

**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

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List of Abbreviation

AI	Artificial Intelligence
AR	Augmented reality
BIM	Building Information Modelling
CAPA	Corrective and Preventive Action
CQM	Construction Quality Management
CV	Computer Vision
FMEA	Failure Mode and Effects Analysis
IoT	Internet of Things
ITP	Inspection Testing Plans
JSWP	Jeddah Stormwater Program
ML	Machine Learning
MIR	Material Inspection Request
MOM	Minutes of Meetings
MOS	Method of Statements
NCR	Non-Conformance Report
NLP	Natural Language Processing
PDCA	Plan Do Check Act
PMO	Project Management Office
PQP	Project Quality Plan
QA	Quality Assurance
QC	Quality Control
QI	Quality Improvement
QMS	Quality Management Systems
SOR	Site Observation Reports
SPC	Statistical Process Control
TQC	Total Quality Control
TQM	Total Quality Management

Chapter Three

Research Methodology

Overview

This chapter will outline and explain the research methodology employed in the study to provide a clear understanding of the framework used. The research seeks to examine the relationship between Construction Quality Management practices and project outcomes, and how it is negatively affected by the complexity and scale of large infrastructure projects. Additionally, the study will investigate the moderating role of AI in enhancing the effectiveness of CQM practices to amplify the positive influence of CQM practices to overcome the effect of size and complexity of projects, and project outcomes

Using a convergent mixed method case study approach as explained by Creswell & Plano Clark (2017), the study will use both qualitative and quantitative data, collected in parallel. The collection method for the primary data (quantitative) involves a structured questionnaire that the researcher developed to align it with the context of the case study. The secondary data (Qualitative) includes historical documentation including records and related logs—and Minutes of Meetings (MOM) from both completed and ongoing JSWP projects, which provide valuable qualitative insight and real-world context to the analysis.

Finally, to ensure the validity and reliability of the instrument and findings, statistical techniques using SPSS will be employed for descriptive testing, and SmartPLS to analyze the relationship between the variables, especially the moderating one. This combined methodological strategy enables triangulation of findings and offers a perspective on how AI integration can strengthen quality management practices in infrastructure development

3.1 Research Design

At the foundation of this research lies a clear articulation of its philosophical stance, methodological approach, and data strategy, following the guidance of Creswell and Plano Clark (2017, pp. 96–97) for reporting mixed methods studies. Adopting a convergent parallel mixed-methods design, this study employs a case study core design to integrate quantitative data with qualitative insights. This approach, grounded in pragmatism, enables the selection of the most suitable methods to address the research questions, considering the research context and potential consequences. Also, it involves the concurrent collection and analysis of both quantitative and qualitative data, followed by a phase of integration where the findings are synthesized to formulate comprehensive interpretations.

Within this convergent mixed-method design, both quantitative and qualitative data are gathered and analyzed concurrently. This parallel approach aims to provide a more comprehensive understanding of the relationship between Construction Quality Management practices and their impact on project outcomes, while also examining how Artificial Intelligence can enhance this relationship. The mixed-methods approach allows for data diversification, which enhances the clarity and comprehensibility of the data by supporting numerical data with qualitative data (Gürsoy & Özpolat, 2020). Also, it is appropriate for addressing research questions that require both breadth (quantitative) and depth (qualitative) of understanding (Ivankova et al., 2005).

For the quantitative part, a survey, developed by the author, will be used to gather information and insights from infrastructure projects including JSWP, focusing on CQM components and AI integration within the projects. The questionnaire is specifically designed to capture quantitative metrics related to project performance, quality management practices, and the adoption of AI technologies.

The qualitative part involves a thorough review of project documentation, including quality reports, audits findings, and projects logs, to extract in-depth and thematic insights into the practical application of CQM practices. Both parts will be given equal priority, and the results will be brought together during interpretation using a partial triangulation

strategy, where selected qualitative themes will be used to support, contrast, or elaborate on the quantitative findings.

Figure 3.1 illustrates the Procedural Flowchart of the Convergent Mixed Methods Case Study Design, inspired by Creswell and Plano Clark. This diagram represents the study's methodological structure, showing how quantitative data (collected via a structured survey of engineers, contractors, and stakeholders involved in JSWP and other infrastructure projects) and qualitative data (gathered through analysis of historical records like NCRs, SORs, and project dashboards) are collected concurrently and analyzed independently. Integration occurs at the interpretation stage, using partial triangulation to compare and relate findings. The diagram clarifies the procedural steps and reinforces the embedded nature of mixed methods within the Jeddah Stormwater Program case, ensuring methodological transparency and coherence.

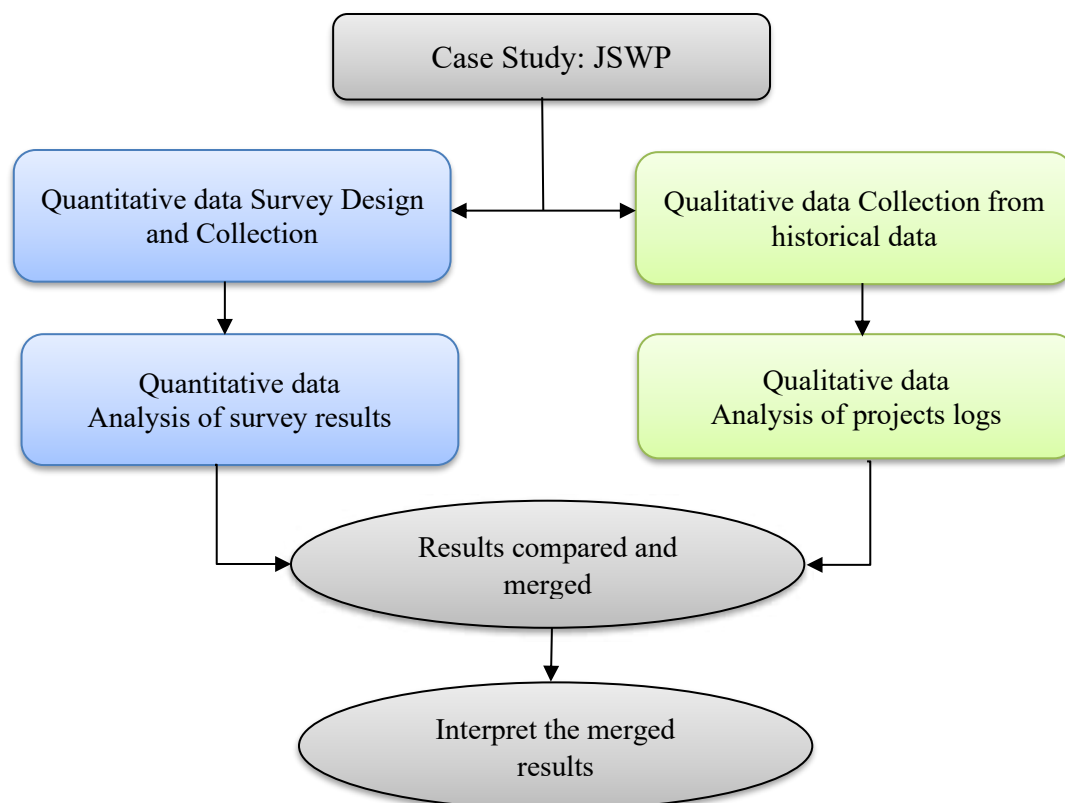


Figure 3.1: Procedural Flowchart of the Convergent Mixed Methods Case Study Design
Source: Inspired by Creswell and Plano Clark (2017, p. 119)

