

**EXPLORING THE MODERATING ROLE OF
ARTIFICIAL INTELLIGENCE ON THE IMPACT
OF QUALITY MANAGEMENT ON
CONSTRUCTION PROJECT OUTCOMES**

(A Case Study of Jeddah Stormwater Program)

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Table of Contents

Overview	1
Keywords	5
Problem Statement	5
Purpose of the Study	6
Significance of Study	7
Practical Background	8
Hypothesis.....	10
Theoretical Background.....	12
Literature Review	21
References.....	34

Overview

Over the past decades, technological innovations have significantly transformed business practices across industries, with the construction sector experiencing particularly noteworthy benefits. Advancements such as Building Information Modeling, automated and robotic construction technologies, and advanced project management software have revolutionized the planning, execution, and management of construction projects (Regona et al., 2022). These technological tools enable more precise planning, enhanced communication among stakeholders, and improved resource allocation efficiency, all of which contribute to more effective project scope, cost, time, and quality management. Furthermore, integrating IoT devices and sensors on construction sites facilitates real-time monitoring of project progress and conditions, allowing for proactive management of schedules and safety standards (Abioye et al., 2021). Technological advancements have profoundly impacted businesses in various sectors, but the construction industry has particularly benefited from these innovations, enabling more precise and improved project management.

Among the most promising and rapidly evolving technological advancements in construction is the application of Artificial Intelligence and Machine Learning. Artificial Intelligence and Machine Learning have emerged as transformative technologies that are revolutionizing business operations and project management across industries, with the construction sector poised to particularly benefit from their application (Dip Datta et al., 2024). In project management, AI's ability to analyze vast amounts of data enables predictive analytics and machine learning models to accurately forecast project timelines, budget variances, and potential risks. AI also can automate complex tasks like scheduling and resource allocation, enhancing efficiency and decision-making. AI-driven tools can assess ongoing project metrics, optimize project delivery, and ensure adherence to schedules and budgets (Sahadevan, 2023).

In construction project management, successful outcomes rely on balancing quality, time, and cost—principles known as the **Project Management Triangle** or **Triple Constraint** (Barnes, 1960s). Changes to one of these elements typically affect the others, impacting the overall project performance. Beyond these core outcomes, **customer satisfaction** is a crucial measure of success, reflecting the extent to which the project met or exceeded client expectations. This study explores how AI technology can act as a moderating factor, optimizing the balance

between these constraints in construction quality management practices. By focusing on quality, time, cost, and customer satisfaction, this research aims to demonstrate how AI-enhanced quality management practices can help deliver more efficient, high-quality projects that satisfy client needs.

Quality management in the construction industry is critical, ensuring that projects meet predefined standards and regulations through meticulous planning, rigorous testing, and continuous oversight. Construction firms leverage a diverse array of quality management processes and techniques throughout the project lifecycle to monitor, control, and enhance the quality of their work, beginning with the initial conceptual design stage and continuing through the final construction and handover phases. This management approach encompasses various processes to enhance efficiency, minimize waste, and ensure adherence to the project's Scope, cost, and time constraints. Effective quality management directly impacts a project's success by involving systematic procedures such as quality planning, quality control, quality assurance, and quality improvement, each tailored to uphold the highest standards throughout the lifecycle of a project. By emphasizing prevention over rectification, quality management reduces rework and delays, helps maintain budget control, and enhances overall project value.

As construction projects grow in complexity, robust quality management becomes more pivotal, ensuring that each phase of the project aligns with the strategic goals and quality benchmarks set forth at its inception. Keeping up with the expanding complexity and size of construction projects can challenge traditional quality management practices. Additionally, the construction industry encounters various obstacles like tight schedules, budget limitations, and a need for more skilled labor. These difficulties underscore the demand for inventive strategies in quality management within construction projects; one promising approach involves incorporating AI technology (Seyman-Güray, 2023).

Artificial intelligence presents the opportunity for a paradigm shift in construction quality management (CQM) by leveraging advanced algorithms and data analysis capabilities, which can improve the efficiency and accuracy of overall traditional quality management practices while also addressing some of the critical challenges faced in the industry. Datta et al., 2024 and Makaula et al., 2021 investigated how harnessing the power of AI by construction companies can automate routine quality control processes, detect defects or deviations more effectively, and optimize resource allocation for improved project outcomes. Furthermore, AI

improves quality management by using image recognition and computer vision technologies to monitor construction progress, detect deviations in real-time, and ensure compliance with safety regulations. This integration of AI streamlines operations and fosters a proactive and adaptive project management approach, redefining traditional project delivery and setting new standards for efficiency and quality in the construction industry.

However, despite the potential benefits of AI in CQM, there still needs to be a gap in understanding the moderating role of AI on the impact of quality management on construction project outcomes (Makaula *et al.*, 2021). This research will explore the potential of AI technologies, such as machine learning, computer vision, and natural language processing, to enhance existing CQM practices. Recognizing the limited research examining this potential within the Saudi Arabian context and the scarcity of case studies on AI applications in the construction industry, this study will offer valuable insights. Using the Jeddah Stormwater Program as a case study will explore the interplay between AI and established CQM processes in a real-world setting. The case study aims to reveal current practices' limitations and AI's opportunities for optimization. It will help in future projects to ensure that AI is effectively integrated and utilized for optimal project results and provide recommendations for researchers, policymakers, and industry professionals in adopting AI for quality management in construction projects.

Keywords

Quality Management, AI, Construction Project Outcomes, Infrastructure Projects

Problem statement

The Saudi Vision 2030 outlines a bold roadmap for national transformation, with infrastructure development playing a pivotal role in improving the quality of life for citizens, fostering vibrant cities, and promoting environmental responsibility. The construction industry is instrumental in realizing these infrastructure goals that demand robust quality management in construction, highlighting the potential of Artificial Intelligence (AI) to transform quality practices (Vision2030). Despite this potential, the adoption of AI within the Saudi Arabian construction industry still needs to be improved. Effective quality management is crucial for complex construction projects, yet the impact of CQM can be influenced significantly by

technological factors, particularly AI (Neyestani, 2016). Research is crucial to understanding AI's moderating role and its capacity to enhance Construction Quality Management (CQM) by exploring how AI-powered data analysis can preemptively identify quality issues, reduce reworks, predict project risks, and optimize resource allocation.

However, more research will be needed to understand how integrating AI with quality management practices impacts construction project outcomes, particularly within the Saudi Arabian context (Datta et al., 2024). Existing global studies often focus on the general advantages of AI in construction, especially related to project outcomes, but not the specific challenges and established practices of the Saudi Arabian construction sector. More focused research is needed to ensure our understanding of effectively integrating these technologies with existing quality practices to optimize project outcomes.

Purpose of the Study

Given the potential benefits of AI in improving construction project outcomes through enhanced quality management, this research aims to explore the moderating role of artificial intelligence in improving the effectiveness of quality management practices in construction projects. The study will focus on infrastructure projects, which are typically complex and involve multiple stakeholders. They are crucial in driving economic growth, improving quality of life, and fostering long-term sustainability in the Saudi Arabian construction industry. This study will employ a mixed-methods approach to critically assess AI's direct and moderate impact on quality management processes and their subsequent effects on project cost, Schedule, work quality, and customer satisfaction. The specific objectives of the study are:

1. **Comprehensive Review:** Conduct a comprehensive review of empirical studies that investigate the impact of AI on construction CQM practices and project outcomes, aiming to synthesize key findings and identify gaps in the current literature.
2. **Current state of quality:** Assess the current CQM practices in JSWP and identify critical challenges and areas of possible improvement.
3. **Examine the moderating role of AI:** Investigate the relationship between CQM practices and project outcomes, focusing on AI's moderating role in translating CQM capabilities into tangible improvements. This will be achieved by gathering data from selected contractors and surveying approximately 100 project stakeholders within JSWP projects.

4. **Identify challenges:** Based on insights gathered from the selected contractors, identify and analyze the challenges associated with implementing AI-driven CQM practices in infrastructure projects (construction).
5. **Explore future opportunities:** "Explore emerging opportunities for AI to enhance CQM practices in infrastructure projects further and outline future research directions based on the findings from the study.

Significance of Study

Theoretical Contributions: This research seeks to fill a significant gap in construction management literature by empirically investigating the moderating role of Artificial Intelligence (AI) in quality management within construction projects. It will enhance theoretical frameworks by integrating advanced AI technologies, such as machine learning and computer vision, and examining their impact on the effectiveness of quality management practices. This study will contribute to a deeper academic understanding of how AI can be systematically applied to improve construction project outcomes, offering a new perspective on the interplay between technology and project management.

Practical Implications: The study is poised to offer substantial value to the construction industry, particularly within the context of the Jeddah Stormwater Program (JSWP). The findings will help develop more efficient, cost-effective, and high-quality construction practices by exploring and validating AI-driven quality management approaches. The insights gained could lead to the development of refined AI-enhanced quality management frameworks that reduce rework, delays, optimize resource allocation, and improve stakeholder satisfaction, thus providing a model for future construction projects in Saudi Arabia.

