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QUANTITATIVE EVALUATION OF RISK MANAGEMENT AND STRUCTURAL INTEGRITY IN LARGE-SCALE GLOBAL CIVIL CONSTRUCTION PROJECTS

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Abstract

This study addresses a persistent problem in enterprise, case-based civil construction delivery: risk tools are common, yet structural integrity outcomes still vary substantially across interfaces, increasing exposure to nonconformities, rework, and reliability risks. The purpose was to quantify how Risk Management Effectiveness (RME) predicts Structural Integrity Performance (SIP) and to identify which risk-cycle dimensions drive integrity outcomes. A quantitative cross-sectional, case-study–based design used a five-point Likert questionnaire in a large-scale global civil construction project case ($N = 210$ valid responses after screening). Key variables were overall RME and four dimensions (risk identification, risk assessment and prioritization, mitigation or planning, monitoring and communication) and SIP as the dependent construct (compliance discipline, inspection and testing rigor, materials control, and defect closure). The analysis plan applied data screening, composite indexing, descriptive statistics, reliability testing, Pearson correlations, and hierarchical multiple regression controlling for role, experience, and phase. Reliability was strong (RME a = 0.91; SIP a = 0.88). Descriptively, RME was high ($M = 3.87$, $SD = 0.54$), with monitoring and communication the lowest RME dimension ($M = 3.71$, $SD = 0.66$); SIP was high ($M = 3.76$, $SD = 0.57$) but showed weaker areas in defect closure ($M = 3.62$, $SD = 0.69$) and materials traceability and QC consistency ($M = 3.67$, $SD = 0.65$). RME correlated strongly with SIP ($r = 0.68$, $p < .001$), and each dimension was positively related to SIP ($r = 0.56$ to 0.63, $p < .001$). In regression, controls explained 12% of SIP variance ($R^2 = 0.12$), while adding overall RME increased explanatory power to 49% ($\Delta R^2 = 0.37$; $\beta = 0.66$, $p < .001$). The dimensional model reached $R^2 = 0.53$, with risk assessment ($\beta = 0.22$, $p = .004$), mitigation or planning ($\beta = 0.31$, $p < .001$), and monitoring or communication ($\beta = 0.19$, $p = .011$) as significant unique predictors, whereas identification was marginal ($\beta = 0.12$, $p = .071$). The findings imply that integrity improvements depend most on execution-focused risk governance that strengthens prioritization discipline, mitigation ownership, and monitoring and escalation, especially to speed defect closure and improve traceability across subcontract tiers.

Keywords

Risk Management Effectiveness (RME); Structural Integrity Performance (SIP); Civil construction megaprojects; Mitigation planning; Monitoring and communication;

INTRODUCTION

Risk management and structural integrity are two foundational constructs in civil engineering that shape how large-scale construction projects are conceived, delivered, and operated across national boundaries. In construction scholarship, risk commonly refers to uncertain conditions that have measurable effects on project objectives such as time, cost, scope, quality, and safety, while risk management refers to a structured set of processes used to identify, analyze, prioritize, respond to, and monitor those uncertainties through the project life cycle (Schieg, 2006). Structural integrity refers to a structure's capacity to sustain intended actions and environmental demands while maintaining reliability, serviceability, and durability under real operational conditions, including gradual deterioration mechanisms (Brownjohn, 2007).

Figure 1: Model of Risk Governance and Structural Integrity in Global Civil Projects

In global civil construction, these definitions acquire international significance because infrastructure projects connect trade corridors, energy systems, logistics networks, and urban services that cross jurisdictions, contracting regimes, and supply chains. Research on global megaprojects characterizes these initiatives as large-scale collaborative systems in which complexity, strategic decision behavior under uncertainty, and multi-party governance arrangements form a persistent risk environment (Kardes et al., 2013). Within this environment, risk management is not treated only as a contractual exercise, because project outcomes depend on coordinated technical decisions, quality control routines, and organizational behaviors that propagate through networks of clients, designers, contractors, and regulators (Laory et al., 2014). Parallel structural engineering research frames integrity as a life-cycle concern: long-term monitoring, deterioration modeling, and maintenance planning function as evidence mechanisms that support reliability evaluation and operational decisions (Catbas et al., 2008). From this combined perspective, large-scale civil projects are often studied as socio-technical systems where managerial risk controls and engineering integrity controls interact through procurement choices, construction execution, and asset management practices (Gjørv, 2013). Consequently, quantitative evaluation of risk management and structural integrity aligns with international priorities around reliability of transport, resilience of built assets, and accountability in public and private investment decisions, particularly when project performance is judged through measurable indicators such as defect rates, rework costs, schedule deviation, safety events, and structural condition metrics (Wang & Yuan, 2011).