3.2 Justification for Mixed Methods

Quantitative researchers increasingly acknowledge the value of qualitative data in enriching and contextualizing their findings, while qualitative researchers recognize that relying solely on the views of a limited number of participants may restrict the generalizability of their results. The decision to adopt a mixed-methods approach is driven by the need to obtain a holistic and nuanced understanding of the intricate relationship between CQM, project outcomes, and the moderating effects of AI within the context of infrastructure projects. This is particularly important in the construction industry, where projects are diverse and complex, and AI technologies are rapidly evolving (Minc et al., 2022; Smajic et al., 2022).

Adopting a mixed methods design in this research is rooted in the premise that neither quantitative nor qualitative methods alone are sufficient to fully capture the complexity of issues inherent in large-scale construction projects (Ivankova et al., 2006). It also enables the collection and analysis of both qualitative and quantitative data, thereby providing a more comprehensive understanding of the research problem, by combining the generalizability of quantitative data with the contextual depth of qualitative insights.

The quantitative phase is conducted through structured surveys targeting key stakeholders within the infrastructure sector. The survey is designed to provide measurable insight into the perceived impact of CQM practices on project outcomes, highlighting the major challenges of current practices and the potential benefits of implementing AI applications. This will help to quantify the relationship between quality practices and project performance dimensions, including cost, time, quality, and client satisfaction.

The qualitative phase involves analyzing historical projects and quality records to explain, validate, and deepen the understanding of the survey findings. Drawing on the researcher's professional experience in quality management within the infrastructure sector, it is evident that while surveys provide valid perceptions, actual project logs reveal the root causes and operational realities behind quality failures. These records document real-world challenges observed during the execution of

infrastructure stormwater projects, offering detailed evidence of recurring issues, gaps in quality control, and systemic inefficiencies.

As a result, integrating quantitative and qualitative results enhances the robustness of findings, improving the interpretation of relationships between CQM, project outcomes, and AI technologies. This robust triangulation supports the development of a data-driven, AI-enhanced CQM model, aligning with Creswell and Plano Clark's convergent mixed-methods design to produce actionable, practice-informed conclusions.

3.3 Research Population and Sampling

The target sector for this research is the infrastructure construction segment within the Saudi construction industry. This focus is driven by the recurring issues in quality, coordination, and project outcome as discussed within previous Chapters, which are common in large-scale infrastructure projects, including JSWP. The unique challenges associated with these projects, such as their extensive scale, complex logistics, and significant public impact, make them a critical area for improving the traditional CQM practices. Furthermore, given the substantial investment in infrastructure development as part of Saudi Arabia's Vision 2030, enhancing CQM with AI in this sector holds significant economic, sustainability, and social value.

In alignment with this sectoral focus, the Jeddah Stormwater Program has been selected as the primary case study due to its complexity and scale as a key infrastructure initiative within the Kingdom, encompassing the entirety of Jeddah's master plan. The master plan comprising 92 projects across diverse disciplines, making JSWP a valuable representative of the infrastructure sector in the Western Region of Saudi Arabia. The program spans the entire city, adding another challenge due to the changing geology. Its multifaceted nature, involving numerous stakeholders, including 14 contractors, 20+ suppliers, and 3 consultants. In addition to the challenges it presents, and incidents from past rainy seasons and social impacts, the case provides a robust context for exploring CQM practices impact on project outcomes and the moderating role of Artificial Intelligence.

Given the program's complexity and its representative role in the infrastructure sector, a non-proportional stratified sampling strategy will be employed to ensure depth and relevance of insights. The target sample includes approximately 500 participants involved in infrastructure projects, particularly the Jeddah Stormwater Program (JSWP). Participants will be drawn from distinct strata—such as engineers (including managers, supervisors, site engineers, and inspectors), contractors, subcontractors, consultants, and suppliers.

To estimate the minimum required sample size (n_0), Cochran's formula was applied for a finite population. Assuming a 95% confidence level ($Z = 1.96$), a 5% margin of error ($e = 0.05$), and a 50% response distribution ($p = 0.5$), the formula is as follows:

$$n_o = \frac{Z^2 \times P \times (1 - p)}{e^2} = \frac{(1.96)^2 \times 0.5 \times 0.5}{0.05^2} = 384.16$$

Since the target population (N) is estimated at 3,000 individuals across the infrastructure sector in the Western Region, the adjusted sample size (n) was adjusted using the finite population correction (FPC):

$$n = \frac{n_o}{1 + \frac{n_o - 1}{N}} = \frac{384}{1 + \frac{383}{3000}} \approx 353$$

As per the result above, the final sample size will be increased to 500 participants to enhance representatives of the sample and to account for potential non-responses and errors discarded ones. Additionally, this non-proportional approach intentionally overrepresents certain strata particularly quality engineers and construction managers, engineers and supervisors, to obtain richer insights about site issues that are critical to the research focus on Construction Quality Management, project outcomes, and AI integration. This sampling approach aligns with established mixed-method research practices that prioritize analytical depth over strict proportionality.

3.4 Instrumentation

Given the mixed-methods approach explained earlier in this chapter, this study employs two primary instruments to gather comprehensive data: a structured questionnaire for the quantitative phase and document analysis for the qualitative phase. The structured questionnaire is designed to collect quantifiable data from a broad sample of participants, enabling statistical analysis and the generalization of findings. Document analysis, on the other hand, involves in-depth review of project-related documents, such as quality control reports, meeting minutes, and progress updates, to provide rich, contextual insights that complement and validate the quantitative data obtained through the questionnaire.

3.4.1. Quantitative instrument

The research employed a structured, bilingual questionnaire (Arabic and English) as the primary data collection instrument for the quantitative phase of the mixed-methods design. The questionnaire was designed by the researcher to align it with the study objectives, drawing upon literature from Construction Quality Management, Artificial Intelligence integration, and project performance measurement frameworks. Its design was also informed by practical field experience within the Jeddah Stormwater Program (JSWP), ensuring contextual relevance. The survey instrument consists of four main sections.

Section A – Demographics and Project Background: Captures key demographic variables and contextual information such as role in the organization, department, type of stakeholder (client, consultant, contractor, etc.), years of experience, project size and complexity, educational background, and certifications. This section also includes identifiers for JSWP participants to enable contextual data analysis.

