

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

(A Case Study of Jeddah Stormwater Program)

By

ISMAIL HASAN R. UJAIMI

Kingdom of Saudi Arabia

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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 tools have enhanced precision in planning, improved stakeholder communication, and optimized resource allocation, contributing to better management of project scope, cost, time, and quality. Despite these advancements, the construction industry continues to lag behind other sectors in fully leveraging emerging technologies like Artificial Intelligence (AI) to address persistent challenges in quality management (Dip Datta et al., 2024).

The construction industry continually faces difficulties in maintaining quality standards, particularly in large and complex infrastructure projects like the Jeddah Stormwater Program (JSWP). These projects involve numerous stakeholders, dynamic conditions, and high volumes of simultaneous activities, which strain traditional Construction Quality Management (CQM) practices. Issues such as material defects, utility conflicts, and inadequate compliance monitoring frequently lead to delays, cost overruns, and reduced stakeholders or customer satisfaction. Addressing these challenges requires innovative solutions, and this study explores the potential of AI enhanced CQM systems.

This research is significant for both theoretical and practical reasons. Theoretically, it investigates AI's role as a moderating variable, examining how it can optimize CQM practices and mitigate the negative impacts of project size and complexity on outcomes such as cost, time, quality, and customer satisfaction. Practically, the research will focus on some of AI driven technology such as machine learning, predictive analytics, natural language processing, and real-time monitoring to improve predictive capabilities, decision-making, defect detection, and automation of quality control and assurance processes in infrastructure projects. By addressing challenges associated with AI adoption, such as costs, technical expertise, and organizational resistance, this study provides actionable insights into leveraging AI technologies in CQM.

The study is guided by three research questions: (1) the limitations of CQM practices in large infrastructure projects, (2) the moderating role of AI in enhancing project outcomes, and (3) the barriers to adopting AI in construction projects. Through these questions, the research aims to contribute to the growing body of knowledge in construction quality management and provide a practical framework for AI adoption.

This study's findings are expected to offer substantial value by addressing the gaps in traditional CQM practices and demonstrating the transformative potential of AI in complex construction environments. Focusing on JSWP, the research not only highlights challenges unique to large-scale projects but also provides a replicable model for integrating AI into construction quality management globally.

Keywords

Quality Management, AI, Construction Project Outcomes, Case Study – Saudi Arabia, Stormwater, Machine Learning, Natural Language Processing.

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 AI to transform quality practices (Vision2030). Despite its promising potential, AI adoption Saudi Arabian construction industry remains significantly behind the global trend of technological innovation. 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.

Challenges in Implementing Quality Management in Construction

Implementing quality management in construction, despite its well-recognized benefits, remains a significant challenge for many organizations. 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 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.

Secondly, 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.

Thirdly, 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 spread across all sides of Jeddah, demonstrates how the involvement of multiple stakeholders, subcontractors, and ever-changing site conditions can challenge standardization and consistent quality control. These challenges are further compounded by varying levels of client involvement and the geographically dispersed nature of the projects

and inadequate staffing levels, which strain supervision capacity and make it even more difficult to ensure adherence to quality standards.

Despite JSWP 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 coordination with other stakeholders, modification and approvals of shop drawings and execution methods. Such delays increase resident complaints due to prolonged excavation works, extended closures of roads, escalating the cost of reworks, and extending the overall project's progress.

Additionally, constraints such as tight budgets, short timelines, customer satisfaction, and shifting client demand place pressure on prioritizing quality over immediate deliverables. Combined with that 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 CQM practices, to streamline processes and deliver better project outcomes.

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 emphasize the general advantages of AI in construction, such as its impact on project outcomes or its application to specific quality management issues. However, they rarely address the unique challenges and established practices specific to the Saudi Arabian construction sector. Therefore, more focused research is needed to investigate and understand the effect of AI on the overall CQM, 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. 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. **Evaluate CQM Practices:** Assess the limitations of traditional CQM practices in addressing the challenges posed by the size and complexity of infrastructure projects, particularly within JSWP.
3. **Examine AI's Impact:** Investigate the potential of AI technologies to enhance CQM practices focusing on AI's moderating role in mitigating CQM practices insufficiencies, with a focus on improving project outcomes such as cost efficiency, schedule adherence, quality, and customer satisfaction.
4. **Identify AI challenges:** Based on insights gathered from the selected contractors and projects data, identify and analyze the challenges associated with implementing AI-driven CQM practices in infrastructure projects.
5. **Develop Strategies and Frameworks:** Propose practical strategies and frameworks for effectively integrating AI-driven CQM practices, ensuring improved outcomes in large and complex infrastructure projects.
6. **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 AI in quality management within construction projects. It will enhance theoretical frameworks by integrating advanced AI technologies, such as machine learning and natural language

processing, 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, through enhanced CQM practices 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 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, cost, 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.

