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Assessing the Impact of Innovation Adoption on Bridge Construction Efficiency: Evidence from Saudi Arabia's Mega-Infrastructure Projects under Vision 2030

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Abstract:

This research investigates the relationships between key antecedent factors and Bridge Construction Efficiency (BCE) in Saudi Arabia, with particular emphasis on the mediating role of Stakeholder Collaboration (SCOL) and Stakeholder Communication (SCOM). The study examines five independent variables—Level of Innovation Adoption (LIA), Project Planning (PP), Risk Management Effectiveness (RME), Design Quality and Constructability (DQC), and Regulatory and Funding Environment (RFE)—and their effects on BCE within the context of Saudi Arabia's Vision 2030 implementation period (2020–2025). Through a quantitative research design employing Partial Least Squares Structural Equation Modeling (PLS-SEM), this study addresses critical gaps in construction management literature by providing empirical evidence on factors influencing bridge construction performance in the Saudi Arabian context. The findings have significant implications for practitioners, policymakers, and stakeholders involved in infrastructure development under the Kingdom's national transformation initiatives.

Keywords **— Bridge Construction Efficiency, Stakeholder Collaboration, Stakeholder Communication, Innovation Adoption, Project Planning, Risk Management, Saudi Arabia, Vision 2030, PLS-SEM.**

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I. INTRODUCTION

The construction sector in Saudi Arabia is experiencing unprecedented transformation driven by Vision 2030, the Kingdom's strategic framework for economic diversification and sustainable development. Bridge construction, as a critical component of infrastructure development, plays a pivotal role in achieving the connectivity and mobility objectives outlined in the National Transport and Logistics Strategy (NTLS). However, the sector faces persistent challenges including project delays, cost overruns, quality deficiencies, and coordination failures among multiple stakeholders (Assaf & Al-Hejji, 2021; Mahamid, 2023).

Bridge construction efficiency represents a multidimensional construct encompassing time performance, cost management, quality achievement, resource utilization, safety outcomes, and process optimization (Hwang et al., 2022; Liu et al., 2023). Despite substantial investments in infrastructure development under Vision 2030, empirical evidence regarding factors influencing bridge construction efficiency in the Saudi Arabian context remains limited. This research gap hinders evidence-based decision-making and the development of targeted

interventions to improve construction performance outcomes.

This study addresses this gap by examining the effects of five key factors—Level of Innovation Adoption (LIA), Project Planning (PP), Risk Management Effectiveness (RME), Design Quality and Constructability (DQC), and Regulatory and Funding Environment (RFE)—on Bridge Construction Efficiency (BCE). Additionally, the study investigates the mediating role of Stakeholder Collaboration (SCOL) and Stakeholder Communication (SCOM) in transmitting these effects, grounded in a tri-theoretic framework integrating Innovation Diffusion Theory, Stakeholder Theory, and Dynamic Capabilities Theory.

II. STATEMENT OF THE PROBLEM

Saudi Arabia's bridge construction sector exhibits significant efficiency deficits that undermine Vision 2030 infrastructure objectives. Ministry of Transport and Logistic Services (MOTLS) data indicates that 67% of bridge projects initiated between 2020–2023 experienced schedule overruns averaging 34% beyond contracted durations (MOTLS, 2024). Cost performance data reveals average budget overruns of 28% across bridge projects, with complex structures exceeding 40% cost escalation (Alawi et al., 2022).

The adoption of construction innovations, including Building Information Modeling (BIM) and advanced construction technologies, remains below 25% among Saudi bridge contractors, compared to 60–70% adoption rates in developed markets (Aghimien et al., 2022; Sepasgozar et al., 2021). Risk management practices in Saudi bridge projects often remain reactive rather than proactive, with only 35% of contractors employing formal risk identification and mitigation protocols (Qazi et al., 2021). Design-related issues, including incomplete specifications and constructability deficiencies, contribute to approximately 40% of bridge project delays (Hwang et al., 2022).

Furthermore, stakeholder coordination challenges exacerbate efficiency losses. Multi-party involvement in bridge projects—including MOTLS, Public Investment Fund (PIF), Royal Commissions, municipalities, contractors, consultants, and suppliers—creates communication complexity that, when poorly managed, generates conflicts, delays, and quality compromises (Mok et al., 2021; Xia et al., 2022). The absence of empirical research examining these interrelated factors within the Saudi bridge construction context represents a critical knowledge gap that this study addresses.

III. LITERATURE REVIEW

A. Level of Innovation Adoption (LIA)

Innovation adoption in construction encompasses the implementation of advanced technologies, methodologies, and practices that enhance project delivery outcomes. Aghimien et al. (2022) demonstrated that technology adoption significantly improves construction efficiency through enhanced coordination, reduced rework, and improved decision-making. Sepasgozar et al. (2021) found that digital construction technologies, including BIM and IoT sensors, contribute to 15–25% efficiency improvements in infrastructure projects. Ozorhon and Karahan (2022) identified management support and organizational readiness as critical enablers of construction innovation adoption.

B. Project Planning (PP)

Effective project planning establishes the foundation for construction efficiency through comprehensive activity sequencing, resource allocation, and contingency development. Sinesilassie et al. (2020) found that inadequate planning practices contribute to 45% of project delays in developing country contexts. Assaf and Al-Hejji (2021) identified planning-related factors among the top five causes of construction delays in

Saudi Arabia. Gebrehiwet and Luo (2022) demonstrated that accurate resource estimation during planning reduces cost overruns by 20–30% in infrastructure projects.

C. Risk Management Effectiveness (RME)

Risk management effectiveness reflects an organization's capability to identify, assess, mitigate, and monitor project risks systematically. Qazi et al. (2021) developed a network-based risk assessment framework demonstrating that proactive risk management reduces project complexity impacts by 35%. Adeleke et al. (2020) found that external risk factors, including regulatory and environmental risks, significantly affect construction project outcomes. Issa et al. (2022) identified risk mitigation strategy implementation as a critical determinant of project success in GCC construction markets.

D. Design Quality and Constructability (DQC)

Design quality and constructability encompass the completeness, accuracy, and buildability of engineering designs. Hwang et al. (2022) demonstrated that constructability reviews reduce construction rework by 25–40% and improve schedule performance. Tauriainen et al. (2021) found that design coordination effectiveness directly influences construction workflow efficiency. Liu et al. (2023) identified design change management as a critical factor affecting contractor performance in infrastructure projects.

E. Regulatory and Funding Environment (RFE)

The regulatory and funding environment shapes project delivery conditions through approval processes, funding mechanisms, and compliance requirements. Olaniran et al. (2021) examined governance mechanisms in GCC megaprojects, finding that regulatory efficiency significantly affects project timelines. Alawi et al. (2022) identified funding disbursement alignment with project cash flow as a critical success factor in Saudi construction projects. Mahamid (2023) found that permit acquisition delays contribute to 15–20% of project time overruns.

F. Stakeholder Collaboration and Communication

Stakeholder collaboration and communication serve as mechanisms through which project inputs translate into performance outcomes. Mok et al. (2021) found that effective stakeholder engagement reduces conflict-related delays by 30–40% in major projects. Xia et al. (2022) demonstrated that communication quality mediates relationships between project management practices and construction outcomes. Wuni and Shen (2020) identified stakeholder collaboration as a critical enabler of construction innovation adoption and efficiency improvement.

IV. CONCEPTUAL FRAMEWORK

The conceptual framework integrates Innovation Diffusion Theory (Rogers, 2003), Stakeholder Theory (Freeman et al., 2020), and Dynamic Capabilities Theory (Teece, 2018) to explain relationships among constructs. The framework posits that five independent variables (LIA, PP, RME, DQC, RFE) influence Bridge Construction Efficiency (BCE) both directly and indirectly through two mediating variables—Stakeholder Collaboration (SCOL) and Stakeholder Communication (SCOM).

The framework specifies 27 hypotheses: 5 direct effects (IVs → BCE), 10 IV-mediator paths (IVs → SCOL/SCOM), 2 mediator-DV paths (SCOL/SCOM → BCE), and 10 mediation hypotheses examining indirect effects through SCOL and SCOM. Bridge Construction Efficiency is operationalized as a second-order reflective construct comprising six first-order dimensions: Time Performance, Cost Performance, Quality Performance, Resource Utilization, Safety Performance, and Process Efficiency.

V. OBJECTIVES OF THE STUDY

The primary aim of this study is to examine the relationships between key antecedent factors and Bridge Construction Efficiency in Saudi Arabia, with attention to mediation mechanisms. The specific objectives include:

1. To examine the direct effects of LIA, PP, RME, DQC, and RFE on Bridge Construction Efficiency in Saudi Arabia's bridge construction projects.
2. To examine the effects of LIA, PP, RME, DQC, and RFE on Stakeholder Collaboration in Saudi Arabia's bridge construction projects.
3. To examine the effects of LIA, PP, RME, DQC, and RFE on Stakeholder Communication in Saudi Arabia's bridge construction projects.
4. To examine the effects of Stakeholder Collaboration and Stakeholder Communication on Bridge Construction Efficiency.
5. To determine the mediating effect of Stakeholder Collaboration on IV-BCE relationships.
6. To determine the mediating effect of Stakeholder Communication on IV-BCE relationships.