Section B - This section assesses the current practices and perceived effectiveness of Construction Quality Management (CQM) as the independent variable of the study. The first part covers the presence and application of quality management tools, including quality management systems (QMS), KPIs, dashboards, manual reports, ISO certifications, and procedures for managing defects and ensuring compliance. Respondents evaluate their use of these tools and the challenges they face in maintaining quality—such as early defect identification, corrective

actions, and workforce training—using Likert scale ratings. The second part includes structured statements designed to measure the effectiveness of key CQM dimensions: Quality Planning, Quality Assurance, Quality Control, and Quality Improvement. These items assess how current quality practices influence project success in terms of cost, schedule, quality, and client satisfaction.

Section C – This section represents the dependent variable of the study. It focuses on the perceived impact of quality practices on four critical project outcomes: cost, time (schedule), quality of delivered work, and customer satisfaction. Respondents rate their agreement with a series of Likert-scale statements reflecting how effectively the current quality management efforts contribute to achieving these outcomes. The section serves to link the effectiveness of CQM practices, as perceived by stakeholders, with tangible project performance dimensions.

Section D – Artificial Intelligence (AI) in Quality Management: This section reflects the moderating variable of the research. It explores the current state of awareness, readiness, and expected benefits of integrating AI technologies into construction quality practices. Participants evaluate the extent to which AI can support quality planning, defect detection, real-time monitoring, data analysis, decision-making, and continuous improvement. The section also includes Likert-based items assessing perceived challenges in AI adoption—such as cost, skills, ethical concerns, and integration complexity—as well as enabling factors like management support and training. These insights aim to clarify how AI might strengthen the link between CQM and improved project outcomes in complex infrastructure projects.

As explained above, the instrument integrates both closed and open-ended questions, facilitating triangulation by allowing statistical analysis of trends and qualitative insight into contextual challenges and opportunities. Questions were formulated to reflect constructs identified in the literature and structured to support the convergent mixed-methods approach (Creswell & Plano Clark, 2017). The 5-point Likert scale was employed for attitudinal and perception-based items, allowing for meaningful quantification and subsequent statistical correlation between independent (CQM), dependent (project outcomes), and moderating (AI)

variables. Prior to full deployment, the questionnaire will undergo expert review for content validity, and a pilot test will be conducted to assess reliability, clarity, and time efficiency. Revisions will be made accordingly.

3.4.2. Qualitative instrument

For the qualitative component, the study will analyze historical quality documentation, primarily NCR, SORs, Logs, MOM, and dashboards, all collected from completed and ongoing infrastructure projects within JSWP. These documents offer direct evidence of recurring quality issues, contractor performance, and procedural gaps, enabling deeper insight into the practical challenges of current CQM practices in large-scale infrastructure projects.

This document analysis complements the survey findings by providing context to statistical trends and uncovering underlying patterns not easily captured through questionnaires. The qualitative data will undergo thematic coding and categorization to identify key themes, including causes of non-compliance, effectiveness of quality interventions, CAPA and quality improvement efforts, and coordination challenges.

During the data analysis stage of qualitative data, AI tools such as Microsoft Azure will be utilized by integrating them into dashboards to enhance analytical capabilities. Historical NCR and SOR logs will be digitized and processed using predictive analytics and natural language processing (NLP) techniques to detect trends, classify issue categories, and forecast potential quality risks. Integrating AI within this phase supports the study's objective of developing a data-driven framework to strengthen Construction Quality Management (CQM) practices and improve project outcomes.

3.5 Validity and Reliability

Ensuring the validity and reliability of the research instruments and findings is critical to the credibility and generalizability of this study's outcomes to the broad infrastructure projects witting Saudi Arabia. Given the use of a mixed-methods convergent design, steps were taken to address both quantitative and qualitative standards of research rigor.

3.5.1 Quantitative Part

Content validity will be established through expert review. The questionnaire will be evaluated by academics in the fields of quality management and artificial intelligence, as well as practitioners from the Jeddah Stormwater Program (JSWP), to assess clarity, relevance, and alignment with the study's variables. Based on their feedback, necessary modifications will be made to enhance construct accuracy and eliminate ambiguities.

In addition to expert review, construct validity will be addressed by ensuring the final survey structure aligns with the theoretical framework discussed in Chapters 1 and 2. Each section of the questionnaire, as outlined in Section 3.4, will be mapped to specific research constructs to ensure conceptual coherence and measurement accuracy. The instrument will capture the four dimensions of Construction Quality Management (CQM)—quality planning, quality control, quality assurance, and quality improvement—alongside project outcomes (cost, time, quality, and stakeholder satisfaction) as the dependent variable. The moderating role of AI will be reflected in items measuring application level, awareness, perceived impact, and organizational readiness. To further assess convergent and discriminant validity, structural model testing will be conducted using SmartPLS.

Furthermore, face validity will be assessed through pilot testing with a small sample of 15–20 professionals representing the target population. Participants will evaluate the wording, structure, and usability of the questionnaire, and their feedback will guide revisions for clarity and reliability. Established measures for constructs such as CQM practices, project outcomes, and AI adoption will also be incorporated to strengthen validity (Mitra & Tan, 2012).

Finally, reliability will be examined using Cronbach's alpha to determine internal consistency of the Likert-scale items. A threshold of $\alpha \geq 0.70$ will be considered acceptable for each construct, in line with established guidelines. Items with low inter-item correlations will be reviewed and, if necessary, removed to improve scale reliability.

3.5.2 Qualitative Part

To ensure the dependability of the qualitative analysis, this study will apply a structured and replicable framework when reviewing and coding NCR and SOR logs, as well as meeting notes. Dependability, as described by Lincoln and Guba (1985), refers to the stability and consistency of research findings over time, ensuring that results are not arbitrary but are produced through a systematic process. This consideration is essential because the qualitative phase of this study involves large volumes of text-based data extracted from multiple projects within the Jeddah Stormwater Program (JSWP).

The analysis will follow a planned approach that includes the creation of a data extraction template to standardize the recording of relevant attributes, such as issue category, cause, project phase, and corrective actions. A coding manual will then be developed to provide explicit definitions of codes, inclusion and exclusion rules, and examples for clarity. Codes are expected to cover recurring themes such as material non-conformities, procedural deviations, inspection delays, and design-related errors.

The coding process will adopt an iterative strategy: an initial pilot test will be conducted on a small subset of logs to refine the coding scheme before applying it to the entire dataset. Comprehensive documentation will be maintained throughout the process to ensure auditability and transparency. In addition, where feasible, a subset of the data will undergo secondary review to validate the application of codes and enhance consistency.

3.6 Study Variables

The independent variable in this study is Construction Quality Management (CQM). CQM is measured through four established dimensions commonly adopted in construction quality frameworks: quality planning, quality control, quality assurance, and quality improvement. These dimensions collectively represent the formal practices, tools, and systems applied to ensure quality across the project lifecycle. Each of these sub-dimensions is addressed in the survey instrument using Likert-scale items that capture the extent of implementation and the perceived effectiveness of these practices in infrastructure projects, with a particular focus on the JSWP.