Expected Added Value: The integration of AI in managing complex infrastructure projects, as explored in this study, aligns with the strategic goals of Saudi Vision 2030. The successful application of AI in the JSWP could serve as a benchmark for the national construction industry, promoting broader adoption of intelligent technologies. This research will provide actionable strategies for leveraging AI to overcome common quality management challenges, enhancing project delivery across the board. Furthermore, the study recommends that policymakers, project managers, and industry professionals adopt AI-driven solutions, potentially transforming construction practices nationally and internationally.

Practical Background

The Jeddah Storm Water Program (JSWP), tasked with a significant overhaul of the city's stormwater management systems, involves 89 projects that incorporate similar construction activities such as excavation, laying network pipes, installation of manholes and catch basins, and construction of marine outfalls and pumping stations. Despite these projects being similar in concept and executed by the same contractors, they continue to encounter persistent issues.

These issues include material defects, supply and handling challenges, and inadequate quality control measures, which compromise the effectiveness and efficiency of the construction efforts. The projects need adequate supervision, which is exacerbated by the increased high volume of simultaneous projects, leading to frequent utility conflicts and substantial delays. These conflicts often result in prolonged processes for design approvals and modifications and frequent issues with shop drawing modification and approval. Such delays increase resident complaints due to prolonged excavation works, escalate the cost of reworks, and affect the overall project's progress.

Moreover, a critical challenge exacerbating these problems is some contractors' non-compliance with established work procedures and method statements. This disregard for protocol leads to quality issues and undermines strategic quality management efforts to meet project standards. Integrating advanced monitoring and compliance technologies, such as Artificial Intelligence (AI), is imperative. Projects can promptly identify deviations and enforce corrective actions by leveraging AI to automate compliance checks and monitor adherence to method statements in real-time. This proactive approach mitigates the risk of non-compliance and enhances overall project delivery.

Compounding these challenges is the risk associated with the rainfall season, which can severely impact both ongoing projects and the residential areas if managed promptly and effectively. Addressing these issues is critical to meet the immediate project timelines and align with broader strategic goals such as those outlined in Saudi Vision 2030. Integrating AI into project management practices presents a potential solution. By leveraging AI's capabilities in predictive analytics and automated decision-making, there is a significant opportunity to enhance the management of such complex infrastructure projects, ultimately ensuring they are delivered efficiently, within budget, and to the highest quality standards.

This research aims to fill this gap by focusing on integrating AI into CQM practices, particularly in stormwater network projects, examining several vital aspects, and identifying the most impactful ways to tailor AI solutions to the unique context of Saudi Arabia's construction industry. Successful Integration of AI will benefit JSWP in overcoming some of the quality issues and concerns in four significant areas of quality management within the project, areas are:

1. **Quality Planning:** Exploring how AI-enhanced planning can improve overall quality and mitigate cost overruns and delays, improving economic and temporal efficiency in stormwater network projects.
2. **Quality Control:** Analyzing how AI-driven tools detect/predict and correct defects early in construction.
3. **Quality Assurance:** Assessing AI's role in enhancing adherence to quality standards and related project requirements, which are crucial for the integrity of stormwater projects.
4. **Quality Improvement:** Investigating how AI contributes to the sustainability and resilience of stormwater networks, mainly through failure detection, and recommending preventive measures based on pattern recognition from historical data.

Against this backdrop of exploring AI's potential to transform areas of CQM practices, the research is structured around two critical questions:

Research Question 1: Is there an impact of quality management on project management outcomes?

This question explores the comprehensive impact of quality management practices on the core outcomes of project management within stormwater network projects. The sub-questions to address project outcomes will be:

- **Question 1.1:** Is there an impact of quality management practices on the quality of construction projects work?
- **Question 1.2:** Is there an impact of quality management practices on the cost outcomes in construction projects?
- **Question 1.3:** Is there an impact of quality management practices on the Schedule of construction projects?
- **Question 1.4:** Is there an impact of quality management practices on customer satisfaction within construction projects?

Research Question 2: Does artificial intelligence modify the impact relationship between quality management and project management outcomes?

This research question will explore how AI, as a moderating factor, influences the relationship between quality management practices and project management outcomes.

Hypothesis

CQM is essential for ensuring projects' success and sustainability in the rapidly evolving construction industry. With the ongoing development of AI, there is significant interest in leveraging its capabilities to enhance the efficiency, accuracy, and overall outcomes of CQM practices. Through this approach, the study aims to offer a comprehensive analysis of AI's role in refining CQM processes and its broader implications on the efficiency and success of infrastructure projects, particularly in stormwater network management. The following hypotheses were formulated to guide this investigation:

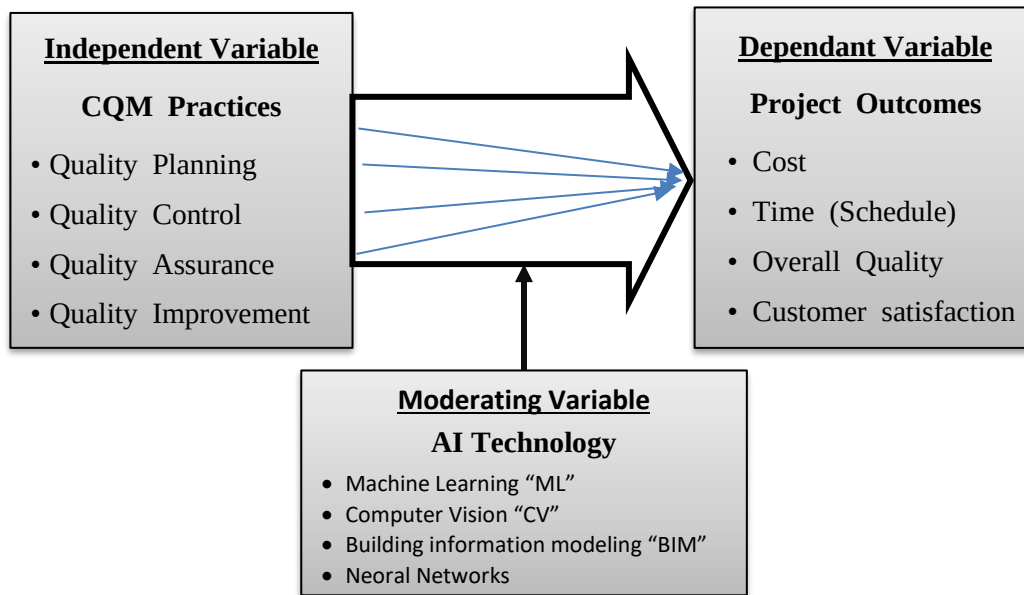
Hypothesis (H1):

Quality management practices significantly improve the overall project management outcomes in stormwater network projects.

- **Hypothesis (H1a):** Comprehensive quality management practices significantly enhance construction project work quality.
- **Hypothesis (H1b):** Comprehensive quality management practices significantly reduce the cost overruns in construction projects.
- **Hypothesis (H1c):** Integrated quality management practices are significantly associated with better adherence to project schedules.
- **Hypothesis (H1d):** Quality management practices increase customer satisfaction in construction projects.

Hypothesis (H2):

Artificial intelligence acts as a moderating variable, enhancing the positive effects of quality management practices on project management outcomes. This improves the quality of work, cost efficiency, schedule adherence, and customer satisfaction.



The diagram represents the variables and their relationships
Source: prepared by the researcher

Theoretical background

The concept of quality management has evolved significantly since its early applications in manufacturing, transforming industries by promoting consistency, efficiency, and customer satisfaction. Initially focused on basic inspection and defect detection, quality management has developed into a sophisticated system that integrates planning, control, and continuous improvement to enhance organizational performance. This evolution reflects an increasing awareness that quality is not merely a production issue but a fundamental organizational objective. In construction, where project complexity and stakeholder expectations are high, robust quality management is crucial for meeting performance goals and sustaining competitive advantage.

Several pioneering figures, often called quality management "gurus," laid the groundwork for modern quality practices. **Walter Shewhart**, often called the father of statistical quality control, introduced the concept of **control charts** to monitor process variability in the 1920s. Building on Shewhart's ideas, **W. Edwards Deming** promoted continuous improvement through his **PDCA cycle** (Plan-Do-Check-Act) and emphasized data-driven decision-making. In the 1950s, **Joseph Juran** introduced the **Quality Trilogy**—quality planning, control, and improvement—which underscored the importance of quality as a company-wide responsibility. **Philip Crosby** added to this foundation with his philosophy of **zero defects** and the idea that "quality is free," advocating for preventive measures over costly corrections. **Armand Feigenbaum** introduced **Total Quality Control (TQC)**, asserting that quality should be integrated across all departments. At the same time, **Kaoru Ishikawa** emphasized the role of collaborative problem-solving and developed tools like the **fishbone diagram** for root-cause analysis.