Research Methodology

This study employs a mixed-methods research approach, combining in-depth qualitative case studies and comprehensive quantitative data analysis, to thoroughly investigate the relationship between Construction Quality Management practices, construction project outcomes, and the moderating influence of Artificial Intelligence technologies. The qualitative component will provide rich contextual insights, exploring how AI-enabled CQM processes are implemented and integrated within real-world construction projects. The quantitative analysis will then examine the statistical significance and magnitude of the moderating effect of AI on the link between CQM and key project outcomes, such as reduced rework, enhanced productivity, and improved cost and schedule performance. This holistic mixed-methods

approach will yield a deeper understanding of the complex interplay between quality management, AI, and construction project success.

Data Collection, Sampling and Analysis

Primary data will be collected through structured surveys from stakeholders involved in JSWP, including project managers, quality professionals, construction teams, contractors and suppliers, and AI technology experts. Secondary data will be gathered from project documentation, industry reports, academic journals, case studies, and other relevant literature on the application of Artificial Intelligence technologies in the context of construction quality management. This comprehensive secondary data collection will provide a robust understanding of the current state of research and industry practices in leveraging AI to enhance not only project management, but also quality management processes and outcomes in construction projects.

Purposive sampling will be employed to ensure participants have direct experience with CQM practices or AI implementation, with an estimated sample size of 50–70 participants from stakeholders, and to ensure comprehensive insights, the sample size will include a diverse set of stakeholders from various roles within the JSWP projects. **Project Managers** can provide perspectives on overall project execution and quality management integration, while **Quality Control and Assurance Teams** can highlight the application and challenges of CQM practices. **Engineers and Site Supervisors** offer practical insights into quality-related issues and AI implementation on-site. Additionally, involving other key disciplines such as **Planning Engineers** allows for exploring how AI can optimize scheduling, anticipate delays, and enhance time management. **Cost Control Engineers** can contribute insights into cost forecasting and budget management, focusing on how AI aids in controlling project expenses. **Technical Engineers** provide knowledge about design and specifications, and utility issues, emphasizing AI's role in streamlining technical solutions and design reviews. **Clients or Regulatory Representatives** ensure a focus on compliance and stakeholder satisfaction, while **AI or Technology Specialists** can offer expertise on the deployment and potential of AI technologies. This multidisciplinary approach ensures a holistic understanding of the integration of AI into CQM practices in large infrastructure projects. Quantitative data from surveys will be analyzed using statistical Tools such as SPSS.

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 (Daneshjo et al., 2021). 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 (ASQ, 202024). **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 (Huggins, 1998). 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 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 (PMI, 2021, p.XX) 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 (ASQ, 2024).

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) defines 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 is essential to deliver 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 (Pheng & Teo, 2003). **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 (Feng & Price, 2005).

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 (Juran & Joseph, 2012). 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 (PMI, 2021) 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.

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.

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. The JSWP was chosen as a case study as these projects face significant challenges in maintaining quality standards due to the complexity of the work, tight timelines, and the dynamic nature of the construction environment as well as utility clashes. This setting offers a unique opportunity to investigate how CQM practices perform under demanding conditions and to evaluate AI's potential to address these challenges effectively.

Despite JSWP projects being similar in concept and executed by the same contractors, these projects consistently face recurring challenges that hinder their progress. Issues such as material defects, supply and handling difficulties of materials, lack of site supervision, and inadequate quality control measures compromise construction efficiency and effectiveness. Additionally, the high volume of simultaneous projects strains supervision capacity, leading to frequent utility conflicts and significant delays. These conflicts often result in prolonged design changes and approvals, frequent shop drawing modifications, extended excavation activities, escalating rework costs and increasing resident complaints. Together, these factors disrupt the JSWP program timelines and negatively impact overall project outcomes.

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 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, the risk associated with the rainfall season can have severe impacts on both ongoing construction projects and surrounding residential areas if not managed promptly and effectively. The dynamic nature of construction, coupled with tight timelines, heightens the risk of disruptions. Effective quality management, supported by AI-driven predictive analytics and automation, can mitigate these risks, ensuring projects are delivered efficiently, on budget, and to high standards.

Integrating AI technologies into the Jeddah Storm Water Program (JSWP) offers transformative solutions to overcome the recurring challenges faced by the program's projects. AI-driven tools, such as predictive analytics and real-time monitoring systems, can enhance material quality control by identifying defects and optimizing supply chain management. Automated compliance systems ensure strict adherence to method statements and established protocols, reducing the risk of quality lapses caused by contractor non-compliance. Furthermore, AI's ability to forecast potential conflicts, such as utility clashes, and simulate design scenarios enables proactive planning, minimizing delays and costly rework. During critical periods like the rainfall season, AI's predictive capabilities can help anticipate risks, prioritize interventions, and safeguard ongoing projects and surrounding residential areas. By leveraging AI, JSWP can significantly enhance the efficiency, consistency, and effectiveness of Construction Quality Management practices, ensuring improved project outcomes despite the complexities and dynamic conditions of the program.

This research aims to fill the 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 the following four significant areas of quality management:

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 three critical questions:

Research Question 1: Does CQM practices become insufficient in addressing the challenges of size and complexity in infrastructure projects, and how does this inadequacy negatively impact project management outcomes?

- **Question 1.1:** Do the challenges of managing large and complex infrastructure projects lead to schedule delays, as CQM practices become inadequate in mitigating these challenges?
- **Question 1.2:** Do the size and complexity of infrastructure projects contribute to cost overruns, as CQM practices become insufficient in preventing these overruns?
- **Question 1.3:** Do the size and complexity of infrastructure projects negatively affect customer satisfaction, and CQM practices are unable to address these concerns effectively?
- **Question 1.4:** Do the size and complexity of infrastructure projects result in substandard quality outcomes, as CQM practices fail to maintain consistent quality under such conditions?

Research Question 2: Do the AI-driven construction quality management practices in the Jeddah Stormwater Program modify the impact relationship between quality management and project management outcomes?

- **Question 2.1:** Do the AI-driven practices of Quality Planning in the Jeddah Stormwater Program modify the impact relationship between quality management and project management outcomes?
- **Question 2.2:** Do the AI-driven practices of Quality Control in the Jeddah Stormwater Program modify the impact relationship between quality management and project management outcomes?
- **Question 2.3:** Do the AI-driven practices of Quality Assurance in the Jeddah Stormwater Program modify the impact relationship between quality management and project management outcomes?
- **Question 2.4:** Do the AI-driven practices of Quality Improvement in the Jeddah Stormwater Program modify the impact relationship between quality management and project management outcomes?

Research Question 3: What are the financial, organizational, ethical and technical challenges associated with adopting AI technologies in construction projects, and how do these barriers impact the effective integration of AI into CQM practices?

- **Question 3.1:** Does the cost of implementing AI technologies create significant barriers to their adoption in Construction Quality Management (CQM) practices?
- **Question 3.2:** Does resistance to change among stakeholders and organizational culture negatively impact the adoption of AI technologies in construction projects?
- **Question 3.3:** Does the lack of high-quality data, integration challenges, or insufficient technical expertise hinder the effective implementation of AI in CQM?
- **Question 3.4:** Does the skills gap in the construction industry limit the adoption and successful utilization of AI technologies?
- **Question 3.5:** Do concerns about data privacy, algorithmic bias, and regulatory compliance affect the willingness of construction organizations to adopt AI technologies?

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):

CQM practices become insufficient in addressing the challenges posed by the size and complexity of infrastructure projects, leading to negative impacts on project management outcomes, including cost, schedule adherence, quality, and customer satisfaction.

- **Hypothesis (H1a):** Construction Quality Management (CQM) practices become insufficient in maintaining work quality as the size and complexity of infrastructure projects increase, negatively impacting deliverable quality.
- **Hypothesis (H1b):** Construction Quality Management (CQM) practices fail to prevent cost overruns in large and complex infrastructure projects, resulting in increased project costs.
- **Hypothesis (H1c):** Construction Quality Management (CQM) practices are less effective in ensuring adherence to project schedules in large and complex infrastructure projects, leading to significant delays.
- **Hypothesis (H1d):** The insufficiency of Construction Quality Management (CQM) practices in addressing the challenges of size and complexity negatively impacts customer satisfaction in infrastructure projects.

Hypothesis (H2):

AI-driven CQM practices in the Jeddah Stormwater Program significantly modify the relationship between quality management practices and project management outcomes, enhancing cost efficiency, schedule adherence, quality of deliverables, and customer satisfaction.

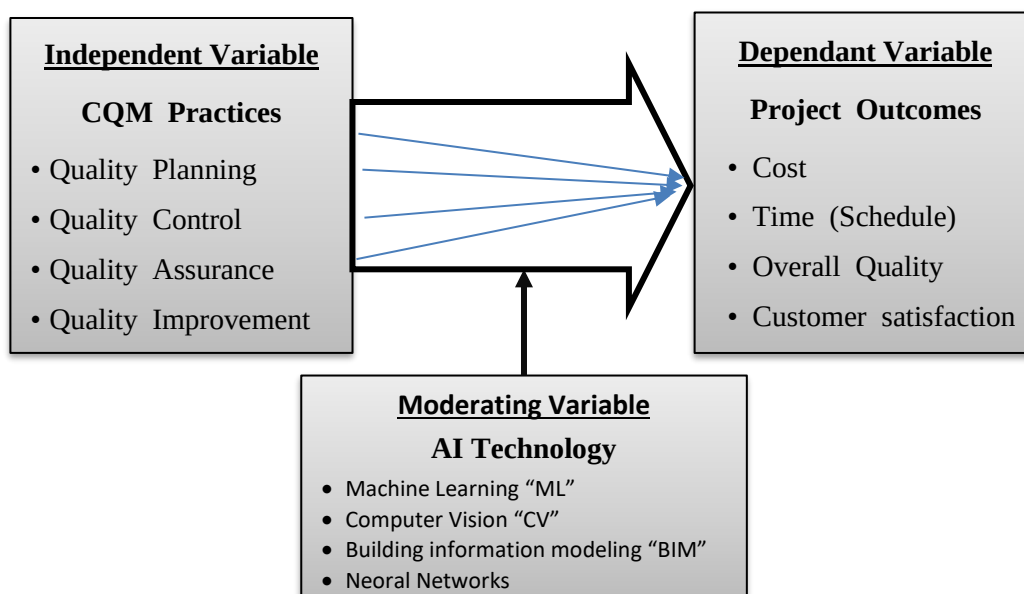
- **Hypothesis (H2a):** AI-driven CQM practices significantly enhance the quality of deliverables in infrastructure projects by improving defect detection and reducing rework.
- **Hypothesis (H2b):** AI-driven CQM practices significantly reduce cost overruns in infrastructure projects by reducing the cost of rework and cost of poor quality.