The dependent variable is Project Outcomes. This variable reflects the effectiveness and success of project delivery, measured through four key indicators: cost performance, schedule adherence, quality of delivered works, and stakeholder or client satisfaction. These indicators are widely recognized in construction and project management literature and serve as tangible outcomes influenced by the application of quality management practices. Data related to these outcomes are captured through respondent perceptions in the survey, enabling quantification of the relationship between quality inputs and project-level results.

The moderating variable is Artificial Intelligence (AI) Technology. AI is included to explore its potential influence on the strength or direction of the relationship between CQM and project outcomes. This variable is assessed through dimensions such as awareness and familiarity with AI tools, current and planned usage, perceived benefits, readiness for adoption, and key barriers to implementation. AI's moderating role is central to the study's hypothesis that technology, when integrated effectively, can enhance traditional quality management systems and improve construction project performance. This variable will also be contextualized using qualitative analysis of historical project data and digital quality logs, particularly where AI integration may support prediction or pattern recognition.

3.7 Data Collection Procedures

As the study follows a convergent mixed-methods case study design, where quantitative and qualitative data are collected during a similar timeframe, analyzed separately, and then merged for interpretation. The purpose of this design is to develop a comprehensive understanding of the impact of Construction Quality Management (CQM) on project outcomes and the moderating role of Artificial Intelligence (AI) within infrastructure projects, using JSWP as the case context.

3.7.1 Primary Data Collection

Primary data was obtained through a structured questionnaire distributed to stakeholders involved in infrastructure projects, with a primary focus on those working within JSWP. The questionnaire was administered digitally to ensure accessibility and higher response rates. Participants were selected using purposive sampling to ensure they have direct experience with quality management practices or AI-related initiatives. The survey instrument included items targeting the independent variable (CQM), the dependent variable (project outcomes), and the moderating variable (AI). A Likert-scale was used for quantification, and confidentiality of all participants was maintained. The data collection phase is designed to reflect diverse roles (e.g., engineers, managers, consultants, contractors) and project phases to capture a holistic view of the quality landscape.

3.7.2 Secondary Data Collection

To complement the primary dataset and support triangulation, qualitative data was collected from project documentation, particularly NCRs, SORs and MOMs. These documents were extracted from completed and ongoing projects under JSWP. The records span several project phases and involve multiple contractors and consultants, providing rich qualitative evidence of recurring quality issues, interventions, and outcomes. The documents were reviewed using a structured content analysis approach to identify key themes related to quality planning failures, procedural deviations, coordination inefficiencies, and supported by audits findings. This secondary data serves not only to contextualize the quantitative findings but also to identify patterns that may support the development of an AI-enhanced quality management framework.

3.7.3 Additional Qualitative Source: Meeting Minutes

In addition to formal documentation, this study incorporates insights from weekly quality coordination meetings, which served as an interactive forum for stakeholders to review project performance, discuss emerging quality challenges, and propose corrective measures. These sessions, involving consultants, contractors, and client representatives, are conceptually aligned with focus group methodology as they facilitate group dialogue and collective problem-solving. Meeting minutes and recorded discussions were systematically reviewed to extract themes related to CQM practices, recurring non-conformities, reoccurring and trending quality issues, and CAPA. These findings were later compared to survey data and document analysis for triangulation.

AI technologies (such as Microsoft Azure Machine Learning or Google Cloud AutoML) will be used in future phases to analyze patterns in the qualitative data and integrate them with dashboard metrics, enhancing and improving predictive capabilities and decision support. This integration reinforces the case study's applied nature and aligns with the convergent design by enabling data transformation, comparison, and synthesis.

3.7.4 Data Collection Matrix

Table 3.1 and Figure 3.2 provide a comprehensive overview of how this study aligns its research questions with the corresponding data sources, types of data, collection procedures, and analysis strategies. This mapping is an essential step in mixed-methods research design, particularly within a convergent approach, as it ensures methodological coherence and transparency. Each research question is addressed through multiple sources of evidence, combining quantitative survey data, qualitative document analysis, and contextual insights from weekly coordination meetings. For example, Research Question 1 focuses on the adequacy of CQM practices in large-scale projects, which is explored through structured questionnaires to capture stakeholder perceptions and through archival analysis of NCR and SOR logs to validate these perceptions against documented realities.

By presenting this alignment in both tabular and graphical formats, the study not only adheres to the best practices recommended by Creswell

and Plano Clark (2017) but also strengthens the validity of its mixed-methods design. The table serves as a structured summary, while the concept map (Figure 3.2) visually shows the logical connections between research questions, data sources, and analysis pathways, emphasizing the integrated nature of the research process.