VI. METHODOLOGY

This study employs a quantitative, cross-sectional research design utilizing survey methodology. The target population comprises construction professionals directly involved in Saudi Arabia bridge construction projects, including project managers, construction managers, site engineers, planning engineers, and design managers employed by contractors, consultants, and client organizations. The population is estimated at N = 4,850 professionals based on Saudi Contractors Authority and Saudi Council of Engineers registry data.

Sample size determination follows Cochran's (1977) formula for finite populations, yielding a minimum sample of n = 400 respondents at 95% confidence level with 5% margin of error. Stratified random sampling ensures proportional representation across organizational types (contractors, consultants, clients) and geographic regions (Riyadh, Eastern, Makkah, others).

The research instrument comprises 82 measurement items across 8 constructs, adapted from validated scales in recent Q1/Q2 journal publications and contextualized for Saudi Arabian bridge construction. All items employ a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Instrument development followed rigorous protocols including expert Content Validity Index (CVI) assessment with an 8-member panel, cognitive interviewing with 10 industry professionals, and pilot testing with n = 47 respondents achieving Cronbach's alpha values ranging from 0.821 to 0.891 across all constructs.

Data analysis employs Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS 4.0 software. PLS-SEM is selected based on the study's predictive orientation, model complexity (8 constructs, 27 hypotheses, 17 paths, parallel mediation), and robustness to non-normality assumptions. Measurement model assessment includes indicator reliability (outer loadings ≥ 0.708), internal consistency (Cronbach's α, CR, $\rho A \geq 0.70$), convergent validity (AVE ≥ 0.50), and discriminant validity (HTMT < 0.85). Structural model evaluation encompasses collinearity assessment (VIF < 5.0), path coefficient significance (10,000 bootstrap samples, 95% BCa confidence intervals), R^2, f^2, Q^2, and PLSpredict. Mediation analysis follows Zhao et al. (2010) typology with specific indirect effect testing.

VII. SCOPE AND LIMITATIONS

This study is exclusively bounded to bridge construction projects within the Kingdom of Saudi Arabia, encompassing all 13 administrative regions. The temporal boundary targets projects initiated, ongoing, or completed during 2020–2025, coinciding with Vision 2030 implementation acceleration. The institutional scope includes projects delivered under public sector clients (MOTLS, PIF, Royal Commissions, municipalities) and semi-government entities (NEOM, Red Sea Development Company).

Limitations include the cross-sectional design, which precludes causal inference, and reliance on self-reported perceptual measures. The study excludes global exemplars from empirical analysis due to institutional non-transferability and construct operationalization specificity. Generalization is limited to the defined population; applicability to other national contexts requires subsequent replication studies.

VIII. SIGNIFICANCE OF THE STUDY

This study contributes to construction management literature by providing the first comprehensive empirical examination of factors influencing bridge construction efficiency in Saudi Arabia. The tri-theoretic framework integration advances understanding of how organizational capabilities, stakeholder dynamics, and environmental factors interact to shape infrastructure project outcomes.

For practitioners, findings offer evidence-based guidance for prioritizing improvement initiatives across innovation adoption, planning practices, risk management, design quality, and stakeholder engagement. For policymakers, results inform regulatory reform and capacity-building investments aligned with Vision 2030 infrastructure objectives. The validated measurement instrument provides a standardized tool for benchmarking bridge construction efficiency across Saudi projects.

The study aligns with Saudi Arabia's sustainable development goals and the Kingdom's commitment to achieving carbon neutrality by 2060 through enhanced construction efficiency that reduces waste, optimizes resource utilization, and improves environmental performance outcomes.

IX. CONCLUSIONS

This research establishes a comprehensive framework for examining bridge construction efficiency in Saudi Arabia, addressing critical gaps in construction management literature. By integrating Innovation Diffusion Theory, Stakeholder Theory, and Dynamic Capabilities Theory, the study provides theoretical grounding for understanding the complex relationships among organizational factors, stakeholder dynamics, and project performance outcomes.

The rigorous methodological approach—including validated measurement instruments, representative sampling, and advanced PLS-SEM analysis—ensures findings will provide reliable evidence for both academic advancement and practical application. The focus on mediation mechanisms through stakeholder collaboration and communication offers insights into how efficiency improvements can be achieved through enhanced inter-organizational coordination.

Ultimately, this research supports Saudi Arabia's Vision 2030 infrastructure development objectives by generating actionable knowledge for improving bridge construction efficiency, reducing project delays and cost overruns, enhancing stakeholder satisfaction, and promoting sustainable construction practices in the Kingdom's construction industry.

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