- **Hypothesis (H2C):** AI-driven CQM practices significantly reduce schedule delays in infrastructure projects by minimizing rework through proactive defect detection and quality monitoring.

Hypothesis (H3): Financial, organizational, ethical, and technical challenges significantly hinder the effective integration of AI technologies into Construction Quality Management (CQM) practices in infrastructure projects.

- **Hypothesis (H3a):** Financial constraints, such as high implementation and operational costs, significantly limit the adoption of AI technologies in CQM practices.
- **Hypothesis (H3b):** Organizational barriers, including resistance to change and a lack of skilled personnel, significantly impact the successful integration of AI into CQM practices.
- **Hypothesis (H3c):** Ethical concerns, such as data privacy, algorithmic bias, and job displacement fears, significantly hinder the adoption of AI technologies in CQM practices.
- **Hypothesis (H3d):** Technical challenges, including insufficient data quality and integration difficulties, significantly reduce the effectiveness of AI technologies in improving CQM practices.

The following diagram illustrates the conceptual framework for this study, highlighting the relationships between the independent variable (**Construction Quality Management Practices**), the dependent variable (**Project Management Outcomes**), and the moderating role of (**AI Technologies**).



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).

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 of large and complex projects and its effect on project outcomes. 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.

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 vital for coordinating processes and ensuring collaboration. Effective planning establishes clear goals, defines critical quality characteristics, and maps workflows and control measures. However, in the JSWP, quality planning has often been insufficiently executed, as evidenced by numerous cases of work commencement without obtaining mandatory approvals for execution methods known as method of statement (MOS) or finalized shop drawings. This lack of adherence to project quality protocols highlights a significant gap in ensuring consistency and alignment in the project's quality management efforts.

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. However, in the JSWP, gaps in quality assurance practices have been observed, such as inconsistent inspection routines and inadequate following of internal testing plans (ITP), often due to the high volume of concurrent projects and strained supervisory capacity. These shortcomings have led to instances where quality issues were only identified after significant work was completed, resulting in rework and delays. By addressing such gaps and implementing robust quality assurance measures, construction projects like those in

JSWP can enhance the overall quality, reliability, and longevity of the constructed facilities, ultimately meeting or exceeding client requirements and expectations.

Quality Improvement

As per (Juran & Joseph, 2012) 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.

In JSWP, the lack of a structured approach to continuous quality improvement has often led to repeated deficiencies, such as material waste and recurring design modifications, due to inadequate coordination, especially with other utilities' providers, and poor communication among stakeholders. These recurring issues highlight the importance of adopting principles like 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. By addressing these gaps and embracing proactive quality improvement measures early during the planning stage and before issue the projects for bidding, JSWP can enhance efficiency, reduce waste, and deliver high-quality outcomes that meet or exceed client expectations.

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 (Yang et al., 2019).

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. 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 by (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 in infrastructure projects 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

The ability of AI to predict potential quality issues is a transformative application in construction quality management. By analyzing historical project data, real-time sensor inputs, environmental factors, and supply chain disruptions, AI-powered predictive models can forecast quality problems such as delays, cost overruns, defects, or equipment failures (Abioye et al., 2021). For instance, machine learning techniques, as demonstrated in recent research by Dip Datta et al. (2024), have proven effective in identifying construction risks by considering factors like project complexity, weather conditions, and supply chain uncertainties. These predictive insights enable project teams to proactively address quality concerns before they escalate, reducing rework, delays, and additional costs. By incorporating AI-driven predictive analytics into quality management systems, construction projects can enhance their ability to meet quality objectives and improve overall project outcomes.

Additionally, AI supports informed decision-making in quality management by providing predictive insights and actionable recommendations. By processing vast amounts of data from past projects, real-time site conditions, and process information, AI systems can identify trends, suggest optimal actions, and highlight areas of

concern. These capabilities enable project teams to make more accurate and timely decisions, improving resource allocation, reducing inefficiencies, and enhancing overall project quality (Dabous et al., 2023). The integration of AI's decision-support systems empowers construction managers to address potential risks proactively and align project outcomes with stakeholder expectations, marking a significant step forward in construction quality management practices.