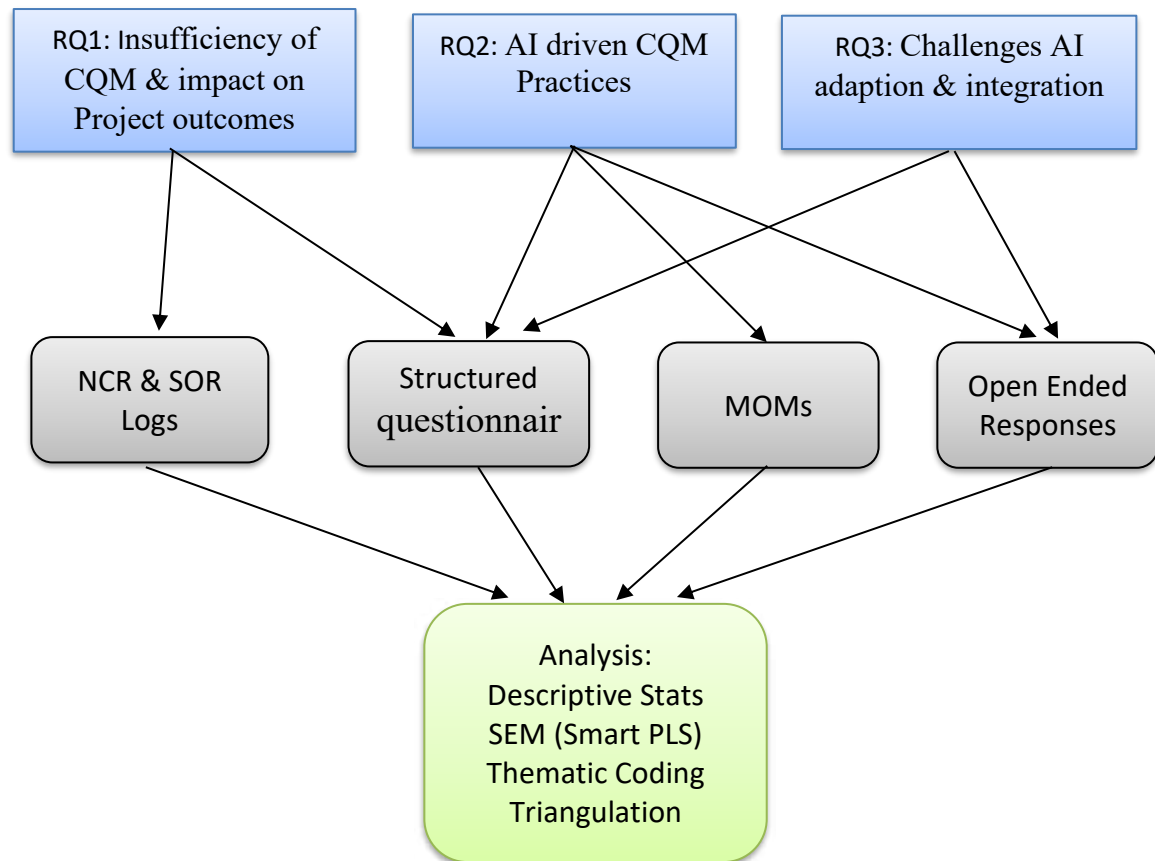


Figure 3.2: Concept map Linking Research Questions, Data Sources, and Analysis Methods
Source: Adapted from Creswell & Plano Clark, 2017

Research Question	Data Source	Type of Data	Collection Method	Analysis Approach
Research Q1: CQM insufficiency and its impact on project outcomes	Questionnaire Section B	Quantitative Likert scale, open question	Structured Questionnaire (Stakeholders)	Descriptive Statistics, SEM (SmartPLS)
	NCR & SOR Logs from JSWP Projects	Qualitative (Document Analysis)	Collection of archived documents	Thematic Analysis (CQM dimensions)
Research Q2: AI-driven CQM modifies impact of CQM on project outcomes	Questionnaire Sec. B & C Open-ended Responses	Quantitative	Structured Questionnaire	Moderation Analysis via SmartPLS Thematic Analysis AI readiness & perceptions
	MOM	Qualitative	Documented meeting discussions	
Research Q3: Challenges for AI adoption and integration in CQM	Questionnaire Section D AI challenges and perception	Qualitative	Structured Questionnaire	Thematic Analysis (AI barriers) Frequency Analysis
	MOM	Quantitative	MOM	
<i>Table 3.1: Data Collection Matrix aligned with research questions</i> <i>Source: Adapted from Creswell & Plano Clark, 2017</i>				

3.8 Data Analysis Methods

As explained earlier in this section, quantitative and qualitative datasets in this study are analyzed independently and merged during the interpretation phase. The aim was to enable triangulation, validation, and a comprehensive understanding of the relationship between CQM, project outcomes, and the moderating role of AI in large-scale infrastructure projects. The analysis is organized into three components: quantitative analysis, qualitative analysis, and data integration.

3.8.1 Quantitative Data Analysis

Quantitative data from the structured questionnaire will be analyzed using descriptive statistics to summarize respondent demographics and distribution across the main constructs: CQM, Project Outcomes, and AI. Following this, Structural Equation Modeling (SEM) will be employed using SmartPLS to assess relationships among variables and test

hypotheses, including moderation effects. SEM is appropriate for handling complex path models and reflective constructs, even with relatively small samples typical of case-based research. Reliability and validity will be examined through composite reliability, AVE, and discriminator validity. Respondents from contractor organizations will be asked to identify the specific JSWP project(s) they are involved in, enabling project-level linkage between survey responses and corresponding NCR/SOR data for deeper case-based analysis (Creswell & Plano Clark, 2017, p.72).

3.8.2 Qualitative Data Analysis

Qualitative data will be drawn from archival sources, primarily Non-Conformance Reports (NCRs) and Site Observation Reports (SORs) from completed and ongoing JSWP projects, supplemented by meeting notes and open-ended survey responses. A structured thematic content analysis will be employed, involving open coding, categorization, and theme development aligned with the CQM framework. Manual coding will be supported by AI-based Natural Language Processing (NLP) tools such as Microsoft Azure Cognitive Services to improve scalability and reduce bias by detecting patterns, clustering keywords, and forecasting quality risks. To ensure dependability, the analysis will follow a documented and replicable coding framework to maintain consistency. Themes related to AI readiness and adoption will also be extracted to complement quantitative findings (Creswell & Plano Clark, 2017, p.75).

3.8.3 Data Integration Strategy

After independent analysis, findings will be merged for triangulation to identify convergence, divergence, and complementarity between the two strands. Where feasible, qualitative themes will be transformed into frequency counts to support comparison, and joint displays will be developed to illustrate alignment between datasets. For instance, if a project shows high NCR rates in qualitative logs and corresponding survey responses report weak quality planning, this convergence will strengthen internal validity. Conversely, discrepancies will be interpreted in light of project complexity and organizational readiness for AI. The integrated insights will inform the development of an AI-enhanced CQM

model, supporting practical recommendations for improving quality performance in large-scale infrastructure programs.

3.9 AI Model Development Plan

As part of the future development phase of this research, an Artificial Intelligence (AI) model is planned to support and enhance Construction Quality Management (CQM) practices within infrastructure projects. This model is not being implemented at this stage but is intended as a conceptual and analytical extension based on the outcomes of the current study. The goal is to explore how AI can assist in identifying quality trends, predicting non-conformities, and improving decision-making processes based on historical project data.

The initial plan involves collecting and preparing existing data sources from completed projects, particularly those within the Jeddah Stormwater Program (JSWP). These include Non-Conformance Reports (NCRs), Site Observation Reports (SORs), project profiles, and performance dashboards. Additional insights will be derived from the survey data, particularly where participants discuss challenges and opportunities in applying AI to quality management.

To develop the AI model, cloud-based platforms such as Microsoft Azure or Google AutoML will be considered for their compatibility with real-time dashboards and analytics tools like Power BI. These platforms may enable integration with existing logs to allow for smarter classification, trend prediction, and real-time alerts.

Initially, AI applications may focus on Natural Language Processing (NLP) to analyze NCR and SOR text, identify recurring issues, and support theme extraction. Supervised learning models may later be explored to predict quality risks or detect early indicators of project non-compliance. The AI model will evolve based on the findings of the current research and data analysis and availability of AI applications.

This plan will be refined and updated after the completion of data collection and analysis phases. It represents a step toward integrating smart technologies into traditional quality frameworks and aligns with broader digital transformation goals within the Saudi infrastructure sector.