These contributions have influenced modern project management, where achieving project success depends on balancing the **Triple Constraint**. In construction, changes to any of these factors, such as an accelerated timeline, can impact both the budget and the quality of the outcome, posing significant challenges for project managers. **Customer satisfaction** further reinforces these constraints to measure project success, reflecting whether the project meets or exceeds client expectations. The principles

established by the quality pioneers provide a theoretical foundation for understanding how quality management practices can help optimize this balance, especially when complemented by modern tools such as artificial intelligence.

Construction Quality Management (Independent Variable)

This study examines the impact of quality management practices in construction on project outcomes, with AI technology as a moderating factor. It is important to understand the key elements of Construction Quality Management and how it is applied in the industry. CQM is vital to the construction industry as it directly influences project outcomes, minimizes costs associated with rework, and improves efficiency. Effective CQM practices ensure that all project phases are executed according to client expectations and regulatory standards (Luo et al., 2022).

PMBOK defines Quality Management as "the process of determining quality policies, objectives, and responsibilities so that the project will satisfy the needs for which it was undertaken." CQM involves applying these principles to ensure project deliverables meet all required standards, specifications, and client expectations, focusing on consistent quality throughout construction.

Philip Crosby advocates for defining quality as "conformance to requirements," focusing on objectively meeting predetermined specifications and standards. This concept is fundamental in the planning phase of construction projects, where a clear, measurable framework for quality management (QM) supports Crosby's zero-defects philosophy, emphasizing the prevention of defects from the outset. Planning for quality early in the project ensures that project specifications fulfill client requirements and regulatory standards.

Expanding on Crosby's view, Juran's Quality Handbook (1999) introduces "fitness for use" as a core aspect of quality, highlighting the importance of ensuring that the constructed facility effectively serves its intended purpose and meets the end-user's needs. This approach extends beyond compliance with specifications to emphasize functionality, reliability, and durability, considering the structure's performance over its entire lifecycle.

Furthering this perspective, Khan et al. (2008) suggest that quality in construction encompasses the fulfillment of stakeholder expectations. Quality management must address the needs of not only the client but also contractors, subcontractors, designers, and the community, ensuring that the final project meets broad expectations. This holistic approach aligns with Construction Quality Management (CQM), which Sogaxa et al. (2021) define as "a management approach that aims to ensure that the construction process is completed within the specified quality requirements, on time, within budget, and safely." Similarly, Neyestani (2016) describes CQM as "the coordination and integration of all quality assurance and quality control activities throughout the life of the project to achieve the project objectives." These perspectives emphasize that effective CQM requires aligning quality planning, control, and assurance efforts to fulfill all project objectives, from specifications to stakeholder satisfaction.

The author defines CQM as a systematic process supported by strategic goals established earlier during the project planning stage toward fulfilling project quality objectives through a preventive approach. This approach can be enhanced by using AI as a predictive tool to improve efficiency, prevent defects, and reduce the cost of reworks in construction projects by preventing defects before they occur.

Construction Quality Management (CQM) is essential to delivering projects efficiently, meeting quality standards, and satisfying client expectations. **ISO 9001** offers a standardized approach to quality management, emphasizing clear documentation, consistent processes, and compliance with international standards. It is particularly beneficial for ensuring that construction projects meet regulatory requirements and maintain consistent quality. **Total Quality Management (TQM)** promotes a quality-centered culture across all levels of an organization, which fosters accountability and teamwork, which are essential for complex construction projects. **Lean Construction** focuses on minimizing waste and maximizing value, directly supporting efficient resource management—a critical aspect of quality planning and control in construction. **Six Sigma** provides a structured, data-driven approach to

reduce defects and improve process consistency, enhancing Quality Control and Quality Improvement through measurable results.

Among these, however, Juran's Quality Trilogy—emphasizing Quality Planning, Quality Assurance and control, and Quality Improvement—provides a balanced, comprehensive framework particularly well-suited to the needs of construction projects. Unlike broader organizational approaches, Juran's Trilogy is adaptable to unique construction challenges, allowing for proactive planning, real-time control, and continuous improvement throughout the project lifecycle. These three interconnected dimensions address the preventive and corrective needs in construction quality management, making Juran's Trilogy an ideal foundation for effective CQM in achieving high-quality, efficient, and timely project outcomes.

Quality Planning

PMBOK defines **Quality Planning** as "the process of identifying quality requirements and/or standards for the project and its deliverables and documenting how the project will demonstrate compliance." It aligns with Juran's definition of establishing the goals and process required to meet quality standards from the outset (Juran). In the construction industry, this means defining the necessary quality standards for materials, processes, and final outputs, setting clear expectations for quality from the outset, and establishing procedures for meeting these standards. Effective quality planning is crucial for establishing quality benchmarks, defining roles and responsibilities, and documenting the quality management strategy (Neyestani, 2016). A well-crafted quality plan will delineate the actions undertaken at each project phase to attain the targeted quality standards.

Quality Assurance & Control

In **Construction Quality Management (CQM)**, **Quality Assurance (QA)** and **Quality Control (QC)** play complementary roles in maintaining and improving project quality. According to the **PMBOK** (PMI, 2021), QA is "the process of auditing the quality requirements and the results from quality control measurements to ensure appropriate quality standards and operational definitions are used." QA in construction is proactive, aiming to prevent defects through regular inspections,

testing, and monitoring, ensuring that work meets the established quality plan and specifications. **Juran's Quality Control Handbook** expands on this by defining QA as a process that instills confidence that quality requirements will be met throughout the project. Juran emphasizes the importance of developing robust systems and preventive measures and conducting audits to verify compliance with quality standards and ensure consistency and reliability across project phases.

Quality Control (QC), on the other hand, is more hands-on and focuses on detecting and correcting quality issues. Defined by Juran as "the process of evaluating (quality) performance, comparing that performance with standards or goals, and acting on the difference," QC emphasizes feedback loops and corrective actions, making it a cyclical process aimed at continuous improvement. QC includes practical, operational techniques for measuring and controlling the characteristics of materials, structures, and systems to meet quality requirements. It operates as a "detection mode," identifying existing issues and facilitating corrective actions. QC systems provide displays of non-conformance to highlight areas requiring attention, allowing for data-driven problem identification and management(A63). In construction, QC procedures often include daily inspections, quality reporting, and minimizing output variation, ensuring that standards are consistently met across all project stages.

In the construction industry, QA and QC form a comprehensive quality framework in CQM. QA establishes preventive processes and systems, while QC detects and addresses deviations from quality standards. This dual approach is essential in construction, where complex projects demand proactive quality assurance and rigorous control over the work that will be executed.

Quality Improvement

The third component of Juran's Quality Trilogy, Quality Improvement, is defined by PMBOK as "the process of enhancing the organization's processes to improve the project's outcomes." This dimension continuously refines processes, systems, and practices to improve construction quality, reliability, and consistency. Quality Improvement involves analyzing performance, identifying opportunities for enhancement, and implementing changes to address the root causes of issues.

Common practices include post-project reviews, benchmarking against industry standards (Crosby, n.d), and incorporating Lean Construction and Six Sigma methodologies to streamline processes and minimize inefficiencies. By embracing a culture of continuous improvement, construction organizations can systematically enhance the quality of their project deliverables and outcomes over time.

Quality Improvement targets two main areas: enhancing product features and reducing deficiencies. Improving product features increases customer satisfaction by introducing innovative designs, sustainable materials, or advanced construction techniques. Reducing deficiencies minimizes waste, rework, and delays, thus boosting efficiency (Juran & Joseph, 2012). The principles guiding Quality Improvement in construction include a customer focus to meet stakeholder needs, continuous improvement through regular assessments, employee involvement in problem-solving, and a process approach that optimizes each project phase. Together, these efforts build a proactive, resilient approach to achieving high-quality outcomes in construction projects.

Quality management is paramount in the construction industry, where the successful delivery of complex, large-scale projects depends on achieving high standards across multiple dimensions, including cost, time, quality, and customer satisfaction. Effective construction quality management, guided by Juran's Quality Trilogy, provides a robust framework for enhancing project outcomes through proactive planning, preventive assurance, and continuous improvement. By embedding quality into every phase of the construction process, organizations can consistently deliver durable, safe, and compliant projects that meet or exceed stakeholder expectations.

The Jeddah Stormwater Program exemplifies the critical importance of CQM in addressing the common infrastructure challenges faced in large-scale, complex construction projects. As a multifaceted endeavor, the JSWP requires meticulous planning, rigorous quality control, and a commitment to continuous improvement to overcome challenges such as cost overruns, schedule delays, substandard quality, and customer satisfaction. By leveraging the principles of Juran's Quality Trilogy and the moderating role of artificial intelligence, the JSWP can establish clear quality

standards, implement robust assurance measures, and systematically enhance processes to optimize project outcomes. Applying Juran's Trilogy will enable the delivery of a high-quality, efficient, and timely stormwater management system for the city of Jeddah.

Construction Projects outcomes (dependent Variable)

Construction project outcomes are multidimensional, encompassing factors such as safety, Schedule, cost, and customer satisfaction. Effective quality management is crucial to achieving positive project outcomes across these critical dimensions. (Nguyen et al., 2020). PMBOK defines project outcomes as the **outputs and benefits** that result from project activities, which should align with the organization's strategic objectives and provide value to stakeholders. ISO 21500 defines project outcomes as meeting the predefined criteria for success, including cost, time, quality, and stakeholder satisfaction.

This study measures project outcomes by four key indicators: Cost, Time (or Schedule), Quality, and Customer Satisfaction. These indicators are chosen in this research as they are universally recognized and used as the core dimensions of project performance in construction management. Cost represents the financial efficiency of the project, aiming to minimize expenses while maintaining standards. Time (or Schedule) measures adherence to timelines, as delays can lead to cost overruns and client dissatisfaction. Quality ensures the project meets all specifications and is durable, safe, and fit for purpose. Also, Poor quality can lead to rework, increased costs, safety hazards, failure to meet regulatory requirements, and reduced customer satisfaction (Hwang & Yang, 2014). Prioritizing quality ensures that the final product fulfills its intended purpose and provides long-term value to the client and end-users. Finally, customer Satisfaction reflects the degree to which the project meets or exceeds client expectations, which is crucial in assessing the project's overall success. These four indicators are interdependent and collectively capture the balance of efficiency, effectiveness, and stakeholder value that defines a successful construction project (Neyestani, 2016) (Kiew et al., n.d.).

Project outcomes are particularly crucial in construction, as they determine the project's viability, efficiency, and overall quality, directly impacting client and end-

user satisfaction. Effective project outcomes are essential in the construction industry, where complex, large-scale projects require adherence to high standards and regulatory compliance (Low & Ong, 2014). Construction projects are complex, involving multiple stakeholders, regulatory requirements, and high-risk activities. Managing cost, time, quality, and customer satisfaction is essential to navigate these complexities. By integrating AI technology into quality management, the study aims to enhance these outcomes, demonstrating practical relevance.

Artificial Technology (Moderating Variable)

Several sources defined Artificial Intelligence (AI) and its related technologies, emphasizing its role in developing intelligent machines that can perform tasks traditionally requiring human intelligence (Chouchene et al., 2020). AI is a branch of computer science dedicated to creating machines capable of visual perception, speech recognition, decision-making, and language translation. Some definitions focus on AI's ability to mimic or replicate human cognitive functions, such as thinking, creativity, and planning (Nagireddy, 2023). Additionally, AI combines computer science and large datasets to solve complex problems, automating tasks typically reliant on human intelligence. In broader terms, AI is the science of developing intelligent systems and models that can replicate human cognitive processes, thus creating systems that enhance and streamline various tasks across multiple industries (Abioye et al., 2021).

AI technology includes tools like machine learning, computer vision, natural language processing, and predictive analytics, which significantly benefit many fields, including construction. Machine learning helps identify patterns in large datasets, enabling predictive insights, while computer vision automates inspections and defect detection, improving accuracy. These technologies streamline tasks, reduce errors, and enhance decision-making, offering efficient, data-driven support to complex projects. (Sahadevan, 2023)

Several AI platforms offer robust tools suited explicitly for data analysis that can support quality management in construction by predictive modeling and process automation. Google AutoML enables users to create custom machine-learning models

that detect patterns and predict outcomes without extensive coding expertise (Google Cloud, 2024). Microsoft Azure AI provides a suite of AI services, including computer vision and natural language processing, that can automate inspections, detect defects, and facilitate project monitoring in real-time (Microsoft, 2024). IBM Watson offers advanced predictive analytics and machine learning capabilities to process complex construction data to forecast potential risks and support data-driven decision-making (IBM, 2024).

In construction, AI technology transforms quality management practices by providing real-time insights, automating quality inspections, and predicting potential issues before they arise. For instance, computer vision algorithms can detect defects during construction activities, reducing reliance on manual inspections and improving accuracy. Predictive analytics, powered by platforms like IBM Watson, help identify trends in project data that could indicate future problems, allowing proactive measures to be implemented. These AI capabilities align well with Deming, Juran, and Feigenbaum's quality management theories, reinforcing data-driven decision-making, strategic planning, and organization-wide quality efforts. By integrating AI as a moderating variable, construction projects can achieve more efficient, consistent, and reliable quality outcomes, meeting evolving demands in the industry (Seyman-Güray, 2023).

Conclusion

Integrating quality management theories with AI technology provides a comprehensive framework for understanding and improving construction project outcomes. By grounding this research in the philosophies of quality management pioneers, this study aims to demonstrate how AI can systematically enhance the effectiveness of quality management practices, ultimately leading to better outcomes in cost, time, quality, and customer satisfaction within the construction industry.

Literature Review

Quality Management Systems in Construction

Quality management systems are crucial for improving the performance of organizations, especially in the construction industry. Research has shown that QMSs can significantly impact customer satisfaction, cost control, time management, and overall quality (Leong et al., 2014) (Aichouni et al., 2014). Neyestani's 2016 paper emphasizes the impact of QMS on these four crucial aspects of construction projects. Furthermore, a study in the Saudi construction industry supports Oakland and Marosszeky's (2006) statement that the industry needs to embrace total quality management concepts and QMSs, especially during growth and rapid expansion.

The effectiveness of a quality management system in construction projects can provide better control over project processes and workflows. Studies conducted across diverse construction markets, including Saudi Arabia, India, China, Pakistan, the United States, and South Africa, have all demonstrated the benefits of implementing robust quality management systems to enhance project outcomes, improve cost control, enhance time management, and increase overall customer satisfaction and industry performance (Likita et al., 2018).

Quality management and QMSs have gained increasing attention in the construction industry due to their ability to address common challenges, such as delays, cost overruns, and customer dissatisfaction. Juran quality trilogy highlights the three quality management processes of quality planning, quality control, and quality improvement that can be implemented through QMSs in construction.

Quality Planning

Quality planning is crucial to effective quality management systems in construction projects. It involves clearly defining the project requirements, identifying the critical quality characteristics that must be addressed, and establishing specific quality goals and objectives to be achieved. This comprehensive planning process helps ensure that the overall project scope, detailed drawings, and technical specifications are well-defined and unambiguous. This clarity is a prerequisite for maintaining high-quality construction processes and workflows throughout the project lifecycle. (Akinradewo et al., 2019).

In complex infrastructure projects like JSWP, where multiple stakeholders and intricate interdependencies are involved, comprehensive quality planning is essential to coordinate the various processes and ensure seamless collaboration across all parties. Detailed quality planning helps establish clear goals, define critical quality characteristics, and map out the necessary workflows and quality control measures throughout the project lifecycle. This level of upfront planning is crucial for maintaining high-quality construction processes and achieving the desired project outcomes, especially in large-scale infrastructure endeavors where numerous stakeholders are involved, and complex interdependencies will require careful management.

Quality Assurance

Quality assurance is a critical component of effective quality management systems in the construction industry. It involves implementing a comprehensive set of planned and systematic activities to ensure the constructed facility or infrastructure meets the specified requirements and customer expectations (Juran & Joseph, 2012). Quality assurance encompasses various activities, including inspection, testing, and monitoring, verifying that the construction processes and materials conform to established standards and specifications. This comprehensive approach helps construction organizations identify and address quality issues early, preventing defects and ensuring the final product meets or exceeds the expected quality levels. By implementing robust quality assurance measures, construction projects can enhance the overall quality, reliability, and longevity of the constructed facilities, ultimately meeting or exceeding the client's requirements and expectations.

Challenges in Implementing Quality Management in Construction

Despite the recognized benefits, implementing quality management in construction is a complex challenge many organizations face. Several factors contribute to the difficulties in effectively implementing robust quality management systems in the construction industry. Firstly, Leong et al. (2014) and (Zakaria et al., 2017) highlighted on their study major challenge of the construction industry as project-based, with each project being unique and often involving numerous stakeholders, subcontractors, and

varying site conditions). Whereas other industries, such as manufacturing, focus on the mass production of standardized products with greater control over processes and environments (Rezaei, 2011). This fundamental difference impacts on how construction projects define, measure, and manage quality.

Additionally, the fragmented and decentralized nature of the construction industry makes it challenging to implement organization-wide quality management systems. The high degree of customization in construction projects, the dynamic nature of construction activities, and site-specific conditions inherent in construction projects make it difficult to standardize processes and achieve organization-wide quality control (Tang et al., 2005). Furthermore, construction projects often face constraints such as tight budgets, short timelines, and changing client requirements, which can compromise the ability to prioritize and invest in robust quality management practices.

Finally, the industry's resistance to change and a lack of awareness and commitment to quality principles among some construction professionals can impede the successful adoption of quality management systems. These inherent complexities and cultural barriers pose significant hurdles in realizing the full potential of quality management in construction projects (Abioye et al., 2021).

In addition to these factors, the author's experience with the JSWP has highlighted the inherent complexity and variability of construction projects, further complicating the implementation of robust quality management systems. JSWP, with its numerous ongoing and unique projects, demonstrates how the involvement of multiple stakeholders, subcontractors, and ever-changing site conditions can challenge standardization and consistent quality control. A temporary workforce and varying levels of client involvement often add further complexity, making it difficult to ensure continuous adherence to quality standards.

Additionally, constraints such as tight budgets, short timelines, customer satisfaction, and shifting client demand place pressure on prioritizing quality over immediate deliverables. Resistance to change and varying levels of awareness and commitment

among construction professionals further impede the adoption of effective quality management systems. Addressing these challenges within JSWP, and more broadly in construction, requires a dedicated effort to foster a quality culture, enhance awareness, and leverage innovative solutions, such as AI-driven quality management, to streamline processes and deliver better project outcomes.

The Role of Artificial Intelligence in Quality Management

Artificial intelligence has emerged as a promising solution to address the complexities and challenges faced while implementing effective quality management systems in the construction industry. AI-powered technologies offer a range of capabilities that can streamline quality management processes and enhance project outcomes. From automating inspections and improving accuracy to leveraging predictive analytics to identify potential issues, AI aligns well with quality management principles and can help construction organizations overcome the inherent difficulties in implementing robust quality management systems.

Recent studies have highlighted several ways AI can enhance quality management in construction. Key technologies like Building Information Modelling (BIM), augmented reality (AR), Internet of Things (IoT), and computer vision (CV) are being integrated into CQM processes (A2a). AI's success in optimizing manufacturing, healthcare, and finance processes offers strong evidence of its transformative power across industries (Abioye et al., 2021). Therefore, AI has a high potential in the construction industry by demonstrating how AI can automate inspection processes, identify potential issues, and improve decision-making (Datta, S. D et al., 2024; Nagireddy, 2023).

Despite this promise, the construction industry needs to catch up in digitalization and technology adoption. This adoption, combined with persistent challenges like productivity issues, reworks, and cost overruns (Pan & Zhang, 2021), underscores the need to investigate AI's specific impact on quality management practices, by integrating AI as a moderating variable. Construction projects can achieve more efficient, consistent, and reliable quality outcomes, meeting the industry's evolving demands.

This study will investigate the impact and outcomes of AI-driven technologies, including automation and predictive analytics, on construction quality management. Prominent AI platforms such as Google ML, Microsoft Azure, and IBM Watson offer relevant AI-powered solutions that merit further exploration and analysis within this research context. These platforms offer AI Technology, such as ML and NLP, which can support transformative construction quality management practices.

Automation of Quality Processes

One of the key areas where AI can enhance quality management in construction is through automated quality control and inspection. AI-powered computer vision and machine learning algorithms can be leveraged for automated quality inspections, detecting defects, and monitoring construction progress (Regona et al., 2022). AI technology improves the accuracy and consistency of inspections and reduces manual effort and time required, enabling construction teams to identify and address quality issues proactively. For example, AI-driven visual inspection systems can analyze site photographs or video footage to identify deviations from design specifications, detect structural defects, or monitor the installation of building components. (Sharma et al., 2021) (Luo et al., 2022)

Previous research (Pan & Zhang, 2021) has shown that computer vision has increasingly supplanted labor-intensive and often inconsistent visual inspections in evaluating the state of civil infrastructure. This technology enables automated detection of damage, recognition of structural components, identification of unsafe behaviors, and assessment of overall conditions. Such applications of AI in quality control and inspection processes can significantly enhance efficiency, accuracy, and timeliness in addressing quality-related issues by facilitating monitoring applications through non-contact methods, capturing a quantitative understanding of infrastructure status, such as estimating strain, displacement, and measuring crack length and width.

Identifying and predicting quality issues

Another critical application of AI in construction quality management is the ability to identify and predict potential quality issues. By analyzing historical project data,

construction materials, and environmental factors, AI-based predictive models can forecast the likelihood of quality problems, such as delays, cost overruns, or defects. For instance, AI-powered predictive analytics can leverage real-time data from sensors, building models, and historical records to forecast potential quality issues, equipment failures, and other problems. Forecasts allow project teams to proactively address quality concerns before they escalate, reducing rework, delays, and cost overruns. (Abioye et al., 2021) (Dabous et al., 2023)

Recent research by Dip Datta et al., (2024) has demonstrated the application of machine learning techniques in predicting construction risks, including quality-related issues. These studies have shown that AI models can effectively forecast potential delays, cost overruns, and health and safety incidents by analyzing project complexity, weather conditions, and supply chain disruptions. The ability to anticipate and mitigate quality problems through AI-driven predictive analytics can significantly improve project outcomes and enhance overall quality management in the construction industry.

Additionally, AI can support informed decision-making in quality management by providing predictive insights and recommendations. By analyzing vast amounts of data from past projects, process information, and real-time site conditions, AI can help project teams make more informed decisions about quality control measures, resource allocation, and risk mitigation strategies.

Improving the efficiency of quality management processes

AI-powered technologies can also enhance the efficiency and effectiveness of quality management in construction by automating routine tasks, streamlining data collection and analysis, and optimizing quality control workflows. AI techniques can also generate valuable insights into the complex construction process. This knowledge is critical to project success and can guide the optimization of the construction execution process, helping to make the project run more smoothly and efficiently (Pan & Zhang, 2021). For instance, AI-driven natural language processing can automate the extraction and analysis of quality-related information from project documentation, such as inspection reports, checklists, and requests for information.

Another way of enhancing construction quality management processes is through integrating artificial intelligence with existing quality management tools and methodologies, such as Failure Mode and Effects Analysis, Statistical Process Control, and Lean Quality Management Systems, to enhance their effectiveness. (Yang et al., 2019). For example, AI can link FMEA data with other quality management systems or IoT devices to better manage, monitor, and optimize quality-related processes across the construction lifecycle. By integrating AI, these established quality management approaches can leverage the power of data analytics, predictive modeling, and automated decision-making to identify and mitigate quality issues proactively, ultimately leading to improved construction project outcomes.

Challenges in Adopting AI in Construction Quality Management

While the potential benefits of AI in construction quality management are significant, there are also several challenges and barriers to widespread adoption. Adopting AI-powered technologies in construction quality management contexts can be improved by factors such as the industry's traditional resistance to change, concerns over data privacy and security, the need for upfront investment in new technologies, and AI-specific skills and expertise among construction professionals. (Regona et al., 2022).

Integration with Existing Systems: Integrating AI systems with existing quality management processes can be complex and often requires high technical expertise. Successful integration demands careful planning to ensure that AI tools complement existing workflows rather than disrupt them. This challenge is particularly evident in construction projects, where established procedures and legacy systems may need to be adapted or updated to accommodate new AI-driven approaches (Na et al., 2023) (Jäkel et al., 2022).

Data Quality and Availability: The accuracy and effectiveness of AI algorithms are heavily dependent on the quality and availability of data. Reliable and relevant data are essential for training AI models to ensure accurate predictions and insights. In construction, data variability, incomplete records, and inconsistent data collection

practices can present challenges in providing a solid foundation for AI applications. (Kelepouris, 2023) (Nagireddy, 2023).

Skills Gap: Abioye et al. stated a notable shortage of skilled professionals in the construction industry with the expertise to develop, implement, and manage AI systems effectively. Addressing this skills gap requires specialized training and education investment to empower industry personnel to leverage AI technologies to their full potential.

Ethical Considerations: (Nagireddy, 2023) indicated that using AI in construction quality management raises important ethical considerations that must be carefully addressed. Issues such as data privacy, algorithmic bias, and the potential displacement of human workers are critical concerns that must be proactively managed. For example, ensuring the protection of sensitive project data and mitigating biases in AI-powered decision-making processes are essential to maintain trust and fairness in AI applications.

Additionally, the potential impact of AI on construction workers, such as job automation, should be considered and balanced with the need for technological advancements. Adopting a human-centered approach that prioritizes ethical principles, such as transparency, accountability, and employee well-being, is crucial for AI's successful and responsible integration in construction quality management. Careful consideration of these ethical factors will help foster trust, acceptance, and the equitable deployment of AI-driven solutions in the industry (Abioye et al., 2021).

Cost of AI integration: The benefits of AI-driven solutions in the construction industry are indisputable. Several researchers, including (Luca et al., 2022) and (Abioye et al., 2021), found that the initial investment and ongoing maintenance costs of AI-driven solutions, such as robotics, can be prohibitively high, particularly for small-scale subcontractors and firms that comprise a significant portion of the construction industry. This poses a significant barrier to the widespread adoption of these technologies. Therefore, (Luca et al., 2022) discussed deeper the cost-benefit challenge of AI adoption. They emphasized the need for construction companies to

invest in data collection and processing technologies to utilize AI effectively. Also, they pointed out that companies should focus on clear target areas for AI implementation rather than simply adopting the latest technology trends without a precise cost-benefit analysis. This suggests that the initial cost of AI and the associated data infrastructure is challenging for broader adoption in the construction industry.

Construction companies will face additional challenges when traditional and manual construction quality management practices are already in place. Integrating AI-driven solutions will require significant changes to existing processes and workflows, and construction firms may be reluctant to abandon their established quality management approaches, even if AI offers potential benefits. Overcoming this resistance to change and ensuring a smooth transition to AI-enabled CQM will be a critical challenge that construction companies must address.

This study argues that integrating artificial intelligence in construction quality management holds significant potential to enhance project outcomes. Nevertheless, researchers have identified that addressing the challenges associated with AI adoption is essential to fully realizing its benefits. Investing in training and education, establishing industry standards, and proactively tackling ethical considerations will be pivotal to successfully integrating AI-driven solutions in the construction industry.

Construction Projects outcomes

Various factors, including project management practices, resource availability, environmental conditions, stakeholder involvement, and organizational culture, influence construction project outcomes. Most research studies concur that key project outcomes in construction are typically evaluated using the Iron Triangle of Project Management, encompassing cost, schedule, and quality, along with additional factors such as Scope, safety, customer satisfaction, environmental compliance, and legal adherence (Leong et al., 2014; Teshome & Gobana, 2018). These metrics are broadly recognized as vital indicators of project success, offering a holistic assessment of a project's performance and alignment with stakeholder expectations and prevailing industry standards.

Cost

Cost is a fundamental measure of construction project success. Effective cost management, including accurate budgeting, cost control, and efficient resource utilization, is crucial for ensuring projects are completed within the allocated budget (a22). Previous studies have highlighted the significant impact of cost overruns on project profitability, client satisfaction, and the overall viability of construction firms. (Nguyen & Akhavian, 2019) Existing literature has extensively explored the negative impacts of cost overruns on various aspects of construction projects. Neyestani, B. (2016) concluded on his research that effective quality management systems (QMS) can positively impact time performance and cost control, leading to better project outcomes.

While high-quality design might initially increase costs, ensuring conformance to quality standards during construction can lead to long-term cost savings. On the other hand, Poor-quality construction can result in significant long-term problems, including structural issues, safety hazards, and costly repairs (Tang et al., n.d.). While robust quality management practices require upfront investment, the costs of rework and remedying defects often exceed these expenses. Additionally, poor quality can undermine customer satisfaction, damage a company's reputation, and lead to legal liabilities. Ultimately, the long-term consequences of substandard quality outweigh any short-term cost savings, emphasizing the critical importance of effective quality management in construction projects.

Schedule

Timely project delivery is another crucial measure of construction project success. Time performance evaluates the project's adherence to its planned Schedule. Delays in construction projects can lead to significant financial losses, missed business opportunities, and reputational damage for construction firms. Moreover, delays can negatively impact resource availability, disrupt workflow, and introduce additional costs not initially budgeted.

The survey conducted by Assaf & Al-Hejji (2006) has identified numerous factors contributing to schedule delays in the construction industry in Saudi Arabia, including poor planning, ineffective subcontractor management, material shortages, adverse weather conditions, and change orders. In addition, Poor quality, defects, and reworks can also lead to significant delays and impact the overall project schedule. Low & Ong, (2014) suggests that integrating quality management practices, such as comprehensive quality planning, quality assurance, and quality control, can help mitigate schedule delays and improve overall time performance in construction projects.

Quality

Quality is the third dimension of the Iron Triangle and is a critical measure of construction project success. This definition of quality in construction aligns closely with the principles of Philip Crosby, who emphasized "quality as conformance to requirements." Therefore, quality in construction is the conformance of the final product or service to the specified requirements, standards, and client expectations. Quality Performance can be used to assess the quality of workmanship and materials and adherence to specifications and standards.

Poor quality in construction can have far-reaching consequences, including structural failures, safety hazards, client dissatisfaction, and legal liabilities. The construction industry has long struggled with quality issues, and research suggests that most quality-related problems are attributed to the human factor, particularly a need for more professional ethics and commitment to quality for all stakeholders involved in the project (Aziz, 2013). To address this challenge, construction firms have increasingly adopted various quality management frameworks, such as Total Quality Management, Six Sigma, and Lean Construction, to improve quality assurance and control throughout the project lifecycle.

However, the adoption of quality management frameworks has faced significant challenges in the construction industry. Despite the potential benefits, construction firms need help effectively implement and sustain these practices throughout the project lifecycle. Lack of employee buy-in, resistance to change, and the complex,

fragmented nature of construction projects has hindered the widespread adoption and success of these quality management initiatives (Aichouni et al., 2014) (Srdoč et al., 2005). Moreover, the construction industry's traditional focus on time and cost, often at the expense of quality, has contributed to the persistent quality issues faced by the sector (Jraisat et al., 2016).

Customer Satisfaction

Customer satisfaction is an essential measure of construction project success, as it reflects the extent to which the client's expectations and requirements are met. This is particularly important in the construction industry, where projects are often highly customized and tailored to the client's needs.

Various factors influence customer satisfaction, including the quality of the final product, the timeliness of project delivery, and overall responsiveness and communication throughout the construction process. In the construction industry, client satisfaction is a multidimensional concept encompassing various aspects, such as project delivery, quality of workmanship, timeliness, responsiveness to issues, and overall project experience. Achieving high levels of customer satisfaction is crucial for construction firms, as it can lead to repeat business, positive word-of-mouth referrals, and improved reputation within the industry. Moreover, satisfied clients are more likely to be willing to engage in collaborative partnerships and support future projects, which can be particularly beneficial in the highly competitive construction market. (Arditi & Günaydın, 1997) (Ferng & Price, 2005) (Jraisat et al., 2016)

Summary

According to (Leong et al., 2014), several methods for measuring construction project outcomes, focusing on both traditional metrics and the potential of AI to enhance measurement accuracy and efficiencies methods for measuring construction project outcomes focusing on both traditional metrics and the potential of AI to enhance measurement accuracy and efficiency. The potential for artificial intelligence to enhance measurement accuracy and efficiency offers a promising opportunity to optimize these outcomes further, providing more precise insights and data-driven strategies for improvement.

Integrating AI-powered technologies can significantly enhance quality management practices in the construction industry by automating inspection processes, predicting and identifying quality issues, and improving the overall efficiency of quality management workflows. At the same time, the existing quality research focused on applying a single digital technology to specific quality management or project outcome issues without a comprehensive understanding of how AI can enable a more holistic, systematic, and responsive quality management approach (Dabous et al., 2023). It is crucial to investigate the effect of applying AI technology to the overall quality management system, considering its impact on various quality management processes and construction project outcomes. It can help understand and measure the effect of the enhanced CQM Process using AI on the outcomes of construction projects. Therefore, the research will investigate the moderating role of AI in the relationship between quality management and construction project outcomes.



<u>No</u>	<u>Title</u>	<u>Author</u>	<u>Year</u>	<u>Literature Summary</u>	<u>Researcher Comments</u>
A	Literature related to Quality Management and Project / Construction management				
A1	Quality Assurance and Quality Control for Project Effectiveness in Construction and Management	Salvi & Kerkar	2020	The paper examines the importance of QA and QC in enhancing project effectiveness within the construction industry. The study emphasizes that defects or failures in constructed facilities can lead to increased costs and delays, making QA/QC crucial for ensuring uniformity and compliance with specifications. The authors outline the methods of implementing QA/QC processes, such as inspections, documentation, and adherence to standards, highlighting how these measures can improve project quality and reduce costs over the project lifecycle	This paper provides valuable insights into how QA and QC practices contribute to project outcomes such as cost efficiency, quality consistency, and stakeholder satisfaction , which are key areas of focus of the thesis on quality management's impact on construction project outcomes. The paper also outlined the challenges and benefits of QA/QC integration, offering context on how these practices might be further enhanced through AI technologies in complex projects like the Jeddah Stormwater Program.
A2	Effectiveness of Quality management system on construction projects	Neyestani, B	2016	This paper found that implementing a Quality Management System can significantly improve customer satisfaction in construction projects and the importance of prioritizing customer needs and incorporating them into the QMS processes to achieve project success. The study also notes that QMS has a lesser impact on quality/scope, potentially due to existing regulations and standards already addressing this aspect.	This paper supports the importance of customer satisfaction and understanding of his requirements and needs as a major outcome of projects and can be forth beside the Trilogy. This approach goes well with Dr. Juran advocates for customer needs and satisfaction.
A3	Effectiveness of Quality Management System (QMS) on Construction Projects	Neyestani	2016	This paper evaluated the impact of QMS implementation in construction projects. It found that QMS can affect customer satisfaction, cost, time, and quality. The findings emphasize that QMS implementation enhances project outcomes by systematically improving management processes. AI can further improve decision-making by providing data-driven insights, predictive analytics, and real-time feedback loops	Although the paper investigates the broader effects of QMS, including customer satisfaction and operational efficiencies, it particularly notes that QMS least affects the project scope or quality compared to other factors. This gap suggests that while QMS frameworks (like ISO 9001) standardize processes, there might be room for enhancing their direct impact on quality, which is where AI could play a transformative role and can be integrated into QMS to amplify its effectiveness, especially quality mangement
A4	Rework and schedule performance: A profile of incidence, impact, causes and solutions	Hwang & Yang	2014	This paper investigated the effect of reworks on projects. It found that rework is a significant factor in schedule delays with a high occurrence rate. Root causes of reworks include design changes and poor design coordination.	The paper discusses rework's impact on schedule and cost, It could investigate how AI integrated into quality management systems can reduce rework and improve schedule adherence. AI could automate parts of the change management process or provide predictive analytics to foresee potential schedule or budget overruns due to rework.

A5	An Empirical Study of Quality Management Systems in the Saudi construction Industry	Aichouni et al.	2014	This paper investigated the readiness of Saudi construction firms in the Hail region to implement QMS tools. The paper identifies several barriers to QMS implementation, including organizational culture, lack of commitment, and poor knowledge of quality tools among staff.	The limited use and understanding of quality management tools and techniques noted in the study suggest a gap that AI technologies could fill. AI could facilitate more widespread and effective use of these tools by making them more accessible, easier to use, and better integrated into daily operations.
A6	An empirical study of quality management systems in the Saudi construction industry	Aichouni et al.	2014	This paper was focused on the Saudi construction industry, "An empirical study of quality management systems in the Saudi construction industry," is that while there's a growing awareness of Quality Management Systems within the Saudi Arabian construction industry, the actual implementation and effective use of quality tools and techniques are still lagging. The study found a gap between the perceived importance of QMS and the practical application	The paper highlighted several challenges for effective implementation of CQM practices which include: - Lack of Proper training and understanding - Resistance to change - Cost and resources constraints The study also identified key success factors for QMS implementation, including top management commitment, employee involvement, and a focus on continuous improvement
A7	Project Quality Management Critical Success Factors for Buildings (IMP)	Low, S. P., & Ong, J	2014	This book explores how effective quality management practices influence the success of projects. The authors identify critical success factors such as leadership commitment, stakeholder engagement, continuous improvement, and adherence to standards. Using case studies, they illustrate strategies for integrating quality management systems, emphasizing customer satisfaction and risk.	The author emphasizes leadership, stakeholder engagement, continuous improvement, and adherence to standards directly ties into the core areas of Quality Planning, Quality Control, Quality Assurance, and Quality Improvement . Also, his perspective for examining how structured quality practices impact project outcomes such as cost, schedule, quality, and customer satisfaction goes well with the aim of the thesis
A8	Study of Quality Management in Construction projects	Chin Keng, Hamzah	2011	The article highlights that quality management should be intertwined with all operational and managerial processes within a construction company. It emphasizes the need for a strong management commitment to quality, the implementation of appropriate quality management practices, and addressing the challenges that hinder effective quality management in construction projects	The findings of this paper highlighted the importance of quality management in construction projects. The author highlighted that quality management in construction is not stand alone management, which support the importance of CQM practices as it the role of every one on the project.
A9	Factors Affecting the Performance Of Construction Projects In The Gaza Strip	Enshassi et al.	2009	The paper identifies several key factors impacting construction project performance in the Gaza Strip, including delays due to border and road closures leading to material shortages, unavailability of resources, escalation of material prices, and the lack of experienced personnel. These issues highlight the complex interplay between external economic and political conditions and internal project management challenges.	the paper does not specifically focus on AI, the challenges it outlines—like resource availability, material cost escalation, and effective project leadership—can be mitigated through AI technologies. AI can predict material shortages or optimize resource allocation, enhancing project performance. conformance to specifications and quality of equipment and materials. AI tools can enhance quality assurance processes, ensuring compliance and improving the overall material management system. This approach is part of the objectives of this research.

A10	The Role of Culture as Driver of Quality Management and Performance: Infrastructure Versus Core Quality Practices	Naor et al.	2008	The study investigated the relationships between organizational culture, infrastructure, core quality management practice, and the link to performance. It provides an insightful exploration of how organizational culture influences quality management practices and overall performance. The study distinguishes between infrastructure and core quality management practices and analyzes their interactions with organizational culture in the context of manufacturing performance.	These findings can be directly relevant to this research by illustrating the crucial role of cultural factors in the implementation and effectiveness of quality management practices in construction projects. The research can find out how similar dynamics apply within the Jeddah Stormwater Program and other construction contexts, particularly how AI can be integrated to enhance these interactions and outcomes.
A11	Quality Assurance and Control in the Construction of Infrastructure Services in Developing Countries – A Case Study of Pakistan	Khan et al.	2008	The authors examined the challenges and implementation of quality assurance (QA) and quality control (QC) practices in construction. The study highlights the importance of QA/QC in achieving stakeholder satisfaction and outlines the project's adoption of ISO 9000/2000 standards. QA/QC activities included audits, inspections, material testing, and compliance with contractual standards to ensure high-quality construction.	This study illustrate the practical challenges and successes of implementing quality management systems in large infrastructure projects. It aligns with thesis investigation into the impact of quality management practices on project outcomes, such as cost, schedule, and quality, within a developing context. It offers a comparative perspective for your study on the Jeddah Stormwater Program
B	Literature related to Quality Management and Artificial Intelligence				
B1	A Literature Review of Artificial Intelligence in Asphalt Quality Assurance	Ryan B. CastronuevoE dwin R. Arboleda	2024	The paper investigate the transformative impact of AI technologies on asphalt quality assurance in road construction. It highlights advancements such as dynamic quality monitoring systems, intelligent sensing aggregates, and AI-integrated IoT and 5G technologies, all designed to enhance the accuracy, efficiency, and sustainability of pavement assessments	This study provides a relevant example of how AI-driven quality management systems can improve construction project outcomes. The integration of AI technologies like intelligent sensing and predictive modeling in asphalt quality assurance illustrates potential applications of AI within JSWP quality control processes since asphalt works are major parts of the work and directly related to customer satisfaction. The study also highlights challenges related to data availability and model interpretability, offering insights into potential limitations and considerations when adopting AI-driven solutions in complex construction projects.
B2	Digital technology for quality management in construction: A review and future research directions	Luo et al.	2022	The research investigated digital- technology that can be used to enhance CQM. Results found enhancement in detecting concealed works and preventive and post-completed defects.	This paper directly tackles the theme of digital technologies in quality management, including the use of AI. It provides a clear connection between digital technology applications and the enhancement of quality management processes illustrating both current capabilities and gaps in technology application within the scope of construction quality management, highlighting opportunities, but not relating those benefits to project outcomes.

B3	Artificial Intelligence for Product Quality Inspection toward Smart Industries: Quality Control of Vehicle Non-Conformities	Chouchene et al	2020	The paper discusses the integration of AI within smart factory systems and how it overcomes limitations of manual inspection, such as operator fatigue and inconsistency, by using AI-driven automation and cognitive capabilities. and the use of AI-based vision systems to improve product quality inspection in smart industries, particularly for the detection of non-conformities in vehicles. The proposed system leverages AI, specifically machine vision (MV), to automate defect detection and minimize human error in inspection tasks	The paper shows how AI-driven systems can improve quality inspection processes by enhancing accuracy, reducing errors, and increasing productivity—concepts that can be adapted to the construction industry, particularly for complex infrastructure projects. Automated detection can ensure quality control aligns with the focus on how AI can enhance quality management practices and optimize project outcomes. Insights from this paper can support the exploration of how AI technology can transform traditional quality assurance and control methods into more data-driven, efficient systems.
B4*	Quality management at construction projects case study of stormwater network project	Yang et al.	2019	Th paper explores the development of an Integrated Quality Management Information System (IQMIS) enhanced by AI. The framework aims to improve traditional quality management by integrating AI-driven capabilities such as decision-making, prediction, and automation of quality control processes. The proposed AI-based IQMIS includes features like intelligent statistical process control, AI-enhanced failure mode and effect analysis (FMEA), and advanced product quality planning. The system emphasizes lean quality management processes to reduce inefficiencies, improve decision-making, and streamline operations through automation and AI technologies.	This paper provides valuable insights into how AI-driven quality management systems can enhance traditional quality practices, aligning directly with your focus on the moderating role of AI in quality management within construction projects . The integration of intelligent tools, such as predictive quality controls and AI-enhanced FMEA, highlights potential pathways for incorporating AI into the Jeddah Stormwater Program's quality management practices. This aligns with your investigation of AI's impact on improving project outcomes, offering practical examples of how AI technologies can streamline processes, improve data-driven decision-making, and enhance quality assurance and control measures in complex construction environments.
B5	Imaging Quality Control in the Era of Artificial Intelligence	Larson and Boland	2019	This paper discusses how AI technologies can transform quality control in medical imaging. The authors outline eight key elements essential for comprehensive process control in AI-based imaging systems. They emphasize that AI tools alone cannot guarantee consistent quality without integrating these essential process control elements.	This paper might be on the medical field, but the concepts might apply on defect detection on construction projects, especially on material delivery inspection. The idea will need future investigation.
B6	Models and Methods for Quality Management based on AI application	Srdoc et al.	2005	The paper presents a comprehensive approach to enhancing quality management through AI-driven techniques by leveraging AI technologies such as text mining, aspect sentiment analysis, and decision tree modeling to evaluate and improve customer satisfaction. The approach emphasizes using big data to monitor and evaluate service quality continuously, thus supporting more dynamic and effective decision-making in quality management.	The paper studied how AI can be leveraged to analyze large volumes of data and transform customer feedback into actionable insights, thereby improving overall project quality and customer satisfaction. It may provide useful frameworks or inspiration for incorporating AI-driven decision support in JSWP. This could help demonstrate how AI tools can enhance data-driven decision-making, using big data tech, i.e. historic data from previous projects.

C Lituratre related to Artificial Intelligence and Project / Construction Management					
C1	Artificial intelligence and machine learning applications in the project lifecycle of the industry: A comprehensive review	Datta, S D et al	2024	The paper thoroughly assesses how AI and ML can be effectively integrated across various phases of a construction project's life cycle. Also how AI and ML can revolutionize the construction industry by enhancing productivity, reducing cost overruns, improving site safety, and optimizing project management efficiency.	The paper did not mention the use of AI in quality planning during the planning stage of the project. Also, the lack of focused investigation into how AI can enhance quality management practices in construction provides a unique angle for the study.
C2	Artificial Intelligence and Its Impacts on Project Management	Reddy Nagireddy, Sindhu	2023	The paper investigated how AI can be integrated into PM practices, concluding that AI can improve project planning, resource allocation, risk management, and decision-making.	AI tools can improve the accuracy of project forecasting, perform repetitive tasks, and enhance decision-making through predictive analytics and data-driven insight. But it did not address the explicit connection between AI technologies and their direct impacts on quality management in construction projects.
C3	A Qualitative Study on Artificial Intelligence and Its Impact on the Project Schedule, Cost and Risk Management Knowledge Areas as Presented in PMBOK®	Friðgeirsson et al.	2023	This paper focuses on the impact of AI on PMBOK's area of knowledge, cost, risk, and schedule. The research shows that AI has potential benefits in these areas, particularly where historical data and repeated tasks are involved	The implications of AI in cost, risk, and schedule management could indirectly influence quality management by improving overall project control and precision, which are essential for maintaining quality standards. Showing that there is a gap in studying how to integrate AI into CQM
C4	Investigating AI Applications in Construction Industry: A Systematic Review	Seyman-Güray, T	2023	This study examined AI's contributions to handling challenges in the construction industry, such as cost overruns, delay, risk, rework, and safety issues. The construction industry's characteristic resistance to new technologies is noted as it is among the least digitized sectors.	this paper provides a broad overview of AI's application in the industry. There is considerable potential for transformative impacts through AI in project monitoring, and enhanced decision-making, but does not focus deeply on quality management practices, emphasizing the gap in direct studies linking AI with CQM in construction projects.
C5	Mapping Two Decades of AI in Construction Research: A Scientometric Analysis from the Sustainability and Construction Phases Lenses	Regina et al.	2023	The paper investigated the effect of AI technology on improving sustainability, productivity, and efficiency. AI technologies such as machine learning, deep learning, and big data can affect construction projects' performance and digitize and modernize the construction industry, consolidating its processes and practices toward a more sustainable future.	The study suggests a growing trend towards integrating AI more comprehensively across all construction phases and deeper into sustainability practices. It provides broad understanding of how AI is applied in the industry but does not focus on quality management, and encourages ongoing innovation and research to overcome existing barriers to AI adoption in construction

C6	A Comprehensive Literature Review of Research Trends of Applying AI to Construction Project Management	Merdžanović et al.	2023	This research investigated how AI affects construction project management, including planning, scheduling, monitoring, execution, and controlling. It emphasizes how AI can automate routine tasks, improve decision-making through data analytics, and optimize project outcomes by enhancing efficiency and accuracy.	This paper provides a foundational understanding of AI's impact on construction project management but does not delve deeply into quality management practices. While it covers AI's role in enhancing project efficiency and decision-making, the direct effects on quality management are not specifically addressed, which presents a gap.
C7	Adoption of Artificial Intelligence for Optimum Productivity in the Construction Industry	Victor	2022	This study focused on bridging the gap between AI and its advantages in the construction industry by reviewing several case studies. It also explores how AI and people should interact and the degree of human trust in AI technology.	The paper emphasizes AI's role in automating processes, improving efficiency, and aligning with lean principles, which prioritize reducing waste and increasing value. A significant part of the study discusses the level of trust between humans and AI systems as a critical factor for successful AI integration.
C9	An investigation into the Impact of Artificial Intelligence on the Future of Project Management	Alshaikhi & Khayyat	2021	This paper discussed the effect of using AI in PM; it highlights several AI tools and applications that could support project managers by automating tasks and providing analytical insights, thus improving the overall management of projects. However, found that AI can automate tasks but cannot replace human minutes or decrease the need for human resources.	The paper provides insights into how AI could be leveraged to automate and optimize project management tasks, which could extend to quality management practices in construction. The paper acknowledges several challenges in implementing AI in project management that require attention in future research, such as data availability, integration difficulties, high costs, and the potential impact on employment due to automation.
C10	Roles of artificial intelligence in construction engineering and management: A critical review and future trends. Automation in Construction	Pan & Zhang	2021	The study notes a shift in focus from traditional expert systems to more advanced technologies like BIM, smart robotics, cloud VR/AR, IoT, digital twins, 4D printing, and blockchain technologies. The study found AI can benefit the construction industry in terms of automation, risk mitigation, high efficiency, digitalization, and computer vision. Challenges in adoption include data quality issues, integration complexities, and investment in new technologies.	This paper directly addresses the broad applications of AI in construction but does not focus specifically on quality management. It provides a solid foundation for understanding how AI technologies are currently used and how they can potentially transform the industry. This research will focus specifically on how AI can improve quality management practices within construction projects

C11	Artificial intelligence in the construction industry: A review of present status, opportunities and future challenges	Abioye et al.	2021	The study explored AI applications in CE, identifying opportunities and challenges for adoption. It explored the benefits of using several AI technologies, such as CV, robotics, NLP, ML, etc. The paper offers a critical review of existing AI applications across various construction activities, highlighting how AI is being used to tackle complex problems and enhance efficiency in construction management.	AI technology uses predictive analytics, such as forecasting project delays or optimizing resource allocation and automated construction processes, enhancing precision and safety on sites. It outlines the potential and challenges of AI in construction, which can be directly relevant to this research focus on enhancing quality management through AI. However, the paper does not explore the impact on quality management practices.
C12	Impact of Artificial Intelligence on the South African Construction Project Management Industry	Makaula et al.	2021	The paper explores AI's role in improving construction project management in South Africa, from planning to execution. It highlights AI's potential to enhance labor productivity and transform the job market by creating new roles. AI also improves risk management and contributes to project success through better efficiency and cost management. However, challenges such as skill gaps and high implementation costs hinder its adoption.	This paper underscores the transformative potential of AI in enhancing various aspects of project management, including indirect impacts on quality management through improved precision and efficiency. However, it does not specifically focus on quality management practices, which provides an opportunity for this research to delve deeper into this aspect, particularly how AI can be integrated to enhance quality management in construction projects.
C13	The Effect of Using Artificial Intelligence on the Quality of Decision-Making in Various Organizations: A Critical Survey Study	El-Emary et al.	2020	The study aimed to investigate the impact of AI on the quality of decision-making in various types of organizations. The results showed a positive impact despite the organization's structure. It also discussed popular techniques and algorithms of artificial intelligence.	The paper provides a critical analysis of existing research, highlighting the use of various AI techniques like Neural Networks, Support Vector Machines, and Bayesian Networks to enhance decision-making accuracy and efficiency. Such an approach can be used in assessing and analyzing the data for the case study.
C14	Research on the Application of Intelligent Construction Site in Construction Site Management	Zhang, M	2020	This paper investigated the use of intelligent construction sites (information tech) to manage construction sites more efficiently, focusing on quality and safety problems by integrating information technologies like BIM, IoT, and cloud computing in construction management.	The paper provides evidence of how AI and related technologies can be utilized to minimize quality and safety issues, and the use of BIM technology to predict potential problems and improve communication among construction site personnel. However, the paper didn't link the positive impact of AI on safety and quality on project outcomes.

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