In the context of the Jeddah Stormwater Program, AI's predictive capabilities can play a pivotal role in addressing recurring challenges such as utility clashes, material shortages, and schedule delays. By leveraging real-time data and predictive analytics, JSWP teams can anticipate risks and implement corrective measures before issues escalate. This proactive approach would enhance coordination across multiple sites, minimize disruptions, and ensure higher-quality outcomes for the program's complex and dispersed projects.

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 (FMEA), 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.

The reliance on traditional inspection methods in JSWP poses significant challenges in managing quality across the program's large and complex projects. With numerous dispersed sites, high volumes of activities, and intricate interdependencies, traditional approaches often fail to provide the scalability and real-time responsiveness needed to ensure consistent quality. These limitations result in delayed identification of defects, inefficient allocation of resources, and increased rework. Integrating AI technologies into the quality management process can bridge these gaps by automating inspections, analyzing data in real-time, and predicting potential quality issues before they escalate. By transitioning from reactive to proactive quality management, AI can enhance the efficiency and effectiveness of CQM practices, ensuring better outcomes for large-scale and complex infrastructure projects like JSWP.

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).

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, and 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, which is the case in JSWP. 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 (Leong et al., 2014). Previous studies have highlighted the significant impact of cost overruns on project profitability, client satisfaction, and the overall viability of construction firms. Also 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.). Similarly, robust quality management practices, like AI-Driven, require upfront investment, but 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 (Hwang & Yang, 2014).

The survey conducted by Assaf & Al-Hejji (2006) 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. Similar issues have been observed in JSWP, particularly poor planning and delayed design approvals, which exacerbate schedule delays across the program's dispersed and concurrent projects. Additionally, poor quality, defects, and reworks further compound these delays, disrupting workflows and increasing the time required to complete projects.

Low & Ong (2014) suggest 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. For JSWP, adopting robust quality management practices would provide a more structured approach to addressing quality-related inefficiencies. By emphasizing quality planning and assurance, the program could proactively identify and mitigate risks that contribute to delays, ultimately improving time performance across its large and complex infrastructure projects.

Quality

Quality is one of the three dimensions of the Iron Triangle and serves as a critical measure of construction project success. In the context of construction, quality refers to the conformance of the final product or service to specified requirements, standards, and client expectations. This definition aligns with the principles of Philip Crosby, who emphasized that "quality is conformance to requirements." Quality performance is assessed by evaluating the quality of workmanship, materials, and adherence to established specifications and standards, ensuring that the constructed facility meets or exceeds stakeholder expectations (Crosby, 1980).

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).

In the context of the Jeddah Stormwater Program, the expansion of projects in size and complexity has led to a noticeable rise in the number of Site Observation Reports (SORs) and Non-Conformance Reports (NCRs). These reports highlight recurring issues such as deviations from approved designs, inadequate compliance with quality standards, material issues, non-adherence to quality plan, and defects arising during construction. The growing volume of SORs and NCRs underscores the challenges of maintaining consistent quality control across a program of this scale, further emphasizing the need for more efficient and proactive quality management practices. Integrating AI-driven technologies could help reduce such occurrences by automating compliance checks, enhancing real-time monitoring, and identifying potential quality issues before they escalate. This would provide a systematic approach to managing quality in large-scale infrastructure projects like JSWP.

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 (Alshihre et al., 2020). 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 (Ramlee et al., 2016).

Conclusion of Literature

The literature highlights several methods for measuring construction project outcomes, focusing on traditional metrics and the potential for AI to enhance measurement accuracy and efficiency (Leong et al., 2014). AI-powered technologies offer transformative opportunities in quality management, such as automating inspections, predicting quality issues, and improving workflow efficiency. However, existing quality research often applies AI to isolated aspects of quality management or specific project outcomes, without addressing its holistic, systematic impact on overall CQM practices (Dabous et al., 2023).

The literature table at the end of this chapter provides a structured review of key themes. The first section examines the challenges of traditional CQM practices, highlighting recurring issues such as defect detection and rework management. The second section identifies gaps in literature on Quality Management and AI, where existing studies focus on isolated applications like predictive analytics. The third

section reviews AI in construction/project management, emphasizing optimization of specific outcomes but lacking a systemic view of its influence on CQM. Together, these insights reveal a significant gap: the need for a comprehensive investigation into AI's transformative potential to optimize quality planning, control, assurance, and improvement as a cohesive framework. This study aims to address this gap, with a particular focus on the Jeddah Stormwater Program, offering a novel contribution to the field.

<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 - Challenges of Traditional CQM Practices				
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	Quality in construction management: an exploratory study	Jraisat et al.	2016	This paper investigated the factors that affect quality in construction. It highlighted the construction industry's focus on cost and time at the expense of quality, leading to persistent issues.	The paper found that the major factors affecting quality in construction are human resource management, customer satisfaction, and construction related issues.
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
A12	Causes of delay in large construction projects	Assaf & Al-Hejji	2006	The author conducted a survey on time performance of different types of construction projects in Saudi Arabia. The survey aimed to find out the cause of delay in construction. It found that average of 10% to 30% of deviation from original schedule. 70% of projects had time overrun, and major cause was change orders.	The author identified poor planning, ineffective subcontractor management, and material shortages as significant challenges to quality management. All these issues directly related to current challenges we are facing at JSWP
B	Literature related to Quality Management and Artificial Intelligence – AI in Enhancing Specific Quality management aspect				
B1	A Literature Review of Artificial Intelligence in Asphalt Quality Assurance	Ryan B. Castronuevo Edwin 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	Editorial: Automation and artificial intelligence in construction and management of civil infrastructure	<i>Dabous et al.</i>	2023	discusses the increasing trend of automation and AI adoption in the construction industry. It highlights the slower pace of adopting new technologies in construction compared to other sectors due to the industry's complexity,	This Demonstrated the use of predictive analytics to identify and mitigate quality risks, such as delays and cost overruns. The author emphasizes the need for more research to understand the potential of AI and automation in addressing construction and management challenges, which in light with the focus of the current research
B3	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.
B4	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.
B5*	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 Discussed integrating AI with FMEA and Statistical Process Control to enhance defect detection and prevention. It help on how AI-driven quality management systems can enhance traditional quality practices, which aligning directly with focus of the thesis 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.

B6	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.
B7	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	Litratre 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 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.
C8	Artificial Intelligence for Product Quality Inspection toward Smart Industries: Quality Control of Vehicle Non-Conformities	Chouchene et al.	2020	This work proposes an automated artificial vision system leveraging AI to detect vehicle defects, aligning with the principles of Industry 4.0. Additionally, a brief review of AI-based quality control methods highlights the challenges of Visual Inspection (VI) and demonstrates AI's effectiveness, particularly in vehicle manufacturing industries.	In this paper the author proposed an Intelligent Quality Management Information System (IQMIS) for real-time monitoring and optimization of quality processes in the car manufacturing industry. This approach can be insightful for developing a framework of AI-driven CQM practices for JSWP.

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 explored AI-powered technologies to automate inspections and improve decision-making in quality control workflows. It can 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.

References

1. Abioye, S., Oyedele, L. O., Akanbi, L., Ajayi, A. O., Bilal, M., Akinadé, O. O., & Ahmed, A. (2021). Artificial intelligence in the construction industry: A review of present status, opportunities, and future challenges. **Journal of Building Engineering*, 44*, 103299. <https://doi.org/10.1016/j.jobbe.2021.103299>
2. Aichouni, M., Messaoudene, N. A., Al-Ghonamy, A. I., & Touahmia, M. (2014). An empirical study of quality management systems in the Saudi construction industry. **International Journal of Construction Management*, 14*(3), 181-190. <https://doi.org/10.1080/15623599.2014.922724>
3. Akinradewo, O., Aigbavboa, C., & Akinradewo, O. F. (2019). Impact of Construction Project Planning on Contractor's Profit. In O. Akinradewo, C. Aigbavboa, & O. F. Akinradewo, *IOP Conference Series Earth and Environmental Science* (Vol. 385, Issue 1, p. 12009). IOP Publishing. <https://doi.org/10.1088/1755-1315/385/1/012009>
4. Alshaikhi, A., & Khayyat, M. (2021). An investigation into the impact of artificial intelligence on the future of project management. In **2021 International Conference of Women in Data Science at Taif University (WiDSTaif)** (pp. 1-4). Taif, Saudi Arabia.
5. Alshihre, F., Chinyio, E., Nzekwe-Excel, C., & Daniel, E. I. (2020). Improving clients' satisfaction in construction projects: the case of Saudi Arabia. In F. Alshihre, E. Chinyio, C. Nzekwe-Excel, & E. I. Daniel, *Built Environment Project and Asset Management* (Vol. 10, Issue 5, p. 709). Emerald Publishing Limited. <https://doi.org/10.1108/bepam-12-2019-0140>
6. American Society for Quality (ASQ). (n.d.). *Honorary members*. Retrieved November 5, 2024, from <https://asq.org/about-asq/honorary-members>
7. Arditi, D., & Günaydın, H. M. (1997). Total quality management in the construction process. In D. Arditi & H. M. Günaydın, *International Journal of Project Management* (Vol. 15, Issue 4, p. 235). Elsevier BV. [https://doi.org/10.1016/s0263-7863\(96\)00076-2](https://doi.org/10.1016/s0263-7863(96)00076-2)
8. Assaf, S., & Al-Hejji, S. (2006). Causes of delay in large construction projects. In S. Assaf & S. Al-Hejji, *International journal of project management* (Vol. 24, Issue 4, p. 349). Elsevier BV. <https://doi.org/10.1016/j.ijproman.2005.11.010>

9. Chen, Y., & Li, haoqi. (2019). Research on Engineering Quality Management Based on PDCA Cycle. In Y. Chen & haoqi Li, IOP Conference Series Materials Science and Engineering (Vol. 490, p. 62033). IOP Publishing. <https://doi.org/10.1088/1757-899x/490/6/062033>
10. Chouchene, A., Carvalho, A. V., Lima, T. M., Charrua-Santos, F., Osório, G. J., & Barhoumi, W. (2020). Artificial Intelligence for Product Quality Inspection toward Smart Industries: Quality Control of Vehicle Non-Conformities. <https://doi.org/10.1109/icitm48982.2020.9080396>
11. Creswell, J. W., & Clark, V. L. P. (n.d.). **Designing and conducting mixed methods research** (3rd ed.). Thousand Oaks, CA: SAGE Publications.
12. Crosby, P. B. (1980). *Quality is free: The art of making quality certain*.
13. Dabous, S. A., Rashidi, M., Zhu, Z., Alzraiee, H., Mantha, B. R. K., & Alsharqawi, M. (2023). Editorial: Automation and artificial intelligence in construction and management of civil infrastructure. In S. A. Dabous, M. Rashidi, Z. Zhu, H. Alzraiee, B. R. K. Mantha, & M. Alsharqawi, *Frontiers in Built Environment* (Vol.9). Frontiers Media. <https://doi.org/10.3389/fbuil.2023.1155240>
14. Datta, S. D., Islam, M. N., Sobuz, M. H. R., Ahmed, S., & Kar, M. K. (2024). Artificial intelligence and machine learning applications in the project lifecycle of the construction industry: A comprehensive review. **Heliyon**, e26888. <https://doi.org/10.1016/j.heliyon.2024.e26888>
15. Daneshjo, N., Malega, P., & Drábik, P. (2021). Techniques for Production Quality Control in the Global Company. In N. Daneshjo, P. Malega, & P. Drábik, *Advances in Science and Technology – Research Journal* (Vol. 15, Issue 1, p. 174). Society of Polish Mechanical Engineers and Technicians. <https://doi.org/10.12913/22998624/131558>
16. El-Emary, I. M. M. (2020). The effect of using artificial intelligence on the quality of decision-making in various organizations: A critical survey study. **Journal Name**, 13(4), 2042-2049.
17. Enshassi, A., Mohamed, S. A. M., & Abushaban, S. (2009). Factors affecting the performance of construction projects in the Gaza Strip. **International Journal of Construction Management*, 15*(3), 269-280.

18. Ferng, J.-J., & Price, A. (2005). An exploration of the synergies between Six Sigma, total quality management, lean construction and sustainable construction. In J.-J. Ferng & A. Price, *International Journal of Six Sigma and Competitive Advantage* (Vol. 1, Issue 2, p. 167). Inderscience Publishers.
<https://doi.org/10.1504/ijssca.2005.006427>
19. Friðgeirsson, Þ. V., Ingason, H. Þ., Jónasson, H. I., & Gunnarsdottir, H. (2023). A qualitative study on artificial intelligence and its impact on the project schedule, cost, and risk management knowledge areas as presented in PMBOK®. *Multidisciplinary Digital Publishing Institute, 13*(19), 11081.
20. Google Cloud. (2024). *AutoML*. Google. Retrieved October 9, 2024, from <https://cloud.google.com/automl>
21. Hwang, B., & Yang, S. (2014). Rework and schedule performance. *International Journal of Project Management, 21*(2), 190-205.
22. Huggins, L. P. (1998). Total quality management and the contributions of A.V. Feigenbaum. In L. P. Huggins, *Journal of Management History (Archive)* (Vol. 4, Issue 1, p. 60). Emerald Publishing Limited.
<https://doi.org/10.1108/13552529810369623>
23. IBM. (2024.). *Watson: AI solutions for smarter business*. IBM. Retrieved October 9, 2024, from <https://www.ibm.com/watson>
24. Ivankova, N. V., Creswell, J. W., & Stick, S. L. (2006). Using mixed-methods sequential explanatory design: From theory to practice. *Field Methods, 18*(1), 3-20.
25. Jeddah Stormwater Program Masterplan. (2021). [Jeddah Municipality, Saudi Arabia]. internal report.
26. Jraisat, L., Jreisat, L., & Hattar, C. (2016). Quality in construction management: an exploratory study. In L. Jraisat, L. Jreisat, & C. Hattar, *International Journal of Quality & Reliability Management* (Vol. 33, Issue 7, p. 920). Emerald Publishing Limited. <https://doi.org/10.1108/ijqrm-07-2014-0099>
27. Juran, J. M., & Godfrey, A. B. (Eds.). (1999). *Juran's quality handbook* (5th ed.). McGraw-Hill.
28. Juran, & Joseph, J. (2012). *Juran's quality handbook*.
<http://lontar.ui.ac.id/file?file=pdf/abstrak-103677.pdf>

29. Kiew, P. N., Ismail, S., & Yusof, A. M. (n.d.). Key Performance Indicators in Construction Quality Management System.
30. Leong, T. K., Zakuan, N., Saman, M. Z. M., Ariff, M. S. M., & Tan, C. S. (2014). Using project performance to measure effectiveness of quality management system maintenance and practices in construction industry. **The Scientific World Journal, 2014**, 1-9.
31. Likita, A. J., Zainun, N. Y., Rahman, I. A., Awal, A., Alias, A. R., Rahman, M., & Ghazali, F. (2018). An Overview of Total Quality Management (TQM) practice in Construction Sector. In A. J. Likita, N. Y. Zainun, I. A. Rahman, A. Awal, A. R. Alias, M. Rahman, & F. Ghazali, IOP Conference Series Earth and Environmental Science (Vol. 140, p. 12115). IOP Publishing.
<https://doi.org/10.1088/1755-1315/140/1/012115>
32. Love, P., & Li, H. (2000). Quantifying the causes and costs of rework in construction. **International Journal of Construction Management, 18*(4)*, 479-490.
33. Low, S. P., & Ong, J. (2014). Project Quality Management. Springer.
<https://doi.org/10.1007/978-981-287-074-2>
34. Luo, H., Li, G., Chen, K., Antwi-Afari, M. F., & Chen, L. (2022). Digital technology for quality management in construction: A review and future research directions. **Developments in the Built Environment, 12**, 100087.
<https://doi.org/10.1016/j.dibe.2022.100087>
35. Makaula, S., Munsamy, M., & Telukdarie, A. (2021, April). Impact of artificial intelligence in South African construction project management industry. In **2nd South American International Conference on Industrial Engineering and Operations Management**.
36. Merdžanović, I., Vukomanović, M., & Vidović, D. I. (2022). A comprehensive literature review of research trends of applying AI to construction project management. In **Proceedings of the 6th IPMA SENET Project Management Conference “Digital Transformation and Sustainable Development in Project Management”**.
37. Microsoft. (2024). *Azure AI: Empowering innovation with AI services*. Microsoft. Retrieved October 9, 2024, from <https://azure.microsoft.com/en-us/services/ai/>

38. Nagireddy, S. R. (2023). Artificial intelligence and its impacts on project management [Doctoral dissertation, University of the Cumberlands].
39. Naor, M., Goldstein, S. B., Linderman, K., & Schroeder, R. G. (2008). The role of culture as a driver of quality management and performance: Infrastructure versus core quality practices. **Decision Sciences*, 39*(4), 671-702.
40. Neyestani, B. (2016). Effectiveness of quality management system (QMS) on construction projects. **European Organization for Nuclear Research**.
41. Pan, Y., & Zhang, L. (2021). Roles of artificial intelligence in construction engineering and management: A critical review and future trends. **Automation in Construction*, 122*, 103517. <https://doi.org/10.1016/j.autcon.2021.103517>
42. Pheng, L. S., & Teo, J. A. (2003). Implementing Total Quality Management in Construction through ISO 9001:2000. In L. S. Pheng & J. A. Teo, *Architectural Science Review* (Vol. 46, Issue 2, p. 159). Taylor & Francis.
<https://doi.org/10.1080/00038628.2003.9696979>
43. Project Management Institute” PMI”. (2021). *A guide to the project management body of knowledge (PMBOK® guide)* (7th ed.). Project Management Institute.
44. Ramlee, N. B., Tammy, N. J., Noor, R. N. H. R. M., Musir, A. A., Karim, N. A., Chan, H. B., & Nasir, S. R. M. (2016). Critical success factors for construction project. In N. B. Ramlee, N. J. Tammy, R. N. H. R. M. Noor, A. A. Musir, N. A. Karim, H. B. Chan, & S. R. M. Nasir, *AIP conference proceedings*. American Institute of Physics. <https://doi.org/10.1063/1.4965067>
45. Regona, M., Yiğitcanlar, T., Hon, C. K., & Teo, M. (2023). Mapping two decades of AI in construction research: A scientometric analysis from the sustainability and construction phases lenses. **Multidisciplinary Digital Publishing Institute*, 13*(9), 2346.
46. Rezaei, A. (2011). Performance Measurement in a Quality Management System.
47. Seyman-Güray, T. (2023). Investigating AI applications in the construction industry: A systematic review.
48. Stake, R. E. (2005). **The Sage handbook of qualitative research** (3rd ed.). Thousand Oaks, CA: Sage Publications.
49. Tang, S. I., Ahmed, S. M., & Poon, S. W. (2005). *Construction Quality Mangement*. Hong Kong University Press.

50. Victor, N. O. C. (2022). Adoption of artificial intelligence for optimum productivity in the construction industry. *Preprints*, 2022110517.
51. Vision2033. (n.d.). Retrieved from <https://www.vision2030.gov.sa/en/vision-2030/vrp/quality-of-life-program/> (Access Date: 19-03-2024).
52. Yang, J., Wang, W., & ZHOU, S. (2019). A Design of Integrated Quality Management System Based on Artificial Intelligence (AI) Technology. In J. Yang, W. Wang, & S. ZHOU, DEStech Transactions on Computer Science and Engineering. Destech Publications. <https://doi.org/10.12783/dtcse/icaic2019/29396>
53. Zhang, M. (2020). Research on the application of intelligent construction site in construction site management. *IOP Conference Series: Materials Science and Engineering, 768*(6), 062005.