استبانة بحثية لرسالة الدكتوراه

عنوان البحث

استكشاف الدور المعدل لتطبيقات الذكاء الاصطناعي في تأثير إدارة الجودة على نتائج مشاريع التشييد
"دراسة حالة لبرنامج تصريف مياه الأمطار بمدينة جدة"

إعداد: م. إسماعيل حسن عجيمي

باحث دكتوراه في إدارة الجودة في جامعة ميدأوشن

تهدف هذه الاستبانة إلى جمع بيانات ميدانية ضمن إطار دراسة أكاديمية لنيل درجة الدكتوراه. تغطي الاستبانة ممارسات إدارة الجودة في مشاريع التشييد، وأثرها على نتائج المشروع، إضافة إلى الدور المحتمل لتقنيات الذكاء الاصطناعي لتحسين ممارسات إدارة الجودة في مشاريع البنية التحتية الأثر الناتج على نتائج المشاريع (التكلفة – الجدول الزمني – رضا العميل)

جميع المعلومات التي يتم جمعها ستعامل بسرية تامة، وستستخدم فقط لأغراض البحث العلمي. المشاركة طوعية، ويحق للمشارك الانسحاب في أي وقت دون أي التزام

نشكر لكم تعاونكم ومساهمتمكم القيمة في إنجاح هذا البحث.

PhD Research Questionnaire

Thesis Title

**"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: Eng. Ismail Hasan Ujaimi

PhD Candidate in Quality Management at Midocean University

This questionnaire is part of a doctoral research study focused on understanding current Construction Quality Management practices, their influence on project outcomes, and the potential role of Artificial Intelligence in enhancing these practices.

All collected information will be treated with strict confidentiality and used only for academic purposes. Participation is entirely voluntary; you may withdraw at any stage without any obligation

Thank you for your valuable time and contribution to this research

This questionnaire aims to understand Construction Quality Management (CQM) practices and changes, and the potential for using artificial intelligence (AI) tools effectively to improve various aspects of project quality management and its impact on project outcomes. Your insights will help us identify current challenges and potential solutions for integrating AI in this crucial domain	تهدف هذا الاستبانة إلى فهم ممارسات وتحديات الجودة في مشاريع البنية بشكل فعال (AI) التحتية وامكانية استخدام أدوات الذكاء الاصطناعي ومعرفة أثر ذلك على لتحسين مختلف جوانب إدارة جودة المشروع مخرجات المشاريع ستساعدنا أفكارك في تحديد التحديات الحالية والحلول المحتملة لدمج الذكاء الاصطناعي في هذا المجال الهام
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Section A: Project Management Background & Experience:	الجزء أ: الخبرة والخبرة في إدارة المشاريع
1. What is your role in the company? (Ans., Senior Manager, Manager, Senior Engineer, Engineer, Inspector)?	1. ما هو منصبك في الشركة؟ (الإجابة: مدير أول، مدير، مهندس أول، مهندس، مفتش؟)
2. What is your department? (Ans. Management, Construction, Quality, HSE, planning, Technical)	2. ما هو القسم الذي تنتمي له؟ (الإجابة: الإدارة، التنفيذ، الجودة، الصحة والسلامة والبيئة، التخطيط، القسم الفني)
3. What is the role of your organization in the project? (Ans., Client, PMO, Supervision Consultant, Contractor, Sub-Contractor, Supplier)	3. ما هو دور المنظمة التي تعمل فيها في المشروع؟ (الإجابة: المالك، PMO، استشاري التنفيذ، مقاول، مقاول باطن، مورد)
4. How many years of experience do you have? (Ans. 0-5, 6-10, 11-15, 16-20, >21 Years)	4. كم عدد سنوات الخبرة؟ (الإجابة: 0-5، 6-10، 11-15، 16-20، أكثر من 21 سنة)
5. What is your highest level of Education? Diploma, Bachelor, Masters, PhD	5. الدرجة العلمية الحاصل عليها؟ الدبلوم، البكالوريوس، الماجستير، الدكتوراه
6. What is the scale of the project based on the budget? (based on MOMRA classification) (Ans. Small < 50 million SR – 50-200 million SR, Big > 200 million SR)	6. ما هو حجم المشروع بناءً على الميزانية؟ (طبقاً لتقسيم الشؤون البلدية والقروية) (الإجابة: صغير أقل من 50 مليون ريال – متوسط 50-200 مليون ريال – كبير أكثر من 200 مليون ريال)
7. What is the scale and complexity of the project team (e.g., small team, large team, large multinational team)?	7. ما هو حجم وتعقيد فريق المشروع (الإجابة: فريق صغير، فريق كبير، فريق كبير متعدد الجنسيات؟)
8. Did you acquire any of the following certificates PMP, RMP, PRINCE, ISO Lead Auditor, Lean six Sigma, Certified Manager of Quality, other...	8. هل حصلت على أي من الشهادات التالية: PMP, RMP, PRINCE, ISO Lead Auditor, Lean six Sigma, Certified Manager of Quality, other...
9. If working on the Jeddah stormwater program please include the project name for analysis purposes?	9. إذا كنت من ضمن برنامج تصريف مياه الأمطار المرجو ذكر اسم المشروع و ذلك لأغراض تحليل النتائج؟
10. Gender: Male – Female – Prefer not to say	10. الجنس: ذكر – أنثى – أفضل عدم الإفصاح

Section B: Project Quality Management	الجزء ب: إدارة جودة المشروع
Part B1: Construction Quality Management “CQM” Practices Background: Please indicate your level of agreement with the following statements regarding how quality management practices have influenced project outcomes (1 = Strongly Agree, 5 = Strongly Disagree)	الجزء ب1: ممارسات إدارة جودة المشاريع الحالية في المشروع يرجى اختيار إلى مستوى موافقتك على العبارات التالية عن مدى تأثير ممارسات إدارة الجودة على مخرجات المشروع (1 = أوافق بشدة ، 5 = اعارض بشدة)
1. Quality is considered a core value within my organization and supported by higher management	1- تعتبر الجودة من القيم الأساسية في المنظمة ويتم دعمها من قبل الإدارة العليا للمنظمة.
2. Quality organizations’ cultural patterns, like rituals, beliefs, values, and everyday procedures, directly or indirectly affect CQM practice?	2- هل تعتقد أن الأنماط الثقافية للمنظمة تجاه الجودة، مثل المعتقدات والقيم والإجراءات اليومية، تؤثر بشكل مباشر أو غير مباشر على ممارسات إدارة الجودة بالمشاريع الانشائية؟
3. Quality organizations’ cultural patterns, like rituals, beliefs, values, and everyday procedures, directly or indirectly affect CQM practice?	3- هل تعتقد أن الأنماط الثقافية للمنظمة تجاه الجودة، مثل المعتقدات والقيم والإجراءات اليومية، تؤثر بشكل مباشر أو غير مباشر على ممارسات إدارة الجودة بالمشاريع الانشائية؟
4. Having ISO 9001 certification among stakeholders positively contributes to organization’s success in achieving its quality management objectives by establishing a common language for understanding and implementing quality requirements.	4- يساهم الحصول على شهادة ISO 9001 بين أصحاب المصلحة بشكل إيجابي في نجاح المنظمة في تحقيق أهداف إدارة الجودة من خلال إنشاء لغة مشتركة لفهم متطلبات الجودة وتنفيذها.
5. We are facing the following challenges in maintaining quality across the current project? • Identifying defects early • Managing and tracking defect resolution • Ensuring compliance with standards/specifications • Implementing effective corrective actions • Establishing preventive action mechanisms • Workforce skill level and training gaps • Lack of effective strategies or best practices	5- نواجه التحديات التالية في الحفاظ على الجودة في المشاريع الحالية: • صعوبة في اكتشاف العيوب في وقت مبكر • صعوبة في إدارة وتتبع تصحيح العيوب • صعوبة في ضمان الالتزام بالمعايير / المواصفات • ضعف في تنفيذ الإجراءات التصحيحية الفعالة • غياب آليات فعالة للإجراءات الوقائية • وجود فجوات في مهارات وتدريب القوى العاملة • نقص في الاستراتيجيات الفعالة أو أفضل الممارسات المعتمدة
6. To what extent do you use the following tools or techniques for quality monitoring and analysis in your current project? (1 = Always Used, 5 = Not Used) • Spreadsheets • KPIs • Manual Reports • Generic software such as MS Projects, Primavera, Unifier, Clouds, Share points	6- ما مدى استخدامك للأدوات أو التقنيات التالية في مشروعك الحالي لمراقبة الجودة وتحليلها؟ (1= يتم استخدامها دائما ، 5= لا يتم استخدامها) • ملفات الاكسل Spreadsheets • مؤشرات قياس الأداء KPIs • لوحة المعلومات Dashboards • التقارير اليدوية • برامج عامة أخرى مثل MS Projects, Primavera, Unifier, Clouds, Share points
7. Please describe any specific challenges faced in implementing or improving quality practices (open ended questions)	7- اذكر أي تحديات أو عقبات واجهتها أو تواجهها أثناء تطبيق أو تحسين عمليات الجودة - الجواب