A central theme in construction risk research is that uncertainty is rarely uniform across stakeholders; it is distributed through roles, incentives, and information asymmetry. Empirical work on construction risk attitudes shows that decision makers' judgments are shaped by experience, perceived consequences, and completeness of project information, and these human factors influence risk-based decision-making routines in project delivery organizations (Jinnat & Kamrul, 2021; Serpell et al., 2015). Complementary methodological research demonstrates that construction risk evaluation frequently mixes quantitative and qualitative inputs, which motivates the use of fuzzy and multi-criteria decision techniques to translate expert judgment into structured prioritization (Hasan & Shaikat, 2021; Serpell et al., 2017). Within joint-venture and cross-border delivery contexts, studies using fuzzy analytic hierarchy approaches operationalize risk as a multi-dimensional construct linked to contractual, financial, technical, and managerial categories, allowing comparison of relative risk weightings across project conditions (Rabiul & Samia, 2021; Zhang & Zou, 2007). In national and regional contexts, empirical investigations identify sets of "key risks" that recur through categories such as financing, design changes, resource constraints, regulatory approvals, and coordination failures, while emphasizing that the salience of these risks depends on institutional settings and market structures (Mohiul & Rahman, 2021; Zou et al., 2010). These insights support the treatment of risk management as both a technical and organizational capability, because risk events often occur at interfaces: design–construction, contractor–subcontractor, client–contractor, and contractor–supplier. Research on public–private partnership infrastructure explicitly frames risk as a life-cycle phenomenon that spans development, construction, and operation, linking early allocation decisions to later performance variability (Rahman & Abdul, 2021; Zou et al., 2007). This framing reinforces that risk measurement needs constructs that capture governance quality, communication adequacy, and process reliability, alongside engineering controls. The international scope of large civil projects further intensifies this requirement, since delivery frequently occurs under layered standards and compliance environments, making stakeholder alignment and information quality measurable determinants of risk exposure (Ko & Ni, 2005; Haider & Shahrin, 2021). Accordingly, a quantitative study that models relationships among risk management practices, structural integrity indicators, and performance outcomes is grounded in a literature that treats risk as a measurable construct influenced by behavioral and institutional factors, not only by technical hazard magnitude (Li et al., 2016; Zulqarnain & Subrato, 2021).

Beyond identification and prioritization, construction scholarship places emphasis on whether risk management practices are actually used and whether they function as effective controls. Survey-based evaluations of risk management in construction organizations show that formal processes can be assessed through measurable dimensions such as identification routines, documentation quality, response planning, monitoring frequency, and organizational learning mechanisms (Li & Zou, 2011). Related empirical work evaluates "effective usage" by examining how consistently teams apply risk procedures across phases and how those practices relate to perceived project performance and control outcomes (Habibullah & Farabe, 2022; Zou et al., 2008). Capability-oriented research also operationalizes risk management maturity by measuring institutionalization of processes and the extent of integration into decision workflows, framing risk management as an organizational system that can be compared across firms and contexts (Arman & Kamrul, 2022; Zavadskas et al., 2010). In infrastructure delivery models such as PPPs, life-cycle risk management frameworks highlight that risk controls must persist beyond construction and connect to operational risk governance, which positions risk management as a continuity mechanism between delivery and asset performance (Rashid & Sai Praveen, 2022; Yu et al., 2019). At megaproject scale, international business research describes how complexity increases coordination costs and introduces behavioral patterns in decision making under uncertainty; these patterns interact with governance structures and can be analyzed as part of a risk management architecture rather than treated as isolated "project issues" (Love et al., 2016; Kamrul & Omar, 2022). This literature base supports a quantitative approach that treats risk management practices as latent constructs measured by Likert-type items and tested through correlational and regression models, because published studies already rely on structured survey data to connect practices with outcomes (Jin et al., 2019). It also supports a case-study–based cross-sectional design in large civil projects because many risk management variables are context-dependent and require boundary specification around a setting, procurement method, and stakeholder configuration (Ni et al., 2009). Internationally, such measurement work gains practical relevance because procurement and delivery are increasingly multi-actor and multi-country, making transparency of risk routines and auditability of control processes central to accountability (Nieto-Morote & Ruz-Vila, 2011). In this way, the research tradition provides defensible constructs and empirical pathways for quantitatively examining how risk management quality relates to observable integrity and performance conditions in complex civil construction systems (Hegazy et al., 2011).

Structural integrity research provides a parallel measurement tradition that emphasizes reliability-based evaluation, deterioration awareness, and evidence from monitoring. Reviews and foundational contributions in structural health monitoring (SHM) describe integrity management as a data-informed process where sensing, data acquisition, feature extraction, and interpretation connect to condition assessment and maintenance decision logic (Brownjohn, 2007). Large-scale bridge SHM literature emphasizes that long-term monitoring supports early warning and operational safety by linking measured responses to changes in structural condition, while also highlighting instrumentation and information-management challenges that arise when monitoring becomes continuous and system-wide (Navarro et al., 2018). Reliability-oriented SHM studies demonstrate that environmental actions, including temperature effects, materially influence structural response patterns and must be integrated into probabilistic reliability estimation rather than treated as measurement noise (Love et al., 2010). This integration creates a measurable pathway between observed data and integrity indicators, allowing integrity assessment to be framed in statistical and probabilistic terms consistent with quantitative analysis norms. In high-profile tall or complex civil assets, research on technology innovation for SHM systems illustrates how monitoring architectures are developed to support long-term evaluation of structural behavior and performance under operational loads (Zavadskas et al., 2010). Methodological advances also address variability in modal properties and other response features, showing that prediction of natural frequency variation and its drivers is central for interpretation of structural condition signals in real settings (Laory et al., 2014; Rony & Samia, 2022). Broader reviews synthesize these developments by framing SHM for complex infrastructures as a multi-layer system involving sensing technologies, communication, data processing, and decision-support integration (Li & Zou, 2011). Alongside monitoring, durability engineering research treats integrity as service-life performance driven by material behavior, environmental exposure, and quality assurance regimes, positioning durability controls as measurable engineering determinants of long-term safety and serviceability (Abdul & Rahman, 2023; Zou et al., 2010). Environmental and maintenance-oriented studies extend integrity to life-cycle considerations by analyzing preventive design strategies against corrosion and linking preventive choices to measurable differences in deterioration-related impacts over time (Love et al., 2010). Taken together, this literature supplies measurable concepts—monitoring adequacy, reliability estimation quality, durability assurance practices, and preventive strategy selection—that align with the quantitative evaluation of integrity in large civil assets (Aditya & Rony, 2023; Catbas et al., 2008).

Quality outcomes during construction form a major bridge between managerial risk controls and engineering integrity, because nonconformance and rework translate process failures into physical defects and performance variability. Empirical research in civil infrastructure projects quantifies rework as a measurable cost burden and identifies predictors associated with information management, client involvement intensity, procedural clarity, and change dynamics, thereby treating rework as a systemic risk manifestation rather than a localized mistake (Arfan & Rony, 2023; Zhang & Zou, 2007). Research on schedule impacts provides complementary quantitative modeling by embedding rework into construction schedule analysis and linking the timing and quantity of rework to delays and recovery decisions through formal analytical approaches (Efat Ara & Shaikh, 2023; Hegazy et al., 2011). Conceptual clarification research further formalizes rework causation as a multi-factor phenomenon, characterizing how managerial practices and organizational conditions generate rework pathways that can be observed and measured across projects (Schieg, 2006). Quality-defect research extends these insights by examining how stakeholder actions contribute to defect occurrence through mechanisms such as misoperations, incomplete inspection and testing, and weak quality control routines, positioning defects as measurable outcomes shaped by stakeholder interaction patterns (Rahman, 2022; Yu et al., 2019). This strand of evidence supports the treatment of defect frequency and rework cost as empirical indicators connected to risk management quality and structural integrity conditions. In large-scale civil works, defects and rework matter structurally because they can reduce effective capacity margins, accelerate deterioration mechanisms, and create hidden vulnerabilities that later become operational integrity risks, especially when assets are subjected to environmental demands and high service loads (Gjørv, 2013; Habibullah & Mohiul, 2023). The monitoring literature complements this argument by showing that integrity assessment depends on understanding true structural behavior under operational conditions; construction-stage defects can distort baseline behavior and complicate interpretation of monitoring data, which positions construction quality as part of integrity management logic rather than an isolated production metric (Hasan & Waladur, 2023; Navarro et al., 2018). Accordingly, quantitative evaluation that includes constructs for risk management practices, defect control practices, and integrity indicators aligns with published findings that these domains share measurable intersections in real project settings (Love et al., 2010; Arman & Nahid, 2023).

Safety and operational risk form another measurable interface between risk management and integrity because construction safety performance depends on organizational practices and influences both project continuity and structural outcomes. Scientometric synthesis of construction safety research maps the domain's development and identifies recurring emphasis on human factors, organizational controls, and risk-related management approaches, reinforcing that safety is evaluated through structured indicators and systematic analysis methods rather than anecdotal reporting (Jin et al., 2019; Md Mesbaul, 2023). Within risk management theory, these safety controls sit alongside other risk controls such as quality assurance, change management, and monitoring, and they can be assessed using survey-based measures that capture procedural consistency, communication effectiveness, and compliance routines (Milon & Mominul, 2023; Schieg, 2006). The contractor risk-attitude literature adds a behavioral lens, showing that perceptions of consequence and information completeness shape decisions under uncertainty, which influences how safety and quality risks are prioritized and managed at operational levels (Mohaiminul & Muzahidul, 2023; Wang & Yuan, 2011). In large-scale projects, the megaproject risk management literature explains that complexity can amplify coordination hazards; governance and decision behavior under uncertainty are treated as systematic risk generators that can be examined using structured frameworks (Kardes et al., 2013; Musfiqur & Kamrul, 2023). Structural integrity research contributes by highlighting that safety is not only a construction-stage concern; reliability estimation and monitoring-based evaluation are part of ensuring operational safety, and they require disciplined data interpretation to avoid misclassification of benign variability as damage or to avoid missing meaningful anomalies (Hegazy et al., 2011; Rezaul & Kamrul, 2023). Durability and corrosion-prevention research further grounds safety in measurable long-term performance by associating preventive design strategies with differences in deterioration pathways and maintenance burdens, which are integrity-relevant variables with safety consequences (Amin & Sai Praveen, 2023; Zhang & Zou, 2007). In this combined view, construction safety indicators, defect indicators, and integrity indicators form a set of measurable outcomes and conditions that relate to the effectiveness of risk management routines. This framing is consistent with empirical work that evaluates risk management effectiveness through survey constructs and relates these constructs to project control outcomes, showing that organizational controls can be quantitatively assessed and compared across cases (Rabiul & Mushfequr, 2023; Serpell et al., 2017). Therefore, an introduction grounded in published evidence can position safety as part of the measurable system of risk governance that intersects with structural integrity through quality control, monitoring, and life-cycle performance management (Kardes et al., 2013; Shahrin & Samia, 2023).

A quantitative evaluation agenda for large-scale global civil construction projects requires constructs that can be operationalized in a cross-sectional, case-study–based design while remaining faithful to the complexity documented in prior research (Roy, 2023). Studies evaluating risk management practices already demonstrate the feasibility of using structured questionnaires to measure process quality and usage intensity across organizations and projects, enabling descriptive statistics and inferential modeling of relationships among constructs (Rakibul & Majumder, 2023; Zavadskas et al., 2010). Risk analysis research provides complementary measurement approaches for prioritizing and comparing risk factors, including multi-criteria and fuzzy methodologies that translate expert judgment into analyzable structures, which supports the development of survey items that capture perceived severity, likelihood, and control adequacy (Nieto-Morote & Ruz-Vila, 2011). Empirical work on contractor risk attitudes offers validated themes—information completeness, experience, consequence perception—that can be adapted into measurable indicators aligned with decision quality under uncertainty (Wang & Yuan, 2011). Life-cycle risk frameworks in PPP infrastructure underscore that risk controls must connect to operational performance, suggesting measurement domains that include monitoring readiness, maintenance planning, and quality assurance continuity (Zavadskas et al., 2010). Structural integrity and SHM research provides well-defined measurable concepts such as monitoring system capability, baseline modeling quality, and reliability estimation practices, which can be captured through case-based indicators and perception-based survey items in organizations responsible for delivery and oversight (Wang & Yuan, 2011). Construction quality research adds measurable outcome variables—defect occurrence and rework costs—that can function as observable proxies for weaknesses in risk controls and execution discipline (Love et al., 2010). Schedule-related modeling of rework further grounds these outcomes in quantitative logic that supports correlation and regression analysis when examining how process quality relates to performance disruption (Li et al., 2016). Megaproject research supplies a contextual layer that motivates cross-sectional evaluation by highlighting the persistent role of complexity and risk governance in global project outcomes (Hegazy et al., 2011). Together, these studies establish an evidence-based basis for constructing survey constructs, applying reliability assessment, and testing correlations and regression relationships between risk management practices and structural integrity–linked indicators within large-scale global civil construction case settings (Nieto-Morote & Ruz-Vila, 2011).

The present study aims to quantitatively evaluate how risk management practices relate to structural integrity performance within the context of large-scale global civil construction projects using a cross-sectional, case-study–based design. Specifically, the first objective is to measure the prevailing level of risk management effectiveness as implemented by key project stakeholders, capturing the practical strength of core processes such as risk identification, risk assessment, mitigation planning, monitoring, and risk communication. This includes assessing how consistently these processes are applied across major project phases and how clearly responsibilities, documentation routines, escalation procedures, and control checkpoints are established within the project governance structure. The second objective is to assess structural integrity performance as an outcome domain using measurable constructs that reflect integrity-relevant practices and conditions during delivery, including compliance with design and code requirements, material quality control discipline, inspection and testing rigor, defect detection and closure effectiveness, and the reliability of quality assurance and quality control routines that directly influence structural soundness. A third objective is to determine the strength and direction of the statistical association between risk management effectiveness and structural integrity performance, providing empirical evidence on whether stronger risk management practices correspond to higher integrity performance levels within the selected case setting. In alignment with this aim, the study further seeks to quantify how distinct dimensions of risk management contribute to integrity performance by modeling the predictive power of risk identification and assessment practices, mitigation and response actions, and monitoring and communication systems as separate explanatory components. Through this objective structure, the study is designed to support hypothesis testing using descriptive statistics to profile current practice levels, correlation analysis to examine interrelationships among constructs, and regression modeling to evaluate predictive relationships while accounting for relevant respondent and project characteristics. Overall, these objectives collectively operationalize the research purpose into measurable targets, enabling a rigorous quantitative examination of risk governance and integrity assurance practices within a large-scale civil construction case environment.

LITERATURE REVIEW

The literature on risk management and structural integrity in large-scale global civil construction projects spans multiple disciplines, including construction management, structural engineering, project governance, reliability engineering, and infrastructure asset management, reflecting the reality that mega civil projects operate as tightly coupled socio-technical systems. Within this body of work, risk management is typically treated as a structured managerial capability that organizes uncertainty into identifiable categories, assesses likelihood and impact, and establishes control actions that can be monitored through formal routines across the project life cycle. Structural integrity is addressed as an engineering performance domain concerned with the ability of structural systems to meet safety, serviceability, durability, and reliability requirements under actual loads and environmental conditions, supported by quality assurance processes, inspection regimes, testing protocols, and evidence-based verification practices. Because global projects commonly involve complex contracting arrangements, multinational supply chains, and multi-jurisdictional compliance requirements, scholars emphasize that both risk and integrity are shaped by organizational coordination quality, decision-making discipline, stakeholder alignment, and the consistency of governance controls across interfaces. As a result, research increasingly examines the interaction between managerial practices and engineering outcomes, where deficiencies in communication, documentation, change control, procurement decisions, and oversight structures may be expressed through measurable construction outcomes such as defects, nonconformance, rework, schedule disruption, and compromised quality control effectiveness. In addition, the literature highlights that structural integrity is not limited to design adequacy but is continually influenced by construction execution quality and the robustness of verification mechanisms that confirm conformance to codes, specifications, and performance requirements. This creates an analytical foundation for treating integrity outcomes as measurable constructs that can be investigated quantitatively in relation to risk management effectiveness, especially when surveys capture stakeholder perceptions of process quality, compliance discipline, and operational control strength in a defined project setting. Furthermore, the literature provides methodological bases for quantitative evaluation through established practices in survey research, reliability assessment, correlation testing, and regression modeling, allowing researchers to move from descriptive characterization of risk and integrity practices toward statistical examination of how strongly risk governance practices predict integrity-related performance. Therefore, the literature review in this study is structured to synthesize core concepts and empirical findings on risk management processes, structural integrity assurance mechanisms, risk factors that threaten integrity, theoretical explanations of failure pathways and control barriers, and conceptual models that link risk governance dimensions to integrity performance indicators within the context of large-scale global civil construction delivery.

Risk Management Capability and Maturity in Large-Scale Civil Construction Projects

Large-scale global civil construction projects operate as socio-technical systems in which uncertainty arises from technical interdependencies, multi-tier supply chains, changing site conditions, and the coordination of many specialized firms across borders and jurisdictions. Within this setting, risk management is commonly defined as an organized capability for identifying events that may affect objectives, estimating their probability and consequences, prioritizing exposures, and selecting responses that align with contractual responsibilities and stakeholder tolerance. For international projects, this capability integrates technical risks such as design change, geotechnical surprise, equipment failure, and material variability; managerial risks such as scope creep, interface breakdown, and schedule compression; and contextual risks such as permitting delays, political or community opposition, and currency volatility. Research emphasizes that codifying risk knowledge and embedding it in workflow improves the consistency of identification and response decisions. Ontology-based approaches structure risk concepts, relationships, and lessons learned so that teams can reuse prior experience during planning and execution rather than relying only on individual memory (Tserng et al., 2009). Complementary work notes that widespread qualitative tools, including probability–impact matrices, still require transparent aggregation rules and comparable scales if risk information is to guide trade-offs across work packages. A synthesis of construction risk assessment research argues for translating heterogeneous risk effects into a common metric, such as risk cost, to support cross-objective comparison and managerial prioritization while keeping traceability to underlying assumptions (Taroun, 2014). Together, these perspectives position risk management as a knowledge-enabled and measurement-oriented process that links uncertainty, decision rights, and operational control throughout the project life cycle. In civil megaprojects, the same logic extends to structural integrity, where identification encompasses limit states, deterioration mechanisms, and construction-stage stability. When these risks are mapped to controls, inspection routines, and contingency budgets, decision makers can compare mitigation cost with expected loss and justify interventions in governance forums.

Because megaprojects involve many concurrent work packages and handoffs, scholars often evaluate risk management through maturity and capability lenses that emphasize process consistency and organizational learning. Maturity-based thinking treats risk performance as observable in the repeatability of procedures, clarity of roles, documentation discipline, and the extent to which risk reviews are integrated into key decision gates. This view asks whether risk data are refreshed, whether response owners are held accountable, and whether mitigation actions are resourced and tracked. A quantitative strand proposes diagnostic models that score organizations on key dimensions of risk practice and benchmark them against higher-performing reference profiles.

Figure 2: Large-Scale Civil Construction Projects

One example develops a maturity measurement approach for large-scale construction projects that links major risk factors to observable management procedures, enabling leaders to locate weak areas and target improvements (Jia et al., 2013). Maturity instruments are valuable because they turn an abstract capability into structured items that can be rated, compared across projects, and analyzed statistically. Recent maturity modeling also stresses that an instrument needs theoretical grounding and expert validation so that scores reflect meaningful differences in how organizations govern risk. A generic risk maturity model inspired by excellence frameworks illustrates this logic by deriving assessment statements from the literature and refining them through expert review to evaluate risk management in construction projects in a standardized way (Hoseini et al., 2021). These contributions suggest that large-scale project risk management can be operationalized as latent constructs—such as risk culture, identification capability, analysis capability, and standardized process use—that are measurable through surveys. For quantitative case-study designs, this supports Likert-scale indicators that model how risk management maturity relates to outcomes, including structural integrity assurance, schedule reliability, and cost control across global civil programs. It also enables hypothesis testing on whether higher maturity predicts fewer nonconformities, reduced rework, and more stable inspection results overall.

Empirical studies of construction practice show that formal risk tools can coexist with uneven adoption, particularly when responsibilities are fragmented among clients, consultants, and contractors and when project controls compete with production pressures on site. Survey-based evidence from a national industry setting indicates that awareness of risk assessment and management practices varies by role, and that application often concentrates on a narrow set of techniques rather than a complete cycle of identification, analysis, response, and monitoring (Yirenkyi-Fianko & Chileshe, 2015). This pattern matters for large-scale global civil works because incomplete implementation can amplify interface risks: procurement decisions may be made without quantified contingencies, design coordination may proceed without clear ownership of residual risk, and construction staging may change without revisiting stability and safety assumptions. At the same time, the literature emphasizes that risk information becomes actionable only when it is connected to governance routines, such as risk review meetings, escalation thresholds, and performance reporting. For structural integrity, this connection is visible when risk registers are aligned with inspection and test plans, nonconformance workflows, and quality assurance records, allowing teams to detect early signals of deterioration, workmanship variability, or deviation from design intent. These operational linkages also create a clear basis for quantitative evaluation: survey items can capture how consistently teams document risks, update assessments, and close mitigation actions; project records can represent integrity outcomes through defect rates, rework incidents, and compliance scores; and statistical models can test relationships between these domains. Consequently, in a cross-sectional case-study design, risk management practice can be treated as a set of measurable constructs that explain variance in structural integrity indicators and overall project performance across comparable work packages and stakeholder groups. Such operationalization aligns with correlation and regression analysis by enabling control variables like project phase, contract type, and respondent experience to be included.

Structural Integrity Measurement and Assessment in Large-Scale Civil Projects

Structural integrity in large-scale civil construction refers to a structure's capacity to sustain intended loads and environmental actions while maintaining acceptable safety, serviceability, and durability over its design life. In global projects, integrity is treated as an operational condition because it must be translated into measurable thresholds, performance indicators, and allowable risk for multiple stakeholders. Such translation is crucial in multinational delivery contexts where codes, materials, and workmanship standards vary across regions (Saikat & Aditya, 2023). Integrity is strongly shaped by time-dependent deterioration processes that erode resistance and stiffness, especially when structures are exposed to aggressive environments for long periods. Chloride-induced corrosion of reinforcement is one of the most consequential mechanisms for reinforced concrete assets, because it links environmental exposure, transport processes, and electrochemical reactions to cracking, spalling, section loss, and reduced bond (Zaki & Masud, 2023). A synthesis of research on steel-reinforced concrete in chloride environments emphasizes that durability depends on coupled choices about mix design, cover depth, supplementary cementitious materials, inhibitors, curing, and quality control, as well as the monitoring of corrosion initiation and propagation during service (Rifat & Rebeka, 2023; Shi et al., 2012). From a modeling perspective, deterioration is not deterministic: humidity cycles, temperature gradients, rainfall and splash zones, and spatial heterogeneity create uncertainty in both chloride transport and the time to corrosion initiation. Probabilistic modeling frameworks for chloride ingress represent these uncertainties explicitly by combining coupled heat–moisture–ion transport with stochastic descriptions of boundary conditions and material properties, enabling integrity assessment to be expressed in terms of probabilities of reaching critical chloride thresholds at the steel depth (Bastidas-Arteaga et al., 2011; Kumar, 2023). For large projects delivered across diverse climates and supply chains, these findings support a literature view that structural integrity must be evaluated through durability-informed limit states and uncertainty-aware indicators, so that the same nominal design can be interpreted consistently across locations, materials batches, and operational exposure regimes (Zaki & Hossain, 2023; Zulqarnain & Subrato, 2023).

Structural integrity at the asset scale also depends on system behavior, because large civil facilities rarely fail through a single isolated component; instead, performance emerges from redundancy, load redistribution, and correlated deterioration across multiple elements (Rashid, 2024; Md & Sai Praveen, 2024). A system viewpoint becomes salient in complex global projects where long spans, modular construction, and hybrid materials create multiple load paths and interaction effects between subsystems. Structural system reliability scholarship formalizes this idea by defining integrity in terms of system-level failure events—such as loss of global stability, loss of load-carrying capacity under key scenarios, or unacceptable functionality reduction—rather than only member-level limit states. Within this literature, system reliability methods are positioned as practical tools for evaluating redundancy, identifying critical component sets, and supporting reliability-based optimization of topology and design decisions that influence robustness (Mohaiminul & Majumder, 2024; Foysal & Abdulla, 2024; Song et al., 2021). Time dependence further complicates integrity assessment because deterioration evolves gradually, inspections provide intermittent evidence, and the meaning of a measurement depends on prior condition and load history (Ibne & Aditya, 2024; Milon & Mominul, 2024). Dynamic Bayesian network formulations address this challenge by modeling deterioration as a stochastic process over discrete time steps while encoding probabilistic dependencies among components and system response. By combining a deterioration model with Bayesian updating (Mosheur & Arman, 2024; Rahman & Aditya, 2024), the approach allows inspection or monitoring outcomes to revise the posterior distribution of component states and, consequently, the estimated probability of system failure at each time point. In a representative contribution, a dynamic Bayesian network–based method was developed to estimate and update the reliability of deteriorating structural systems using inspection and monitoring information, explicitly linking observations to revised system reliability through probabilistic inference (Luque & Straub, 2016; Saba & Hasan, 2024; Kumar, 2024). Taken together, these studies frame structural integrity as an emergent, updateable property of a system whose safety margin can be tracked quantitatively as new evidence accumulates during construction and service. This perspective aligns metrics with governance, accountability, and audits (Sai Praveen, 2024; Saikat, 2024).

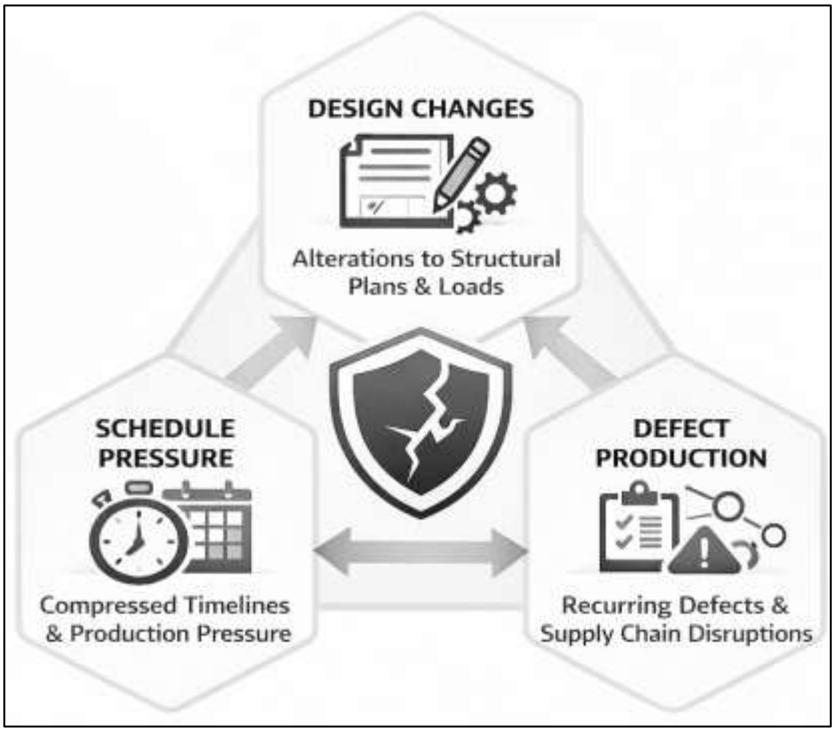
Figure 3: Structural Integrity Measurement Framework for Large-Scale Civil Projects

While deterioration science and system reliability provide analytical foundations, structural integrity in practice is governed by the decisions owners make about inspection timing, monitoring intensity, and maintenance interventions under cost, access, and safety constraints. Large-scale global projects typically operate for decades, involve multiple contracting phases, and experience institutional handovers that fragment condition data, making decision structures essential for sustained integrity assurance. Inspection and maintenance policies influence integrity in two ways: they change the information available about hidden damage states, and they change the physical state itself through repairs, strengthening, or replacement. Consequently, integrity management is increasingly framed as a sequential decision problem in which actions taken today affect both future deterioration trajectories and the quality of future assessments (Arfan, 2025; Shaikat & Aditya, 2024). Risk-based inspection planning extends this view by comparing the expected reliability gain from an action to its expected lifecycle cost, while acknowledging that component decisions can interact nonlinearly at the system level. For large structural systems with interacting components, identifying good strategies is computationally challenging because the number of possible action sequences grows rapidly, and because inspection outcomes are uncertain and partially observable (Efat Ara, 2025; Jinnat, 2025). An example is an adaptive inspection and maintenance planning approach that explicitly optimizes system-level plans for deteriorating structures, balancing expected reliability improvements against expected costs across the lifetime while incorporating uncertainty in deterioration and observation processes (Bismut & Straub, 2021; Rashid, 2025a, 2025b). From a structural integrity standpoint, this strand of literature highlights that integrity is not only a material or structural property; it is also an outcome of governance choices about when to look, what to measure, and how to intervene. Within case-based quantitative research, these decision-oriented perspectives provide a basis for defining constructs that connect integrity condition ratings, observed defect types, and management responses in a manner compatible with survey measurement and multivariate modeling. They link management choices to outcomes.

Risk Drivers in Large-Scale Civil Construction

Large-scale civil construction projects face structural-integrity risk when technical decisions, managerial controls, and site execution drift out of alignment, because integrity depends on preserving design intent while controlling uncertainty during delivery. A major pathway is design change: revisions introduced during construction can alter load paths, member sizing, reinforcement detailing, joint tolerances, and temporary works requirements, while also creating new interface conditions between design packages, subcontract scopes, and procurement orders. Design-change drivers span internal factors such as client instructions, design consultant updates, contractor proposals, and construction-management coordination, and external factors such as regulatory shifts, environmental conditions, and third-party constraints (Mesbaul, 2025; Milon, 2025). When changes arrive late, the project must translate revised intent into shop drawings, method statements, inspection and test plans, and as-built records under time and cost constraints, increasing the probability that critical checks are missed or that partially completed work is modified without full traceability (Mosheur, 2025; Rabiul, 2025). Empirical evidence from questionnaire-based analysis shows that owner-related drivers can dominate the occurrence of design changes, with subsequent influence from designers and construction managers, implying that governance and information quality are integrity-relevant risk sources rather than administrative concerns (Shahrin, 2025; Rakibul, 2025; Yana et al., 2015). In megaproject settings, design changes also amplify rework cycles and disrupt sequence logic, which can increase the exposure of newly cast or partially erected elements to unintended loads. Therefore, structural integrity risk is heightened when design changes are managed as isolated events rather than as system-level disturbances requiring coordinated recalculation, constructability review, and field verification across all affected interfaces (Kumar, 2025; Praveen & Md, 2025). Effective change control requires impact assessment on safety and durability limit states, explicit responsibility assignment for revised assumptions, and update of procurement and quality documentation so that materials and workmanship match the new requirements. Without these steps, hidden nonconformities may persist into commissioning, and the integrity of the completed asset may depend on undocumented field fixes. Time compression is a driver of integrity degradation, because schedule pressure can motivate behaviors that weaken the quality controls that protect structural performance. Under pressure to accelerate, teams may increase out-of-sequence work, shorten verification cycles, reduce hold points, or prioritize visible progress over less visible testing and documentation activities. These adaptations raise the likelihood of latent defects such as insufficient compaction, misplaced reinforcement, improper bolt tensioning, or premature formwork removal, each of which can reduce capacity or durability even when the project appears on schedule. Survey evidence from active sites indicates that practitioners associate schedule pressure with more out-of-sequence work and more work defects, illustrating how time-driven decisions can translate directly into quality losses that matter for integrity (Nepal et al., 2006). Schedule pressure also alters supervisory attention: managers may focus on critical-path completion metrics, leaving fewer resources for inspection planning, independent checking, and closure of nonconformities. At the same time, the underlying mechanism is not only calendar time but production pressure, meaning the push to maintain output in the face of delays, rework, or resource constraints. Systems-thinking research modeling production pressure shows feedback pathways through which pressure influences safety participation, training, supervision, and compliance, thereby increasing incident potential and indirectly increasing error probability in structural work operations (Han et al., 2014). In civil construction, integrity-sensitive activities such as lifting, placement, post-tensioning, and grouting require stable work conditions and disciplined checks, so declines in safety and compliance can co-occur with shortcuts that compromise structural outcomes. Integrity risk therefore rises when schedule recovery strategies rely primarily on speed rather than on process redesign, resource leveling, and quality reinforcement. