap
(Chang et al., 2012)	Apply Six Sigma for construction process improvement for precast components. Investigate of precast construction quality Xtics,	- Literature review and - Case study	- Improve production time from 15.87hr/ unit to 13.04hr/unit by setting goal of 12.5hr/ unit - Standard deviation improved from 4.588 to 1.468	Rework cost S/holder insight SS implementation F work in Ethiopia
(Sui Pheng & Sze Hui, 2004)	To investigate wheth er Six Sigma can be effectively applied in the construction sector to achieve significant quality improvement.	-Literature review, -Case study on plastering work	Significant improvement in quality metrics, with the sigma level rising from 2.66 to 3.95	Not used tools like Fishbone & pareto analysis to know Root cause. Rework cost
(Yilmaz, 2012)	Application of Six sigma within constr uction sector as a quality initiative and performance indicator .	-Literature review & Interview	- Six Sigma increases quality directly or indirectly and has a positive impact on process efficiency in construction sector.	Quantitative study not included Focused only quality aspects SS implementation F work in Ethiopia
(Heon Han et al., 2008)	Six Sigma Based Approach to Improv e Performance in Construction Operation	Case studies & simulations on iron reinfo rceed bar asse mbling	Initial 1.41 to 3.64 sigma level	S/holder insight Rework cost SS implementation F work in Ethiopia

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the detail research methodology, which forms the core of the research and encompasses four key components essential for achieving the research objectives. The first component provides an overview of the research design. Following this, the sampling criteria and the approach used to calculate the sample size are discussed. The third and fourth components elaborate on the data collection methods and data analysis is outlined. The methodology describes the systematic approach followed to organize and execute the research project. Developing a clear action plan outlines how the research problem have been investigated, the type of information to be collected, the methods employed to gather this information and the analytical techniques used to draw conclusions and propose recommendations. The problem identified in this study is limited to exploration of application of six sigma methodologies in the Ethiopian building construction for the success of building projects.

3.2 Study area

The study focuses in the city of Adama, one of the major urban centers in Ethiopia, known for its rapid urbanization and growing demand for residential housing. Adama is situated at a latitude of approximately 8.54° N and a longitude of 39.27° E, with an average elevation of around 1,712 meters above mean sea level.

Adama has experienced a surge in residential building construction in recent years, driven by population growth and urban expansion. This provides a rich context for investigating inefficiencies and defects within residential construction processes. The study specifically targets these projects to evaluate the applicability and impact of Six Sigma methodology in improving construction quality and reducing rework. By focusing on Adama's residential construction sector, the research generates insights that are practical and relevant, addressing critical challenges in similar urban settings across Ethiopia.

Figure 3.1: Study area of the research

3.3 Research design and approach

To comprehensively address the research objectives concerning inefficiencies in the Andode Village residential building construction projects and the potential impact of Six Sigma implementation, a combination of descriptive and explanatory research designs within a mixed methods approach has been employed. The combined use of descriptive and explanatory research designs within a mixed-methods framework is strategically chosen to thoroughly investigate the current inefficiencies and the potential benefits of Six Sigma implementation in the Andode Village residential building construction projects. This methodological approach not only facilitates a detailed understanding of existing challenges but also provides a solid foundation for developing actionable strategies to enhance construction quality and efficiency in the Ethiopian context.

3.3.1 Research Design

The descriptive research design is utilized to systematically identify and document existing inefficiencies within the construction processes of the Andode Village Residential projects. This approach facilitates a detailed understanding of the current state of operations, enabling the quantification of defects and inefficiencies. Such a foundation is essential for establishing baseline metrics, including the calculation of sigma levels, which are critical for subsequent process improvement initiatives. Descriptive research is particularly effective in providing a clear picture of the phenomena under study without delving into causal relationships, thus setting the stage for more in depth analysis

Building upon the descriptive findings, the explanatory research design is employed to investigate the causal relationships between the implementation of Six Sigma methodologies and the observed defect levels in the construction projects. This design enables the exploration of cause-and-effect dynamics, assessing how specific Six Sigma tools and practices influence construction quality and efficiency. By understanding these relationships, the research can provide evidence-based recommendations for process improvements.

3.3.2 Research Approach

A mixed methods approach, integrating both quantitative and qualitative data, is adopted to enhance the robustness and validity of the research findings. Quantitative methods are employed to gather measurable data on construction inefficiencies, defect rates, and process performance. This data facilitates statistical analysis, allowing for the calculation of sigma levels and the identification of patterns and trends within the construction processes. Qualitative methods, including semi-structured interviews and focus group discussions with stakeholders such as project managers, engineers, and workers, provide contextual insights into the challenges and perceptions related to six sigma implementation. These insights are crucial for understanding the human and organizational factors that influence the effectiveness of quality improvement initiatives.

The integration of quantitative and qualitative data ensures a comprehensive analysis, capturing both the measurable outcomes and the contextual nuances of the construction processes. This methodological triangulation enhances the credibility and applicability of the research findings, particularly in the complex and dynamic environment of Ethiopia's construction industry.

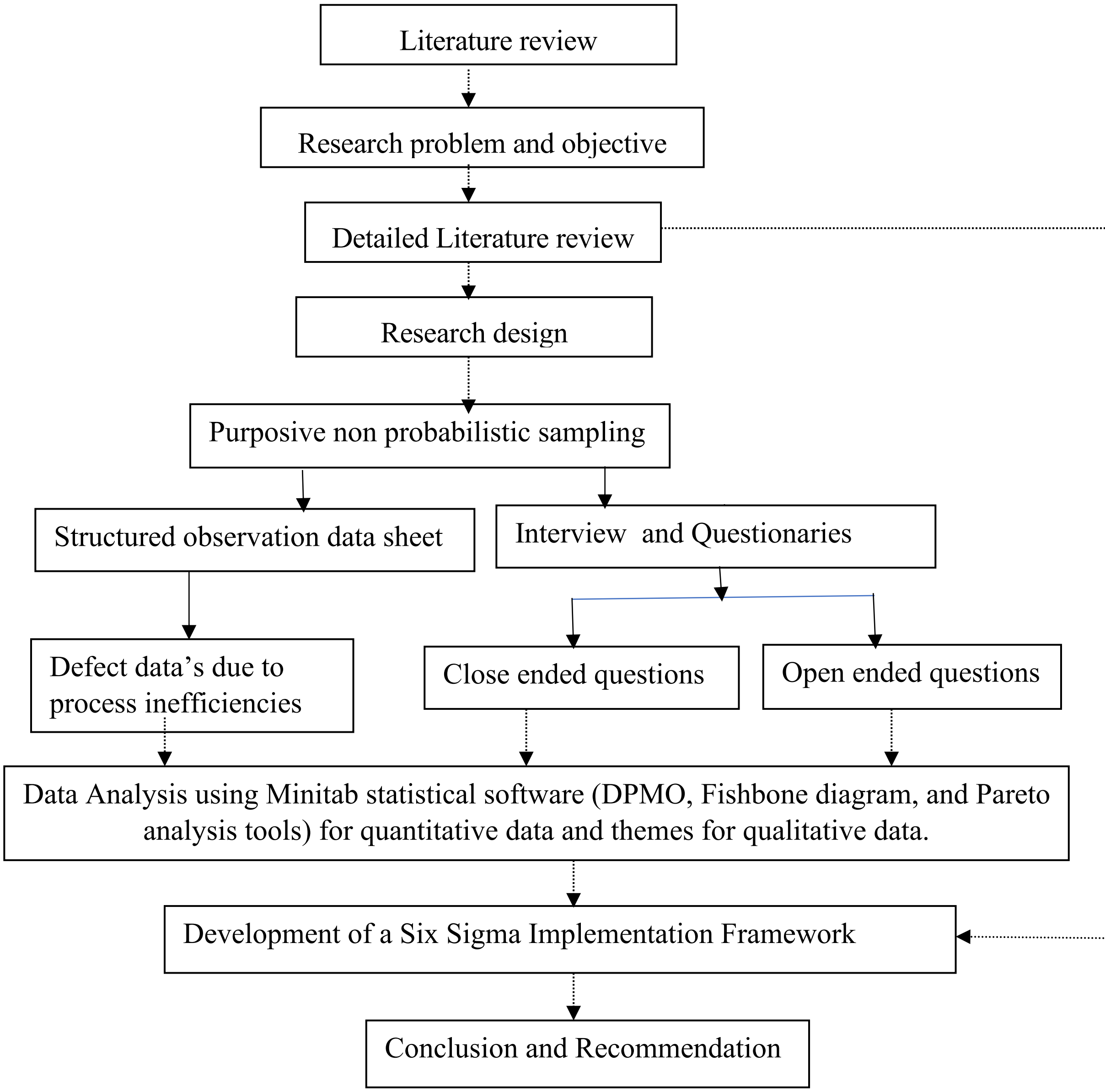

Figure 3.2: Study flowchart

3.4 Population and sampling

3.4.1 Population

The populations of this study was Andode village G+5 residential building construction projects in Adama. These projects encompass various stages of construction and involve key stakeholders such as project managers, site engineers, and quality assurance teams. Selecting the Andode

Village G+5 residential building construction projects as the research population is a deliberate choice that aligns with Six Sigma project selection best practices. The project's relevance, manageable scope, and potential for measurable improvements make it an ideal case study for exploring six sigma's efficacies in Ethiopia's construction industry. Focusing on a single project ensures depth of analysis and practical applicability, laying the groundwork for future, more expansive research endeavors. The selection of the Andode Village G+5 residential building construction projects in Adama as the focal point of this Six Sigma study is a strategic decision grounded in both theoretical frameworks and practical considerations. This choice ensures the research's relevance, feasibility, and potential for impactful outcomes.

Andode Village projects encompass various stages of construction and involve key stakeholders such as project managers, site engineers, and quality assurance teams. This diversity allows for a comprehensive analysis of the construction process. Moreover, the project's scale is manageable, ensuring that the research can be conducted within the available time frame and resource constraints. The project's current inefficiencies provide a baseline for measuring improvements post-Six Sigma implementation. Quantitative data, such as defect rates can be collected to calculate sigma levels and assess performance enhancements. Qualitative insights from stakeholders would further enrich the analysis, capturing contextual factors influencing project outcomes.

While conducting Six Sigma research across multiple projects in different areas can provide comparative insights, several factors justify the focus on a single project: Different projects across various regions may have varying scopes, resource availability, and stakeholder engagement levels, making it challenging to maintain consistency in data collection and analysis. Expanding the research to multiple sites would require additional resources, including time, personnel, and funding, which may not be feasible within the current research framework. Focusing on a single project allows for a more in-depth analysis, enabling the identification of root causes and the development of targeted improvement strategies. Engaging with stakeholders in one location facilitates stronger relationships and more effective collaboration, which is crucial for the successful implementation of Six Sigma methodologies.

3.4.2 Sampling Technique

Sampling serves as a practical approach to facilitate data collection and analysis in research, ensuring that the selected subset accurately represents the broader population. To maintain the integrity of the research findings, it's crucial that the sampling process minimizes bias otherwise, the reliability of any generalizations drawn from the sample could be compromised. Sampling techniques are broadly categorized into two main types: probability and non-probability sampling. For both quantitative and qualitative data collection, non-probability purposive sampling strategies used. Purposeful non probability sampling consists of hand picking interested and experienced professionals in the purposefully selected projects. In a purposive sample, the researcher identifies the characteristics of the target population and identifies units that match these characteristics to include in the sample. It is a useful sampling method consisting of getting information from a sample of the population that one thinks knows most about the subject matter. So, for this study project managers, site engineers, consultants and quality engineers are selected based on the experience and exposure with required information in the research. These individuals possess specialized knowledge and experience pertinent to the construction processes under study. Their insights are invaluable for understanding the practical challenges and potential strategies for Six Sigma implementation in the Ethiopian construction context.

Sample size was calculated by Slovin's formula (Chanuan et al., 2021): **$n = N/(1+Ne^2)$,** where n is sample size, N is size of population and e is level of precision considering error of 0.05 with a reliability of 95%. The sampling frame comprised of 27 residential blocks in Andode village. The inclusion criteria was blocks that had achieved 50% or more completion in hollow concrete block construction were considered. From this list, blocks that had achieved 50% or more completion in hollow concrete block (HCB) construction were identified, resulting in 8 eligible blocks. The sample size was calculated using the formula: Sample size, $n = N/(1+Ne^2) = 27/(1+27(0.05^2)) = 25.29 \approx 26$blocks Rounding up, a sample size of 26 blocks was determined. However, given that only 8 blocks met the inclusion criteria (≥50% HCB completion), all 8 were included in the study.

3.5 Data collection method

Data collection is the process of gathering and measuring information on variables of interest, in an established systematic fashion that enables one to answer stated research questions, test hypotheses, and evaluate outcomes. The data collection for this research have been conducted using a combination of methods to ensure comprehensive analysis and accurate findings. These methods include structured observation, interviews, document analysis, and a literature review. Each approach serves a distinct purpose in collecting data on the application of Six Sigma methodology in construction projects. Primary data is data collected by self designed interviews, questionnaires & case studies. Secondary data on the other hand is data collected previously by a researcher and office documents. This particular research is aimed at exploring the implementation of six sigma methodologies in Ethiopian construction sector.

3.5.1 Structured Observation Using a Check Sheet

In this study, data were collected through structured observation, utilizing a check sheet as the primary instrument. This method involves systematically observing and recording specific events or conditions as they occur, providing a consistent framework for data collection.

A check sheet is a structured form used to collect data in real time at the location where the data is generated. It allows for the systematic recording of occurrences, such as defects, facilitating easy analysis and identification of patterns. In the context of this research, the check sheet was designed to record defects observed in hollow concrete blocks (HCB) and internal plastering works in residential buildings. The check sheet was structured to capture the following information, Specific area within the building where the defect was observed, Categorization of the defect (e.g., cracking, peeling, misalignment) and Number of times each defect type was observed.

Observers conducted systematic walkthroughs of selected residential buildings, recording defects as they were identified. Each observed defect was marked on the check sheet under the appropriate category, allowing for the accumulation of data on defect frequency and distribution. It facilitates immediate recording of observations, reducing the likelihood of data omission. Ensures consistency in data collection across different observers and sites. Organized data allows for straightforward analysis of defect patterns and frequencies. The use of a structured observation method with a check sheet provided a reliable and efficient means of collecting data on construction defects. This approach enabled the identification of common issues in HCB and internal plastering works, informing recommendations for quality improvement in residential construction practices

3.5.2 Interviews

In depth interview have been conducted with project managers, site engineers, quality engineers, consultant and other relevant stakeholders involved in the construction projects. These interviews aim to provide qualitative insights into the root causes of identified defects and inefficiencies, as well as potential solutions using six sigma methodologies. The interviews focused on the challenges faced during construction, the impact of these challenges on project quality, and the stakeholders' perspectives on implementing Six Sigma methodology. These interviews were then analyzed against each other to show the extent of knowledge of six sigma and awareness to its benefits and experience with its challenges. The interviews also facilitated to discover of challenges faced and possible reasons behind the limited understanding of six sigma within the Ethiopian construction industry. Generally the interview focused on definition, adoption, theory, implementation resistance & benefits of six sigma.

3.5.3 Document review:

Document analysis involves systematically reviewing and evaluating existing documents. Collect blueprints, specifications, contracts, and project schedules to identify defects or inefficiencies. Analyze progress reports, quality assurance records, and inspection reports for evidence of inefficiencies and defects. Examine records of rework or corrective actions taken during construction.

3.5.4 Questionnaires

A survey have been administered to key stakeholders in the Adama andode village residential building construction projects. The purpose of the survey is to gather data on the cause of defects and inefficiencies observed during the construction process of HCB and internal plastering work. This information would be essential for a key metric for assessing process quality and identifying areas requiring improvement.

3.6 DMAIC methodology implementation steps

This study implemented the DMAIC (Define, Measure, Analyze, improve and Control) procedure on a construction organization within Ethiopia, to study its implementation and reduce the cost of rework lost due to process inefficiencies. The purpose of the study was to develop a successful implementation and frame work preparation for the application of six sigma principles to improve the process inefficiencies in Ethiopian construction sector. As a medium through which to facilitate the discovery of the best appropriate solution, a DMAIC procedure was implemented as follows:

Define- phase begun by identifying the problem at hand and setting the goals and objectives (Anbari & Kwak, 2004). Clarify research objectives, focusing on defect reduction, cost minimization, and process improvement (Linderman et al., 2003). In this specific research study, this was done through a project charter which served as defect minimization and rework work cost reduction in the construction projects. The goal was set the lowest amount of rework costs lower than at the start. Focus on cost reduction through minimized rework. Identify rework prone areas, like structural defects, architectural defects, Electrical etc. Develop a structured questionnaire to assess common process inefficiencies that cause defects which brings cost rework. Set goals to reduce rework related costs.

Measure - The purpose of this phase was to collect all sufficient data and observe current performance and conditions in order to generate a baseline performance(Ugr & Canatan, 2015). This facilitated the identification of the cause of the problem. To achieve this, three different tools were used; cause and effect analysis to aid in the discovery of the root cause(s) of the problem, process capability analysis to locate where and in which process the improvement is needed. Collect data on defects and inefficiencies across different construction phases (e.g. structural, mechanical, architectural, electrical and sanitary). Use on site inspections, surveys, and existing documentation to record defect details. Categorize defects by type and occurrence frequency. Define Defects per Million Opportunities (DPMO): DPMO= ((Number of Defects / Total Opportunities for Defects) ×1,000,000)(Stewart & Spencer, 2006). Use the DPMO to calculate the sigma level of current construction practices. Identify the sigma level using a standard Six Sigma conversion table. Highlight specific processes with high defect rates for further investigation. Use Pareto Analysis to identify activities or processes with the highest defects and cost implications. Collect financial data related to defect rework costs. Categorize costs by defect type and construction phase. Calculate the total cost of rework as a percentage of the project budget.

Analyze - The goal of this phase is to discover alternative solutions and analyze them (Taner, 2013). To do this, Pareto chart used , which served as a guideline to know which activities caused most cost (defects). Conduct root cause analysis for high frequency defects using Fishbone Diagram or Pareto Analysis tools. Identify systemic issues contributing to inefficiencies. Interview stakeholders for their perceptions on quality management and Six Sigma feasibility. Discuss potential solutions to eliminate or mitigate identified defects.

Improve - Propose practical solutions based on the root cause analysis, such as improved training, better materials, or enhanced process controls(Samman & Graham, 2007). Estimate the potential cost savings from implementing Six Sigma solutions. The purpose of this phase is to analyze possible solutions and develop a final solution and implement it.

Control - Design a framework for integrating Six Sigma into the construction project lifecycle. Including key metrics for quality monitoring, guidelines for defect identification and RCA and protocols for continuous improvement. Share the framework with stakeholders for validation and refinement. Adjust the framework based on stakeholder input and feasibility studies. Monitor improvements in sigma levels and reductions in rework costs. Compile findings, including sigma level improvements, cost analyses, and stakeholder feedback. Present recommendations for broader adoption of Six Sigma in the Ethiopian construction sector.

3.7 Data analysis

The data analysis conducted in three stages, with Minitab software supporting the quantitative analysis. The stages are as follows: Collect structured observation data on defects occurring in HCB and internal plastering work of Adama andode village residential building. Calculate the defects per million opportunities (DPMO) and calculate the sigma level. The sigma level provides a measure of how many defects exist in the processes and indicates the overall quality of the construction project. Minitab tool have been used to process and analyze the DPMO data, allowing for a detailed understanding of the defects and process capability.

To identify which defects have the greatest impact on the process efficiency pareto analysis is used. This method is required to determine the most frequent and significant defects affecting the project, based on the structured observation sheet data. Apply the 80/20 Rule (Pareto Principle) to focus on the top 20% of defects that cause 80% of inefficiencies. Minitab tool have been used to generate pareto charts to visualize the most significant defects in the process, helping to target improvement efforts effectively.

To understand the root causes of the identified defects and inefficiencies fishbone diagram (Ishikawa diagram) was used. A cause-and-effect analysis of the defects identified to categorize potential causes into various factors, such as people, methods, materials, and machinery, to find the root causes of defects. Analyze these causes in relation to construction phases and identify potential areas for improvement. Based on the findings from all previous stages, develop a comprehensive Six Sigma framework tailored to the Ethiopian construction context. Provide actionable recommendations for implementing Six Sigma principles to reduce inefficiencies, improve process quality, and minimize rework costs.

3.8 Validity and Reliability

The study adopts multiple strategies to ensure both validity and reliability. By applying established methods and carefully managing the data collection process, the research provides robust and credible findings. The combination of quantitative and qualitative approaches, alongside the use of well tested analytical tools, ensures that the results was accurately reflected the impact of six sigma on construction inefficiencies and provide reliable guidance for future application in the Ethiopian construction industry.

The collected data for questionaries on listed items was checked using Cronbach’s alpha coefficient of reliability. Cronbach’s alpha is a measure of reliability of the data on a questionnaire and ranges from 0 to 1. In this research Cronbach’s alpha coefficient was checked for listed items of causes of defect in HCB and plastering work and it resulted in Cronbach’s alpha coefficient value of 0.916. This value of Cronbach’s alpha coefficient (0.916) is greater than 0.7, so the reliability of the collected data for this research is good and it is above the minimum level of reliability requirement.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the key findings derived from the application of the Six Sigma DMAIC methodology to minimize defects in hollow concrete block (HCB) and internal plastering works in the Adama andode village residential construction project. The findings are based on quantitative analysis using DPMO, sigma level, yield percentage, pareto and fishbone diagrams, and qualitative insights gathered through interviews. The data was analyzed using Six Sigma tools such as DPMO, Sigma level calculations, and yield percentages. The purpose was to evaluate the current quality performance of construction processes and assess improvements following corrective interventions.

The residential building in Adama andode village, has 27 blocks of 5 floors, each floor covers 414m2. This residential complex is under construction and the HCB & plastering is ongoing. As the site is currently under construction, so to find out the defects on HCB & plastering work checklist was prepared. Once the checklist for defects was prepared the HCB & plastering of 8 block out of 27 blocks were purposively checked on the first floor in a selected room (kitchen, bedroom, toilet and dinning room. Information for the case study was obtained from site visit and interviews with the stockholders of this project. This case study would first concentrate on the implementation process of the six sigma initiative in Adama residential building and focused on patent defects not latent defects that can be seen on HCB and plastering work of building construction as the latent defects need longer period of time to be identified. According to (Act, 1990) patent defects are flaws in a structure that can be identified during or shortly after construction, typically before or during the defect liability period. These defects, often caused by construction workers, are visible and easily detectable (Act, 1990).

4.2 Result and Discussion

As obtained from formal interview results the stakeholder insights suggest that awareness of six sigma among construction professionals in Ethiopia is low. Although project managers and engineers are familiar with quality control practices but often lack exposure to structured statistical methods for process improvement. Furthermore, contractors are primarily focused on cost and schedule pressures, with little incentive or capacity to adopt advanced quality management systems. The formal interviews conducted as part of this study provided valuable qualitative insights into the level of awareness, acceptance, and readiness for Six Sigma implementation among construction professionals in Ethiopia. The awareness of Six Sigma methodology remains significantly low across key stakeholders in the local construction industry.

Although project managers and Engineers demonstrated a foundational understanding of conventional quality control practices such as routine inspections, specification compliance, and corrective action processes they generally lacked exposure to structured, data-driven quality improvement tools such as those found within Six Sigma, including DPMO analysis, root cause evaluation through statistical tools, and continuous process capability measurement.

The interviews also revealed that contractors are predominantly focused on delivering projects within tight cost and time constraints, often dictated by client demands and limited financial margins. As such, there is little institutional or contractual incentive for them to invest in advanced quality management systems. Quality, while recognized as important, is frequently treated as a secondary objective compared to budget and schedule adherence. One interview noted: ″We are evaluated more on whether we finish on time and within budget not necessarily on the long-term performance or durability of our construction."

Furthermore, the absence of a regulatory framework that enforces the use of statistical quality control or modern quality improvement models contributes to a prevailing attitude of reactive quality management, rather than proactive prevention and continuous improvement. These findings reinforce earlier conclusions by (Coronado & Antony, 2002)and (Dagne, 2023)who emphasized that in low-income construction sectors, the lack of awareness, institutional support, and training significantly hampers the adoption of Six Sigma. This underscores the need for targeted capacity building programs, awareness campaigns, and policy incentives to integrate structured quality methodologies like Six Sigma into Ethiopia's construction practices. The stakeholder insights from this study, therefore, play a crucial role in informing the conceptual framework developed in Objective Three, particularly regarding the importance of simplicity, training, and leadership engagement for successful implementation in similar contexts.

Define Phase: Identifying the Quality Problem & customer requirement

4.1.1 Problem Definition

The Define phase serves as the starting point in the Six Sigma DMAIC process, where key performance issues affecting quality and customer satisfaction are identified. In the context of this study, significant quality issues were observed in Hollow Concrete Block (HCB) and internal plastering works, which are among the most critical activities in residential building construction. Defects in these works such as joint misalignments, surface cracks, and uneven finishes not only compromise the structural integrity but also diminish the aesthetic and functional value of the buildings. As emphasized by(Swami & Kadiwal, 2020), such defects can undermine the creativity and planning embedded in the project design.

These issues were prevalent across the selected eight blocks of the Andode Village residential building project, which had achieved at least 50% completion in HCB construction. Observations and site reports indicated frequent rework due to workmanship errors and lack of standard quality control practices, thereby increasing both cost and time.

4.1.2 Understanding Customer Requirements

In addition to identifying defects, the Define phase also focuses on aligning construction performance with customer expectations and project standards. According to (Shibani et al., 2021) and (Yilmaz, 2012) this stage involves understanding what the customer values most typically durability, safety, visual appeal, and timely delivery. In the Andode Village project, key stakeholders including clients and end users expected a structurally sound, aesthetically pleasing, and defect free residential facility. As obtained from the interview question raised for the clients " what is your greatest requirement from this project", durability is their first choice or they expect a good quality durable building with lowest possible cost and time.

To meet these expectations, the project team had to clearly define: who the key customer is in which for this project AIG is the client of the project while the consultants are Engineering corporation of Oromia. The role of the client is giving a clear drawing and paying payments timely not to affect the project quality and time line fixed. While that of the consultant is to supervise and preparing material approval timely. Contractors are responsible to construct the project according to the drawing and specification. According to six sigma implementation standard. This clarity laid the groundwork for forming a quality improvement team and establishing goals aimed at minimizing defects and improving the HCB and plastering processes.

The research identified several visible and repetitive defects in HCB and internal plastering works such as cracks, poor alignment, mortar voids, and efflorescence. These defects were evident across the selected 8 blocks, which had achieved 50% or more construction progress. Stakeholders, including clients, consultants, and contractors, confirmed the negative impact of these defects on project quality and cost during interviews. Defects were categorized as patent, being easily observable during construction

Define is the stage where problem is identified & issues causing decreased customer satisfaction. HCB work and Plastering is the most important part of the job in a building project. But the defects in this activities can spoil all the creativity of building (Swami & Kadiwal, 2020). This phase is for team forming, determining the responsibilities of team members, establishing team goals and review the process steps. In this phase, customer needs, requirements and standards are identified in accordance to the unsatisfactory performance. A few questions are answered in this phase: What is the problem? Who is involved and what are the requirements (Shibani et al., 2021) & (Yilmaz, 2012).

In this phase, Six Sigma team have to be identified first but now I made just a face-to-face discussion with the stake holders to create the understanding of what six sigma is and to make them understand its positive inputs for their interest gained from the project weather the stakeholder is client, contractor or consultant, all are not a looser of implementing this process improvement methodology. So here the defined problem is different defects like crack, poor alignment, improper jointing and the like are occurring in HCB and plastering work of construction projects (Swami & Kadiwal, 2020). This issue can be improved if the processes can be improved using process improvement techniques and the focus of this research six sigma process improvement methodology. Key stakeholders of this project are the client (Adama investment group), Consultants (Engineering corporation of Oromia) and the contractors who are taking the actual execution of the work. The client's need is to get a good quality project with a reasonable lower possible price and the contractor wants to finish the project with lowest possible cost, time and good quality. Through interviews and site inspections, critical customer requirements and expectations were clarified. The main objective established was to reduce rework and enhance construction quality.

4.2.1 Assess the current defects level of process inefficiencies in HCB and internal plastering construction work.

Second stage of DMAIC, is having a plan for data collection, preparing a sufficient data sample and preliminary data of this sample. In this stage, Six Sigma team analyzes current performance through valid data in order to understand improvement opportunities and identify KPIV (Key process input variables). It includes measurement of the current performance of the process and the collection of all relevant data for the process (Shibani et al., 2021) & (Yilmaz, 2012). So here I have prepared an onsite data collection sheet as it is shown on table 4 below. Defect collection data sheet was collected based on the defects acquiring on HCB and plastering works of Andode village residential building construction projects.

Table 4.1 presents the initial measurement phase of defects on Andode village residential building project aimed at improving quality of HCB and plastering works in construction processes. The focus is on quantifying defects and assessing process capability through DPMO (Defects Per Million Opportunities) and sigma level analysis. The calculation of DPMO is a crucial step in evaluating process performance. It is computed as follows:

DPMO=Number of Defects×1,000,000/ No. of opportunities x No. of units

Number of Defects = 537 and Number of opportunity for defect = 1792

DPMO=537×1,000,000/1792 ≈ 299,665.18

Table 4.1: First round defect data collection sheet

Location		HCB Walls defects								Plastering work defects						
		Dimensional Inaccuracy	Poor Alignment	Cracks in Blocks	Efflorescence	Improper Jointing	Incorrect block placement	Joint Cracks	Mortar Gaps and Voids	Debonding	Peeling and flacking	Surface irregularities	Cracks	Hollowness	Efflorescence	**Total**
Bedroom	Wall 1	2	1	0	1	2	2	1	4	3	2	4	1	3	0	
	Wall 2	3	2	1	3	1	3	1	4	3	0	1	4	2	3	
	Wall 3	4	2	1	3	2	1	4	2	1	1	3	4	3	4	
	Wall 4	5	3	1	2	2	1	3	2	4	1	4	3	4	3	
Kitchen	Wall 1	2	2	1	3	1	1	1	2	1	1	3	5	2	1	
	Wall 2	3	4	1	3	1	2	3	3	2	3	3	3	3	4	
	Wall 3	1	3	2	2	2	1	3	4	3	1	2	3	2	1	
	Wall 4	1	3	2	2	1	3	1	4	3	2	3	1	1	1	
Toilet	Wall 1	2	1	2	3	3	1	4	1	1	4	4	1	3	3	
	Wall 2	3	3	2	4	1	7	1	4	3	1	2	5	4	1	
	Wall 3	1	3	3	2	2	3	3	2	4	1	4	3	4	0	
	Wall 4	2	2	3	3	2	4	1	2	1	4	3	1	2	1	
Dinning room	Wall 1	3	4	3	3	4	1	3	3	2	3	3	1	3	4	
	Wall 2	1	3	2	3	1	2	3	4	3	1	2	7	2	1	
	Wall 3	1	3	2	2	4	1	1	4	3	2	3	2	3	4	
	Wall 4	1	2	2	3	3	2	4	1	**2**	**4**	4	1	3	3	
No. of defect		35	41	28	42	32	35	37	46	39	31	48	45	44	34	
No. of Checks		126	126	126	126	126	126	126	126	126	126	126	126	126	126	
Total Number of Defects																537
Total Number of Checks / Opportunity for defects																1792

Using the standard DPMO to sigma conversion table1, a DPMO of approximately 299,665 corresponds to a sigma level of roughly 2.02 sigma. This indicates a process with significant room for improvement, as higher sigma levels of above 3 are generally targeted in Six Sigma initiatives according to (Siddiqui et al., 2016). This initial measurement reveals a high defect rate, corresponding to a sigma level of just over 2. This suggests that, in its current state, the process produces a considerable number of defects, which could lead to increased rework, delays, and costs in construction projects. Compared to other researches (Sui Pheng & Sze Hui, 2004) which obtain 2.66sigma on the first round defect data collection the current level of defect is high. But compared to (Heon Han et al., 2008) research done on iron reinforced bar assembling which got 1.41 sigma level on initial defect level data collection. Achieving higher sigma levels of 3 will require targeted process improvements and the first-round measurement provides a baseline for current process performance. Recognizing a sigma level of approximately 2.02 highlights the need for focused improvement efforts. Subsequent phases should aim to reduce defects, enhance process capability, and move closer to Six Sigma standards. We can also calculate yield percentage which means the ability of HCB and Plastering work process to produce defect free outputs.

Yield (%)= (1-DPMO/1,000,000) x 100

Yield (%)= (1-299665.18 /1,000,000) x100 = 70%

The level of fulfilling the client requirement obtained on HCB and plastering work data is below the recommend value and product is being right 70% only while it was falling to meet customer requirement 30% of the time. It was not acceptable where quality of HCB and internal finishes is concerned because the contractors would only be getting it right 70% of the time of the work done. According to (Sui Pheng & Sze Hui, 2004) a construction process should at least be getting 3.8sigma which means it should have to meet the requirement of the customer 99% of the time. Contractors was encouraged to supervise their on going building projects more closely to ensure that the level of workmanship for HCB and internal finishes complies with the quality standards. This research aims to enhance the defect level by 20% by implementing the six sigma improvements. So hence the obtained defect level in Andode village residential building is below the industry standard which is at least 3sigma.

4.2.2 Evaluate the Applicability and Effectiveness of Six Sigma methodologies in improving construction project performance.

Third stages of DMAIC is for finding the root causes of defects, right approach styles to data and improvement opportunities. The root cause of the problem is identified through the creation of Pareto chart diagrams and fishbone diagram. Using Pareto analysis, the most frequently occurring defects were pinpointed joint cracks, poor alignment, surface irregularities, and mortar gaps accounted for a majority of the defects. This follows the 80/20 principle, where a few defect types were responsible for most inefficiencies. A Fishbone (Ishikawa) diagram was then developed to identify root causes. The most critical underlying factors included: Poor stakeholder communication and unclear instructions, Inadequate supervision and quality control, Unskilled labor and lack of training & Weak project management practices. These root causes were validated through stakeholder interviews and site observation.

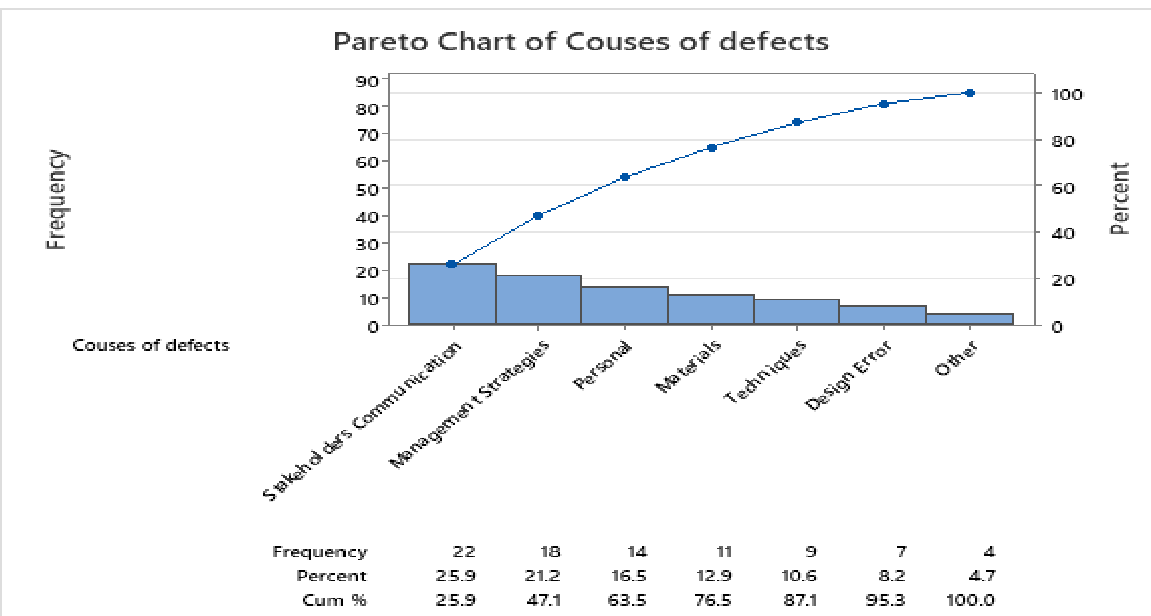

Figure 4.1: Pareto chart for causes of defects

The Pareto chart shown in Figure 4.1 applies the 80/20 principle, which suggests that approximately 80% of consequences arise from 20% of the causes. This tool is vital in Six Sigma's analyze phase of the DMAIC process for identifying the most significant sources of inefficiencies or defects. From the chart, the three most frequent causes of defects are: Stakeholder Communication (22 occurrences; 25.9%), Management Strategies (18 occurrences; 21.2%) & Personnel (Skill/Workforce issues) (14 occurrences; 16.5%) Together, these three categories account for 63.5% of all defects, suggesting that the majority of issues stem from managerial and communication related weaknesses rather than technical execution or materials.

This analysis reveals that, Poor stakeholder communication (25.9%) is the leading defect contributor, highlighting a critical weakness in coordination among owners, contractors, consultants, and suppliers. Ineffective management strategies (21.2%) further reinforce a lack of proper planning, oversight, or risk management, which may lead to rework, schedule delays, or budget overruns. Personnel related issues (16.5%) reflect inadequate skills, training, or labor availability, which directly affects work quality and defect occurrence.

The remaining factors materials, techniques, design errors, and other collectively contribute 36.5% to defects in which Materials (12.9%) refer to poor quality or incorrect materials delivered on site. Techniques (10.6%) indicate the inappropriate or outdated use of construction methods. Design errors (8.2%) likely relate to conflicts or omissions in architectural or structural plans. Other causes (4.7%) are minor contributors, possibly covering unpredictable or external influences. Although these are lower on the frequency scale, they should not be ignored, especially when striving for higher sigma levels (fewer than 3.4 defects per million opportunities).

These defects not only affect the quality and usability of the buildings but also directly contribute to increased rework costs, project delays, and customer dissatisfaction. As rework typically consumes 5–15% of total project cost (Taylor et al., 2013) this inefficiency has substantial financial implications. In projects with limited budgets, high rework costs can compromise other project objectives such as safety, timely completion, and scope fulfillment.

The analysis of the fishbone diagram clearly identifies the lack of clear stakeholder communication as the most significant cause of defects in HCB and plastering work in Andode Village construction projects. Poor communication channels, misinterpretation of instructions, and inadequate reporting systems often lead to design execution errors, delayed corrections, and misaligned expectations between stakeholders. Following communication related issues, other major causes include poor workmanship, inadequate supervision, and poor management practices, as indicated in both the fishbone diagram and survey responses. These issues are deeply connected to the lack of skilled labor, insufficient vocational training, and minimal incentive structures, causing high turnover and inconsistent work quality.

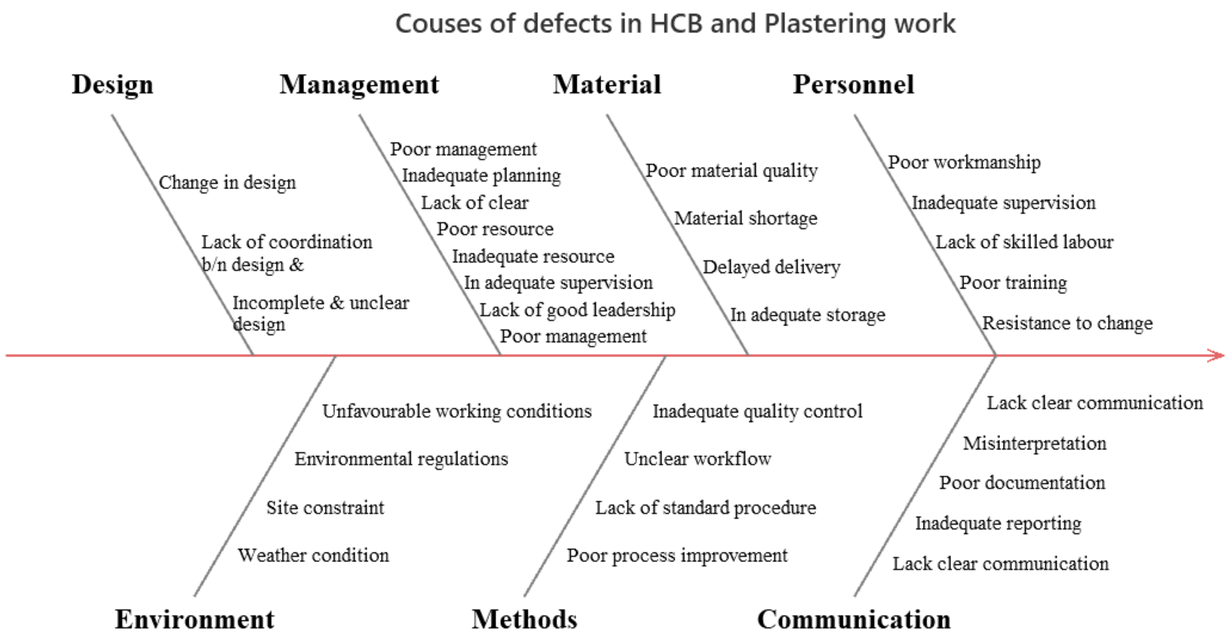

Figure 4.2 Fishbone diagram

While poor material quality and design errors also contribute to defects, their impact appears secondary compared to personnel and management related challenges. These insights align with both local and international research (Taylor et al., 2013) which highlights that without structured communication, supervision, and management systems, process improvement techniques and technical standards cannot be effectively implemented. Therefore, enhancing stakeholder coordination and site level communication should be prioritized to significantly reduce defects in Ethiopian construction projects.

Pareto chart displays the frequency and percentage of different defect types identified in the construction process, ordered from most to least frequent. The chart also includes a cumulative percentage line, illustrating the combined contribution of each defect type to the total defects. The top defects are Surface irregularities, Material gaps and voids, and Cracks in plastering. These three defects account for roughly 26% of total defects (9% + 9% + 8%). Approximately 80% of defects come from about 20% of defect types. Here, the first 5-6 defect types (covering about 57% of total defects) are the most significant contributors. Addressing these top defects could significantly reduce overall defects targeting surface irregularities, gaps/voids, and cracks.

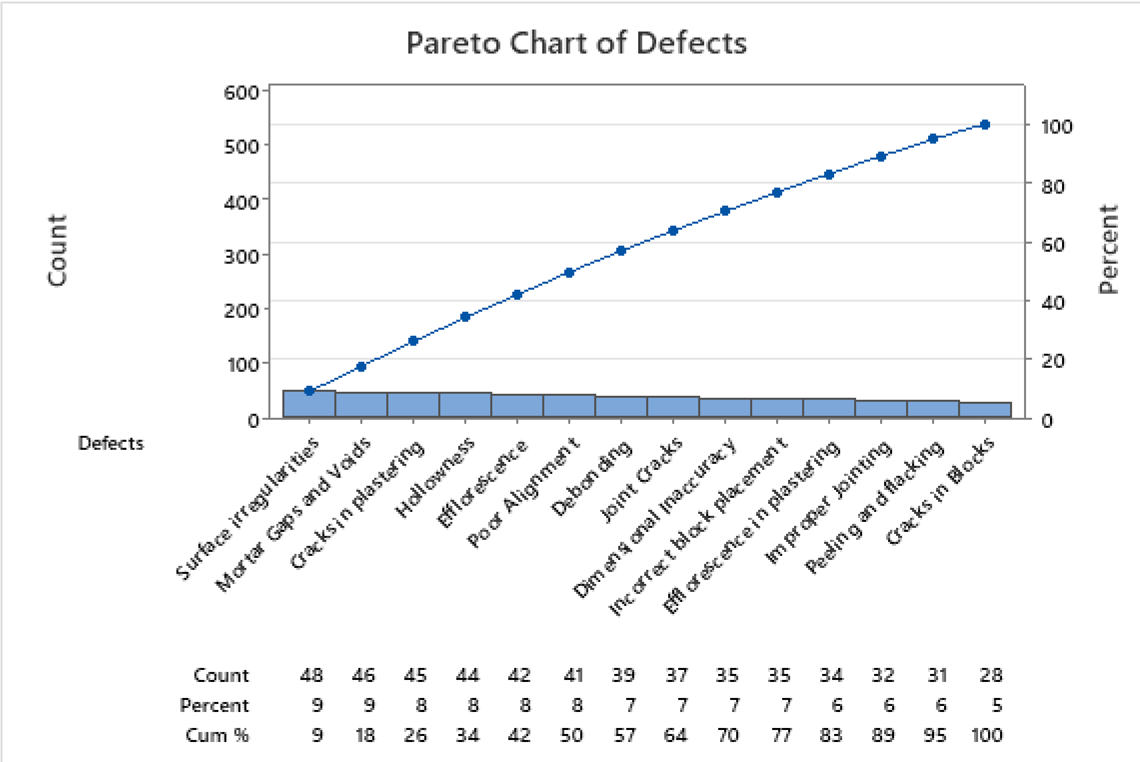

Figure 4.3: Pareto chart implication of defects

This finding reflects a broader organizational and cultural challenge, consistent with (Antony & Banuelas, 2002) who identified lack of training, management commitment, and strategic alignment as key obstacles to Six Sigma implementation in the construction sector. A Pareto analysis could show that a small number of defect types (such as cracks, surface irregularities, and misalignments) account for the majority of the quality issues consistent with the 80/20 rule. This finding aligns with previous studies by (Siddiqui et al., 2016) and , which emphasized the(Henderson & Evans, 2000) significance of poor workmanship, lack of supervision, and inadequate quality control in rework and defects. After addressing defects up to Dimensional inaccuracies, about **57%** of defects are covered. Prioritizing these areas will be most effective in improving quality and reducing waste. Use process improvements such as better training, quality control procedures, material inspection, and process standardization. After interventions, track defect reduction using similar Pareto charts to evaluate effectiveness.

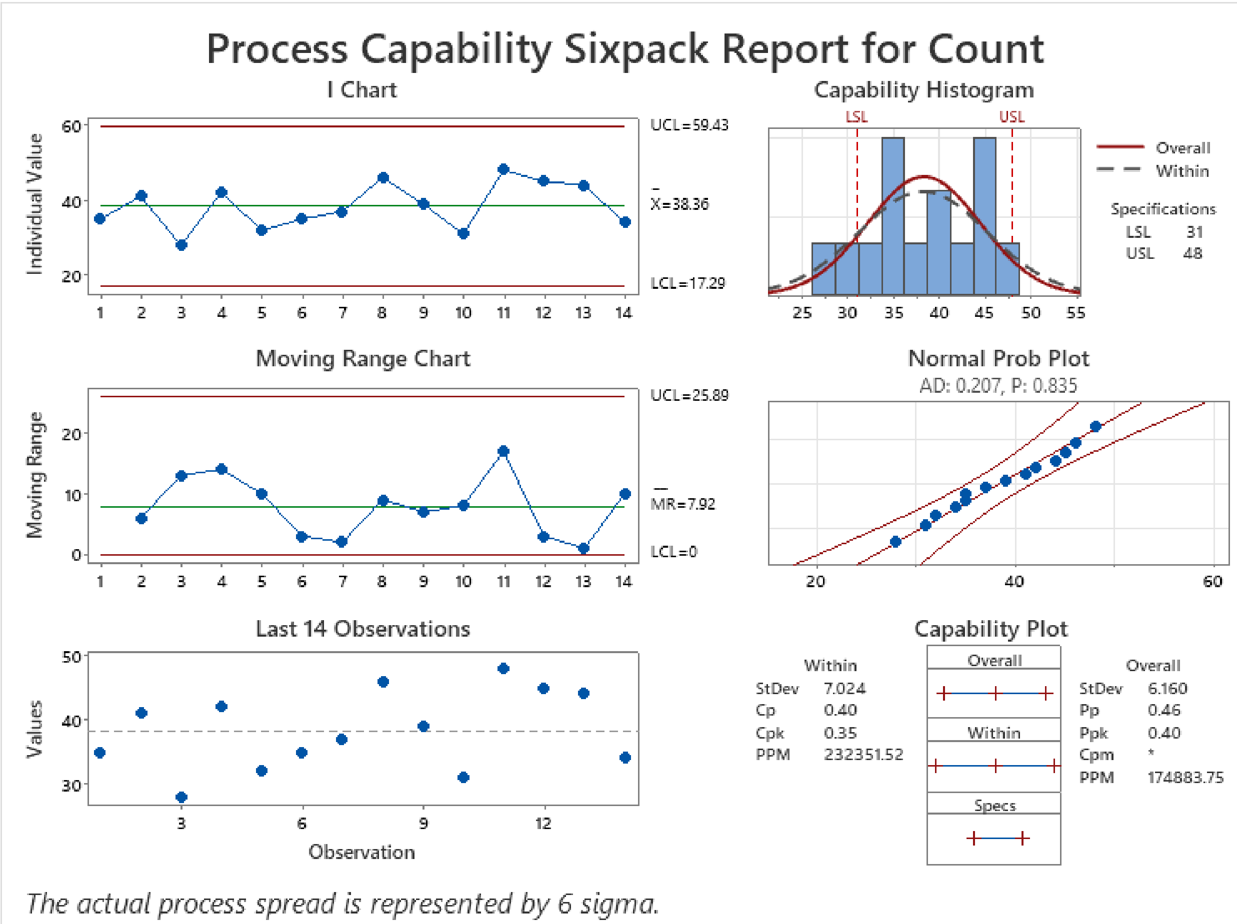

Figure 4.4 Process capability graph

Process Capability Analysis is a statistical tool used to measure how well a given process performs relative to its specified limits. In the context of Six Sigma methodology, this analysis provides essential insights into the stability and predictability of construction activities, especially regarding the frequency and types of defects encountered in building projects. In this study, a Process Capability Sixpack Report was generated using data collected from residential building construction projects in Adama. The goal was to evaluate how capable the current construction processes are in consistently meeting predefined quality specifications and to identify the degree of variation that contributes to rework.

The I-Chart displays the individual values of observed construction process outputs of number of defects or non-conformances per inspection lot. The data showed variation around a process mean ($\bar{X}$ = 38.36) with control limits set at UCL = 59.43 and LCL = 17.29. This range indicates significant variability, which is undesirable in a high-quality construction environment. The

Moving Range Chart further highlights instability in the process. The average moving range ($M\bar{R}$=7.92) and UCL = 25.89 suggest that fluctuations between consecutive construction activities are inconsistent and unpredictable. This implies that the construction process is not in a state of statistical control, which violates a key assumption for the effective application of Six Sigma.

The Capability Histogram compares the process data distribution against the specified limits set for acceptable performance Lower Specification Limit (LSL) = 31, Upper Specification Limit (USL) = 48. In the histogram, it is evident that a substantial portion of the data falls outside the specified range. The process mean is slightly skewed toward the LSL, indicating that the process is not centered. This misalignment reveals a high rate of defect occurrences and performance variability, which is symptomatic of poor process capability. The visual spread also supports the conclusion that corrective action is needed to realign the process to within acceptable tolerance limits. The process capability indices calculated from the dataset are as follows:

Table 4.2 Cp, Cpk, Pp, and Ppk values from the graph

No	Metrics	Value	Interpretation
1	CP	40	Indicates the potential capability of the process (based on spread) is far below the acceptable value of 1.33.
2	CPK	0.35	Indicates that the actual performance of the process is not only poor but also not centered within the specification limits.
3	Pp	0.46	The overall capability (long-term variation) also shows significant inefficiencies.
4	Ppk	0.4	Confirms that the process is not only inconsistent over time but also exhibits substantial misalignment.

These values are well below the industry accepted threshold of 1.33 for capable processes. The high PPM (Parts Per Million defective) values of 232,351.52 for within-subgroup performance and 174,883.75 for overall performance reveal a substantial level of non-conformance. This aligns with field observations in the Adama construction projects, where high rework rates, frequent defect occurrence, and schedule extensions were reported.

Corrective actions were introduced, focusing on: as enhancing communication among site teams, providing training for laborers on proper block laying and plastering, strengthening supervision and quality monitoring practices, creating incentive systems for consistent quality output. Following these interventions, a second round of data collection was conducted using the same checklist and sampling strategy. This time, only 314 defects were recorded out of 1,792 opportunities, resulting in a DPMO of 175,223.21, a Sigma level of 2.46, and a yield of 82.47% indicating a 12.47% improvement in quality performance. Although the sigma level remains below 3.0, this demonstrates that improvement efforts had a measurable impact on defect reduction.
This phase focuses on identifying and implementing solutions to eliminate defects in construction processes. A significant challenge in this context is the communication gap, shortage of skilled labor, often stemming from inadequate education, limited vocational training opportunities, and insufficient motivation due to low wages and delayed payments. These factors contribute to the migration of workers to other regions or countries in search of better compensation and working conditions. This fourth stages of DMAIC, is for designing, implementing and validating the improvements. In the improve phase, cost/benefit analysis is performed to facilitate a final improvement solution which is then implemented so that the process's performance satisfies the performance requirement(Samman & Graham, 2007).

Many construction workers are seasonal or migrants from agricultural regions, lacking formal training in construction activities. To address this, it is essential to provide comprehensive training programs that equip workers with the necessary skills and knowledge. Vocational education plays a crucial role in aligning the workforce's capabilities with industry demands, thereby enhancing overall workmanship. Studies have shown that ongoing training improves problem solving abilities, communication skills, and safety awareness among construction employees. Worker retention can be improved by ensuring timely payments, offering incentives, and maintaining a safe and supportive work environment. Implementing incentive systems has been linked to better safety performance among frontline employees

Addressing issues related to poor workmanship, such as the use of unsuitable tools and materials, requires proper maintenance and storage practices. Assigning dedicated supervisors to oversee these aspects can ensure tools are cleaned and stored appropriately, reducing damage and enhancing efficiency. Improving construction practices, particularly in plastering and HCB involves adhering to established standards and procedures. Ensuring proper mixing ratios cement to sand, adequate surface preparation, and appropriate curing methods can safe different defects. For instance, surfaces should be cleaned and roughened to promote adhesion, and techniques like spatter dash treatment can be employed to achieve the desired texture. Preventing rapid drying by pre wetting the base coat and maintaining moisture for at least 15 days is also crucial. Implementing effective project management practices, including regular monitoring and adherence to standards, can significantly reduce defects and enhance the quality of construction work.

Following the initial analysis, improvement actions were proposed and implemented on-site. These included: Corrective feedback to contractors, Site meetings emphasizing quality control, Enhanced supervision and inspection checklists and Training sessions for site Workers and Forman. The Six Sigma methodology, particularly its DMAIC framework, offers a structured and data driven approach for addressing exactly these types of problems. Implementing Six Sigma in construction especially in the HCB and plastering phases provides the following key benefits that directly target the root causes identified: Six Sigma emphasizes process mapping, standard operating procedures and roles and streamline information flow among stakeholders' clear documentation, which directly reduces communication gaps and misinterpretations. Tools such as SIPOC diagrams (Supplier-Input-Process-Output-Customer) and flowcharts help clarify.

Six Sigma fosters leadership accountability, data-driven decision-making, and the use of KPIs (Key Performance Indicators), With root cause analysis tools (e.g., Pareto, Fishbone, 5 Whys), managers can proactively identify and eliminate bottlenecks or inefficiencies before they escalate. Training is a core element in Six Sigma through certification levels (Yellow, Green, Black Belts), which ensures team members understand and execute their roles effectively. Motivation improves as workers become involved in quality improvement processes and are recognized for performance, reducing rework and enhancing quality. Six Sigma aims for a defect rate of less than 3.4 defects per million opportunities (DPMO), which promotes a culture of near-zero defects. This drastically reduces the cost of poor quality, improves productivity, and accelerates project delivery timelines. After these measures, a second round of inspections was conducted as shown in the table below.

From the above table 4.3, to calculate sigma for the processes, the DPMO or defects per million opportunities formula is used: DPMO= No. of defects x 1,000,000 / No. of opportunities x No. of units

DPMO= 314 x 1,000,000 / 1792= 175,223.21

Based on the sigma conversion table 2.1, the equivalent sigma for 175,223.21, DPMO was approximately 2.46s. This result shows a significant reduction in defects (223 fewer issues) and an increase in yield by 12.47%, indicating that the interventions had a measurable positive impact on construction quality performance. However, the sigma level is still below the acceptable industry benchmark of 3.0 (DPMO = 66,800), implying the need for deeper and more structured improvements.

Yield (%)= (1-DPMO/1M) x 100 = 82.47%

The higher sigma 2.46 achieved showed that the improvement measures taken were effective. If Contractors continues to implement these improvement measures, it can be expected to get the quality standards for internal finishes right more than 99% of the time. Based on this finding, this Contractors was encouraged to work towards getting the quality standards for internal finishes right all the time, i.e., moving towards achieving 6s.

Summary of Key Findings

Table 4.3: Key findings of the research

Item No	Metric	Before intervention	Before intervention	Improvement
1	Defect	537	314	223
2	DPMO	299,665.18	175,223.21	124,441.97
3	Sigma Level	2.02	2.46	0.44
4	Yield(%)	70	82.47	12.47

These results highlight that even though Six Sigma was not fully implemented in a formalized structure (e.g., full Six Sigma teams), the adoption of its tools and principles significantly enhanced construction quality in the project. As discussed before the improvement obtained only shows feedback for future in deep implementation of six sigma in this industry. As shown by (Sui Pheng & Sze Hui, 2004) improvement of 3.95 sigma level from 2.66 sigma in construction industry and

Table **4.4**: Second round defect data collection

Location		HCB Walls defects								Plastering work defects						
		Dimensional Inaccuracy	Poor Alignment	Cracks in Blocks	Efflorescence	Improper Jointing	Incorrect block placement	Joint Cracks	Mortar Gaps and Voids	Debonding	Peeling and flacking	Surface irregularities	Cracks	Hollowness	Efflorescence	**Total**
Bedroom	Wall 1	2	1	0	1	2	2	1	1	0	2	0	1	3	0	
	Wall 2	3	2	1	3	1	3	1	1	3	0	1	0	2	3	
	Wall 3	1	2	1	0	2	1	0	2	1	1	1	1	3	4	
	Wall 4	0	3	1	2	2	1	3	2	4	1	4	0	1	3	
Kitchen	Wall 1	2	2	1	3	1	1	1	2	1	1	3	1	2	1	
	Wall 2	0	1	1	0	1	2	0	0	2	0	3	1	1	1	
	Wall 3	1	3	2	0	2	1	3	0	3	1	2	3	2	1	
	Wall 4	1	0	2	2	1	1	1	1	0	2	2	1	1	1	
Toilet	Wall 1	2	1	2	0	3	1	0	1	1	1	1	1	3	0	
	Wall 2	3	3	2	1	1	1	1	0	1	1	2	0	1	1	
	Wall 3	1	1	1	0	2	3	3	2	1	1	1	3	4	0	
	Wall 4	2	2	3	1	2	1	1	2	1	2	3	1	2	1	
Dinning	Wall 1	0	1	3	0	1	0	0	3	2	3	0	1	1	0	
	Wall 2	1	0	2	1	1	2	1	1	3	1	2	0	2	1	
	Wall 3	1	1	2	2	1	1	1	1	0	2	0	2	3	1	
	Wall 4	1	2	2	0	1	2	0	1	2	1	1	1	3	2	
No. of defect		21	25	26	16	24	23	17	20	25	20	26	17	34	20	
No. of Checks		126	126	126	126	126	126	126	126	126	126	126	126	126	126	
Total Number of Defects																314
Total Number of Checks / Opportunity for defects																1792

when we compare the result of this study to this value it is a relatively minimum improvement. Not only this a research by (Heon Han et al., 2008) also shown as an improvement level from 1.34sigma level to 3.64 sigma which shows a yield of approximately 99.74% from. So in conclusion the applicability and effectiveness of Six Sigma methodologies in improving construction project performance has a positive effect.

Several studies and real world projects have successfully implemented six sigma principles to enhance various aspects of construction performance. (Chang et al., 2012) applied six sigma to precast component manufacturing, reducing production time from 15.87 to 13.04 hours per unit, while also reducing standard deviation from 4.59 to 1.47. These results demonstrate the methodology's ability to increase productivity and reduce process variability.

(Sui Pheng & Sze Hui, 2004) conducted a case study applying Six Sigma to internal plastering works in Singapore. Through focused process mapping and stakeholder training, the project improved sigma levels from 2.66 to 3.95, significantly enhancing quality. This shows the methodology's applicability even in highly variable, labor intensive tasks.

(Heon Han et al., 2008) used a Six Sigma based model to enhance performance in reinforcement bar assembly. By identifying major sources of delay and applying root cause analysis, the project achieved a sigma level of 3.64 from an initial level of 1.41 and demonstrating significant potential in streamlining repetitive structural tasks. These examples validate the versatility and effectiveness of Six Sigma in improving construction productivity, reducing costs, and increasing quality, even in traditionally hard-to-control tasks.

4.2.3 Conceptual Framework for Six Sigma Implementation in Ethiopian Construction

Developing a Six Sigma implementation framework for the Ethiopian building construction sector requires a hybrid approach that blends global best practices with local realities. While literature offers robust methodologies and success cases, there remains a pressing need to design a practical, context sensitive framework that addresses systemic inefficiencies in Ethiopian projects. Such a framework must emphasize leadership involvement, process simplicity, measurable performance, and workforce empowerment to be sustainable and effective.

To sustain these improvements, a control framework was developed, incorporating: a defect tracking system with regular quality audits**.** Clear reporting structures and accountability mechanisms**.** Ongoing training programs and feedback loops between project stakeholders is very important. The framework was validated with stakeholders to ensure its practicality and was designed to be scalable across other similar residential construction projects in Ethiopia. This is the last stage of DMAIC, is for the institutionalization of process/product improvements and following performance. This is a transition phase of process from Six Sigma team to original executers under detailed control plan. The improvement is maintained to ensure the gains in performance remain in the long term (Samman & Graham, 2007).

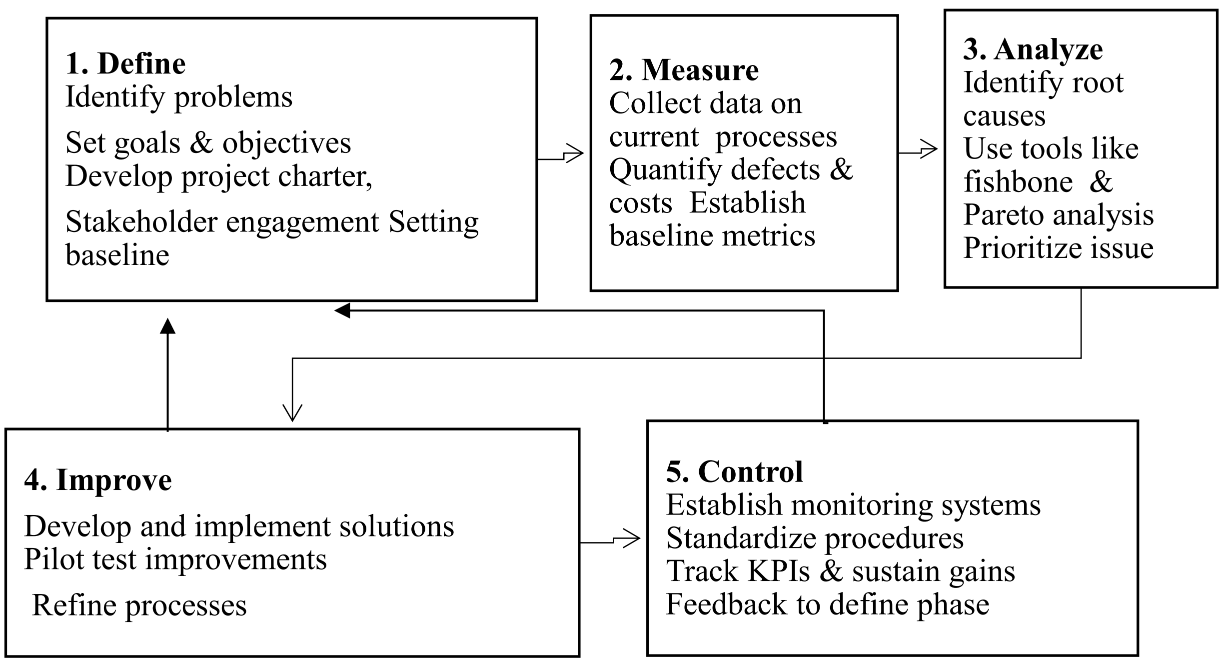

Figure 4.5: Six sigma implementation frame work

The frame work above has been discussed bellow in detail by explaining every and each activity in each phase of the DMAIC stages.

Define phase:- Identify critical processes (e.g., HCB and plastering), engage stakeholders, and map defect prone areas. The Define phase begins by identifying key problems commonly encountered in the construction sector, such as cost overruns, project delays, and recurring quality defects. These inefficiencies are addressed by clearly defining the scope and goals of the Six Sigma project through tools such as project charters. Objectives are established with a focus on minimizing defects, reducing rework costs, and enhancing overall project quality. A crucial part of this phase involves stakeholder engagement actively involving clients, contractors, consultants, and other key actors to build mutual understanding of the benefits and expectations of Six Sigma implementation. This collaborative foundation ensures alignment of goals and commitment from all involved parties.

Measure Phase: Develop tools (e.g., check sheets, audit templates) to quantify defects and calculate DPMO. The Measure phase focuses on gathering accurate, quantitative data to establish a baseline for performance evaluation. Data is collected through a combination of methods, including structured surveys, on-site inspections, and defect assessment sheets. These tools help assess the current process conditions and document the extent of quality-related issues. A key metric calculated at this stage is the Defects per Million Opportunities (DPMO), which serves to quantify the number of defects and measure process efficiency. Furthermore, financial data is collected to determine the cost implications of defects and rework, providing valuable insights into economic inefficiencies within the project.

Analyze Phase: Use Pareto and Fishbone tools to uncover major causes—typically related to communication gaps, lack of skills, or poor supervision. In the Analyze phase, the primary goal is to determine the root causes of the defects identified. Root cause analysis is carried out using structured tools such as Fishbone (Ishikawa) diagrams and Pareto analysis. These tools help prioritize problems based on their frequency and impact. Stakeholder interviews and engagement sessions are also conducted to extract insights on process weaknesses and quality control challenges. Special attention is given to recurring issues such as poor communication, inadequate supervision, and lack of coordination, as these are identified as major contributors to defects and process inefficiencies. Independent Variables (Root Causes): These are the factors contributing to construction inefficiencies: Poor communication, Inadequate supervision, Lack of skilled labor, Poor planning and scheduling, Material management issues, Weak quality control and Stakeholder misalignment

Improve Phase: Apply low-cost, high-impact solutions like workforce training, site meetings, and checklist-based inspections. The Improve phase involves the formulation and implementation of corrective measures aimed at addressing the root causes identified in the previous stage. This includes the design of training programs for workers, adoption of better material management strategies, and improvements in quality supervision practices. Proposed solutions are subjected to

Failure Mode and Effects Analysis (FMEA) to anticipate and mitigate risks associated with implementation. Once verified, corrective actions are put into practice to systematically eliminate the sources of major defects. These interventions aim to elevate the quality performance of the project and reduce defect-related costs.

Control Phase: The final phase, Control, ensures that the improvements achieved are sustained over time. Institutionalize the changes through continuous monitoring and simple KPI dashboards. A monitoring framework is established with clear metrics and action protocols for quality control and continuous improvement. This framework includes procedures for ongoing defect tracking and feedback loops for performance evaluation. Stakeholder feedback is sought on the proposed process changes to validate practicality and encourage adoption. Based on this feedback, refinements are made to enhance the framework's relevance and feasibility. Long-term sustainability is promoted by embedding the improved practices into the standard project lifecycle, thereby institutionalizing Six Sigma principles within the construction process.

The expected outcomes from this frame work are the dependent variables (Outputs**):** Reduction in number of defects, Improved Sigma level, Improved construction quality, Increased project performance and stakeholder satisfaction. This framework should also incorporate feedback loops from field data and adapt to future technological improvements such as digital inspection tools and mobile reporting systems.

4.3 General Reflections

The first objective aimed to quantify existing defects and inefficiencies in hollow concrete block and internal plastering works within the Adama Andode Village residential building project. Two rounds of structured observations were conducted using defect check sheets. The pre-intervention phase recorded a total of 537 defects, which were subsequently reduced to 314 post-intervention representing a 41.5% reduction. The most frequently observed defects included: Cracks and surface irregularities in plastering, misalignment and joint gaps in HCB installation, and uneven finishes. From these observations, the pre-intervention defect rate translated to a defects per million opportunities (DPMO) value of 299,665.18 and a sigma level of 2.02. After the implementation of quality improvement measures, the DPMO dropped to 175,223.21, and the sigma level improved to 2.46. These results indicate that prior to Six Sigma implementation, the construction processes were operating with high levels of variability and inefficiency, consistent with global findings in underperforming construction environments (Taylor et al., 2013) & (Nawade et al., 2022).

Root cause analysis using the Fishbone diagram and Pareto chart revealed that more than 60% of defects originated from organizational issues specifically inadequate supervision, poor stakeholder communication, and unskilled labor. These insights align with the literature (Forcada et al., 2016) reinforcing the need to address not only technical flaws but also systemic process weaknesses in construction management.

The second objective focused on evaluating whether Six Sigma methodologies are effective in enhancing construction project performance in the Ethiopian context. These results in table 6 demonstrate that even a basic implementation of Six Sigma, without full integration of belt-certified roles or advanced software, can significantly enhance process outcomes in Ethiopian residential construction projects. Compared to global benchmarks: Singapore (Sui Pheng & Sze Hui, 2004) reported an increase from 2.66 to 3.95 sigma in plastering work. South Korea (Heon Han et al., 2008) reported sigma improvement from 1.34 to 3.64 in reinforcement bar assembly. China (Chang et al., 2012) reported significant productivity improvements in precast component fabrication.

While the improvements in the present study are smaller, they were achieved in a resource-constrained environment with limited access to Six Sigma professionals, simulation software, and institutionalized quality frameworks. This demonstrates the adaptability and scalability of Six Sigma, even in developing countries where traditional quality control methods are rarely formalized. Moreover, the study confirms prior claims by (Kwak & Anbari, 2006) that Six Sigma principles can lead to measurable gains in customer satisfaction, process consistency, and overall project quality when customized to suit the local construction environment.

The final objective involved formulating a practical and scalable conceptual framework for Six Sigma implementation within the Ethiopian building construction sector. The framework was developed based on the research findings, DMAIC structure, and contextual constraints identified during fieldwork. Unlike the full-scale implementation models used in developed countries (e.g., Six Sigma belts, automated measurement tools), this framework was designed for simplicity and adaptability, relying on manual processes and practical tools that can be readily adopted in local projects. This approach addresses the research gap identified by (Dagne, 2023), who emphasized the lack of localized Six Sigma frameworks in Ethiopian construction literature.

By anchoring the framework in actual project data, and validating it through field implementation, the study contributes a robust, evidence based guide for contractors, consultants, and policymakers interested in improving quality performance in Ethiopia's urban housing sector. The framework is also aligned with the findings of (Stewart & Spencer, 2006), who advocate for tailored Six Sigma models in high variability environments like construction.

The combined findings from all three objectives validate the central thesis that Six Sigma is both applicable and effective in the Ethiopian construction context. While international benchmarks such as a 3.95 sigma level were not achieved, the observed improvements in process yield, defect reduction, and process consistency are substantial. They reinforce the importance of adopting data-driven, structured methodologies in a sector long plagued by inefficiencies, rework, and quality deficiencies. Furthermore, the research highlights the need for future efforts to focus on: Institutionalizing Six Sigma training (Green Belts, Black Belts), integrating digital tools (Minitab), expanding the methodology across more project phases (beyond construction). Such efforts would position Six Sigma as a transformative quality management tool capable of raising construction standards across Ethiopia and similar developing economies.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the application of Six Sigma methodology within the Ethiopian construction sector, particularly in the residential projects of Adama Andode Village, has revealed significant quality management gaps that hinder overall project success. The study demonstrated that despite achieving some improvements, the quality of construction still falls below the industry standards. By implementing the Six Sigma framework, specifically the DMAIC process, the research identified major defects within construction practices, particularly regarding HCB (hollow concrete block) and plastering work.

The effective interventions led to a reduction in the total number of defects from an initial count of 537 down to 314, indicating a significant quality enhancement. This corresponds to a notable improvement in yield, rising by 12.47%, and achieving a sigma level of approximately 2.46. However, this performance is still below the acceptable industry benchmark of 3.0, which points to the need for further structured improvements and adaptation to local conditions.

It is imperative for stakeholders, including clients, contractors, and consultants, to integrate Six Sigma principles more deeply into their processes. This integration would not only address current inefficiencies but also promote a culture of continuous improvement, thereby enhancing project quality, minimizing rework costs, and ensuring better alignment with customer expectations. By focusing on structured communication, thorough training, and effective management practices, the Ethiopian construction industry can significantly elevate its standards and contribute more effectively to the nation's economic development.

5.2 Recommendation

In the recommendations section, the document outlines actionable strategies for stakeholders to adopt Six Sigma methodologies. It stresses the importance of tailored implementation that considers local conditions and issues specific to the Ethiopian construction sector, aiming to bridge existing quality gaps and improve performance through structured process improvement.

The overall focus is on adopting a targeted Six Sigma framework to not only reduce defects and inefficiencies but also to foster better project management practices and enhance the quality of constructions in Ethiopia.

Future research should explore the adaptation of Six Sigma methodologies beyond residential construction to other segments of the Ethiopian construction industry, such as infrastructure, commercial buildings, and public projects. This could help to identify industry-specific hurdles and best practices related to process improvement.

Investigate the integration of Six Sigma with other local practices and methodologies, such as lean construction or total quality management, tailored specifically to the Ethiopian context. Understanding how these approaches can complement each other may yield more effective results.

Explore the role of technology, such as Building Information Modeling (BIM) and construction management software, in enhancing Six Sigma implementation. Research could examine how technological tools can facilitate data collection, monitoring, and process management in line with Six Sigma principles.

There is a need for further empirical studies quantifying the financial impacts of rework and inefficiencies in construction projects using precise Six Sigma tools. This data can help construction companies justify investments in Six Sigma training and implementation.

Developing in-depth case studies that document successful applications of Six Sigma in various construction projects can serve as models for future implementations. This research could highlight overcoming common challenges in the Ethiopian context.

Future studies should consider formulating policy recommendations based on the findings related to Six Sigma implementation barriers and challenges. Collaborating with governmental and regulatory bodies to improve construction standards may enhance the overall construction industry's quality and efficiencies.

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Appendix I

Questionaries

Dear respondent

My name is Genet Neguse. I am attending my Master's Degree in Construction engineering and Management at Adama science and technology University and carrying out academic research on Application of Six sigma methodology in Ethiopian building construction sector: A Case in Adama Residential Building construction. For my study I prepared a questionnaire which contains two parts; the demographic part and the question or statement part. I kindly request you to fill the attached demographic and defect related questionnaires and the return date will be up to 7 days from today. I would like to assure that the information acquired shall be used only for academic purpose and will be kept strictly confidential. Please indicate your level of agreement or disagreement by using (√) mark on the appropriate box given corresponding to each statement, and state your opinion on the space provided for open question. This survey aims to collect data on construction inefficiencies, defects, and quality control practices in Ethiopian construction projects. The results will help analyze Six Sigma's potential application to improve construction efficiency in Ethiopian Construction sector.

Thank you for your cooperation, devotion and precious time taken.

Genet Neguse

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PART ONE – DEMOGRAPHIC INFORMATIONS

Section one: Demographic data of the respondent

Please tick {✓} where appropriate and provide brief answer where necessary

1. Name of respondent__________

2. Company Name _______________

3. Organization type: ☐Government ☐ Private ☐ Both

4. Years of experience in construction industry:☐ 1-5 years ☐ 6-10years☐ Greater than 10 year

5. Position in the organization: ☐Project Manager ☐Site Engineer ☐Office Engineer ☐Quality engineer ☐Client ☐ Consultant

6. Educational Qualification: ☐PHD ☐ Masters Degree ☐ Bachelor's Degree Other:

Section two: Question related to the study

1. Primary causes of defects in Ethiopian construction projects. Please rate using the following scale 1-5. 1= Very low, 2= Low, 3= Medium, 4 = High, 5= Very High

	1	2	3	4	
1. Poor process improvement technique	☐	☐	☐	☐	☐
2. Lack of clear communication	☐	☐	☐	☐	☐
3. Poor workmanship	☐	☐	☐	☐	☐
4. Poor management practices	☐	☐	☐	☐	☐
5. Inadequate supervision	☐	☐	☐	☐	☐
6. Design errors	☐	☐	☐	☐	☐
7. Poor material quality	☐	☐	☐	☐	☐
8. Environmental factors	☐	☐	☐	☐	☐

Appendix II

Interviews

1. Is there any quality department in your company?
2. If your answer to number 5 is yes, are the employees in your company trained for quality?
3. How often does the top management provide the employees essential training opportunities to match their competencies with the company?
4. Are you familiar with new process improvements methods like Six Sigma? Six sigma is a process improvement method that can be used to minimize defect and inefficiencies to 3.4 per million opportunities which follows define, measure, analyze, improve and control step.
5. Do you believe Six Sigma could improve quality and efficiency in Ethiopian construction projects?
6. What are the biggest challenges your company faces to deliver defect free construction projects?
7. What solutions do you propose for reducing inefficiencies and defects in Ethiopian construction projects?
8. If your company were to implement new process improvements like Six Sigma, what do you think would be the biggest obstacles to overcome?
9. What kind of support would be necessary for successful Six Sigma implementation in your company?

Figure 1 Project Picture