Part B2: Dimensions of Construction Management practices	الجزء ب2: ابعاد ممارسات الجودة
Quality Planning: 1. There is a formal Quality Management System (QMS) with clear Quality objectives, policy, documented procedures, and KPIs within the organization. 2. Project Quality Plans (PQP) are prepared during the planning stage for each project according to the project needs 3. We use defined quality objectives, performance indicators, and checklists during planning 4. Stakeholders are involved in the process of quality planning. 5. Lessons learned from previous and similar projects are used during the planning stage	التخطيط للجودة 1- يوجد نظام رسمي لإدارة الجودة (QMS) مع أهداف جودة واضحة وسياسة وإجراءات موثقة ومؤشرات أداء رئيسية داخل المنظمة. 2- يتم إعداد خطط الجودة للمشروع PQP خلال مرحلة التخطيط لكل مشروع وفقاً لاحتياجات المشروع. 3- يتم وضع أهداف الجودة، مؤشرات الأداء، وقوائم التحقق خلال مرحلة التخطيط 4- يتم إشراك أصحاب المصلحة خلال مرحلة التخطيط للجودة 5- يتم الاستفادة من الدروس المستفادة من المشاريع السابقة والمماثلة خلال مرحلة التخطيط للجودة
Quality Assurance: 6. Quality audits and Management review meetings are conducted regularly and effectively 7. There are clear internal communication processes for enforcing quality standards 8. Top management demonstrates strong commitment to quality assurance	ضمان الجودة 6- يتم إجراء عمليات التدقيق الداخلية واجتماعات المراجعة من قبل الإدارة بفعالية وبشكل دوري 7- هناك عمليات اتصال داخلية واضحة لتطبيق معايير الجودة 8- تظهر الإدارة العليا في المنظمة التزاماً قوياً تجاه ممارسات تأكيد الجودة
Quality Control: 9. There is a flow chart and procedures showing the process of each quality control activity such as inspections, NCRs, SORs. 10. Regular inspections and testing procedures are followed for materials and works as per ITP 11. Non-conformities are identified and corrected in a timely manner 12. Documentation systems (e.g., NCR logs, SORs, issue logs) are consistently used to track quality issues	التحكم في الجودة 9- يوجد مخطط انسيابي وإجراءات توضح عملية كل نشاط من أنشطة التحكم في الجودة مثل عمليات الفحص، تقارير عدم المطابقة (NCRs)، طلبات التصحيح (SORs) 10- تم اتباع إجراءات التفتيش والاختبار بانتظام للمواد والأعمال وفقاً لخطة التفتيش والاختبار (ITP) 11- يتم تحديد، تصحيح وإغلاق حالات عدم المطابقة في الوقت المناسب 12- يتم استخدام أنظمة توثيق تشمل سجلات لتقارير عدم المطابقة، تقارير الملاحظات وسجلات مشاكل الجودة
Quality Improvement: 13. Quality procedures are reviewed and updated regularly 14. There are effective mechanisms for capturing feedback and lessons learned 15. Training programs on quality standards are provided continuously 16. Corrective and preventive actions (CAPA) are actively implemented and monitored	تحسين الجودة 13- يتم مراجعة وتحديث إجراءات الجودة بانتظام. 14- توجد آليات فعالة لجمع الملاحظات والدروس المستفادة. 15- يتم توفير برامج تدريبية على معايير الجودة بشكل مستمر. 16- يتم تنفيذ ومراقبة الإجراءات التصحيحية والوقائية (CAPA) بنشاط.
17. Please describe any specific challenges faced in implementing or improving quality practices	17- اذكر أي تحديات أو عقبات واجهتها أو تواجهها أثناء تطبيق أو تحسين عمليات الجودة

Part C: Project Outcomes (Time-Cost-Quality-Customer satisfaction) and Perceived Impact of CQM Practices	الجزء ت: مخرجات المشاريع (الوقت-التكلفة-الجودة-رضاء العملاء) وأثر ممارسات الجودة عليها
Please indicate your level of agreement with the following statements regarding how current quality management practices have influenced project outcomes (1 = Strongly Agree, 5 = Strongly Disagree):	يرجى اختيار إلى مستوى موافقتك على العبارات التالية عن مدى تأثير ممارسات إدارة الجودة الحالية على مخرجات المشروع (1 = أوافق بشدة ، 5 = اعارض بشدة)
<u>Project Cost</u> 1. Quality practices help in controlling project cost overruns by reducing reworks 2. Rework due to quality issues increases project costs	<u>تكلفة المشروع</u> 1- تساهم تطبيقات الجودة في التحكم في زيادة تكلفة المشاريع من خلال تقليل إعادة الاعمال 2- إعادة الاعمال بسبب مشاكل الجودة تزيد من تكلفة المشاريع
<u>Project Time</u> 3. The presence of robust CQM practices can reduce the frequency of rework and schedule overruns 4. Quality-related delays (e.g., material rejection, repair, rework) are concerning in our project	<u>الجدول الزمني</u> 3- يؤدي وجود ممارسات فعالة لإدارة الجودة إلى تقليل تكرار إعادة العمل وتجاوز الجدول الزمني 4- التأخيرات المتعلقة بالجودة (مثل المواد المرفوضة، اصلاح العيوب، وإعادة الاعمال) تشكل مصدر قلق في مشروعنا
<u>Overall Project Quality</u> 5. Robust CQM practices help in improving the overall quality of works 6. Few defects are observed during project handover and included in snag list 7. Project outputs comply with specifications and quality standards	<u>جودة المشروع بصورة عامة</u> 5- تساهم ممارسات إدارة الجودة الفعالة في تحسين الجودة العامة للأعمال. 6- يتم رصد عدد قليل من العيوب اثناء تسليم المشروع ويتم تضمينها ضمن قائمة العيوب Snag list 7- تتوافق مخرجات المشروع مع مواصفات ومعايير الجودة
<u>Customer Satisfaction</u> 8. CQM practices such as audits help to improve the overall quality of work increasing customer satisfaction 9. Clients or end users express satisfaction with delivered quality 10. Quality management improves stakeholder communication and satisfaction	<u>رضاء العملاء</u> 8- تساهم ممارسات الجودة مثل التدقيق في تحسين الجودة في المشاريع بشكل عام وبالتالي رضاء العملاء 9- العملاء أو المستخدمون النهائيون يعبرون عن رضاهم عن الجودة المقدمة 10- إدارة الجودة تحسن التواصل مع أصحاب المصلحة ورضاهم

Section D: Potential AI Applications in CQM	الجزء ج: تطبيقات الذكاء الاصطناعي التي يمكن استخدامها في إدارة جودة المشاريع
<u>AI Awareness & Readiness</u> 1. I am interested in learning and using AI to enhance the current practices in my organization including Quality. 2. I am familiar with AI technologies (e.g., ML, NLP, computer vision) 3. There are initiatives in Our organization to integrate AI in project process including quality 4. Special training on using AI tools is needed for our staff to understand and use AI technology 5. Staff are competent and open to using AI tools in quality management 6. The current system in your organization is ready to be integrated with AI technology 7. The integration of AI and quality practices can positively influence the project's outcomes and overall success	<u>الوعي والاستعداد لاستخدام الذكاء الاصطناعي:</u> 1- أنا مهتم بتعلم واستخدام الذكاء الاصطناعي لتعزيز الممارسات الحالية في مؤسستي بما فيها الجودة. 2- أنا على دراية بتقنيات الذكاء الاصطناعي (مثل التعلم الآلي، معالجة اللغة الطبيعية، الرؤية الحاسوبية). 3- هناك مبادرات في منظمنا لدمج الذكاء الاصطناعي في عمليات المشروع وتشمل عمليات الجودة. 4- هناك حاجة لتدريب خاص على استخدام أدوات الذكاء الاصطناعي لفهم واستخدام التكنولوجيا. 5- الموظفون مؤهلون ومنفتحون على استخدام أدوات الذكاء الاصطناعي في إدارة الجودة. 6- الأنظمة الحالية في منظمنا جاهزة للتكامل مع تكنولوجيا الذكاء الاصطناعي. 7- يمكن أن يؤثر تكامل الذكاء الاصطناعي وممارسات الجودة بشكل إيجابي على نتائج المشروع والنجاح العام.
<u>AI application in Quality Lifecycle:</u> 8. AI tools can be used for generating quality requirements automatically from historical data 9. AI Could help by automating operations and digitalizing processes to improve productivity, safety, and quality. 10. AI Integration with CQM practices can help to analyze quality data and identify trends and patterns to inform future project improvements 11. AI Could help improve communication and collaboration between stakeholders on quality issues 12. AI supports compliance checking with codes, standards, and projects specifications 13. AI-powered dashboards are used for predictive insights during project execution 14. AI tools help in detecting errors or defects earlier than traditional methods, especially when integrated with project dashboards 15. AI Integration with CQM practices can help to predict and prevent errors related to humans, observations, non-conformities, before they occur.	<u>تطبيقات الذكاء الاصطناعي في دورة حياة الجودة:</u> 8- يمكن استخدام أدوات الذكاء الاصطناعي لتوليد متطلبات الجودة بالاستفادة من سجلات المشاريع السابقة. 9- يمكن أن يساعد الذكاء الاصطناعي في أتمتة العمليات ورقمنة الإجراءات لتحسين الإنتاجية والسلامة والجودة. 10- يمكن أن يساعد تكامل الذكاء الاصطناعي مع ممارسات إدارة الجودة في تحليل بيانات الجودة وتحديد الأنماط والاستفادة منها في تحسينات المشاريع المستقبلية. 11- يمكن أن يساعد الذكاء الاصطناعي في تحسين التواصل والتعاون بين أصحاب المصلحة بشأن قضايا الجودة. 12- يساعد الذكاء الاصطناعي على التحقق من الامتثال مع مواصفات ومعايير ومتطلبات المشاريع 13- تُستخدم لوحات المعلومات المدعومة بالذكاء الاصطناعي للحصول على رؤى تنبؤية أثناء تنفيذ المشروع. 14- تساعد أدوات الذكاء الاصطناعي في اكتشاف الأخطاء أو العيوب في وقت مبكر مقارنة بالطرق التقليدية، خاصة عند دمجها مع لوحات معلومات المشروع. 15- يمكن أن يساعد تكامل الذكاء الاصطناعي مع ممارسات إدارة الجودة في التنبؤ بالأخطاء البشرية والملاحظات وحالات عدم المطابقة ومنعها قبل حدوثها.
<u>AI -Challenges, Concerns, Opportunities and Future Vision</u> 16. To what extent do the following factors influence the adoption of Artificial Intelligence (AI) in your Construction Quality Management (CQM) processes? • Management support & commitment • Implementation Cost • Ease of integration with current tools • Training and skills • Data availability 17. Transparency, bias, reliability, accountability, ethical and legal considerations are your biggest concerns regarding the use of AI in CQM	<u>التحديات، المخاوف، الفرص والرؤية المستقبلية للذكاء الاصطناعي</u> 16- إلى أي مدى تؤثر العوامل التالية على تبني الذكاء الاصطناعي (AI) في عمليات إدارة جودة التشييد (CQM) الخاصة بك؟ • الدعم والالتزام من الإدارة • تكلفة الاستخدام • سهولة التكامل مع الأدوات الحالية • التدريب والمهارات • توفر البيانات 17- الشفافية، التحيز، الموثوقية، المساءلة، الاعتبارات الأخلاقية والقانونية هي أكبر مخاوفك بشأن استخدام الذكاء الاصطناعي في إدارة جودة في المشاريع.
18. What recommendations would you give for developing and implementing AI solutions for CQM effectively?	18- ما هي التوصيات التي تقدمها لتطوير وتنفيذ حلول الذكاء الاصطناعي لإدارة الجودة الشاملة بشكل فعال؟ الاجابة:

Ans.	
19. Please share any observations or experiences where AI improved or could have improved project outcomes: Ans.	19- يرجى مشاركة أي ملاحظات أو تجارب ممكن ان يساهم الذكاء الاصطناعي فيها لتحسين نتائج المشروع: الإجابة: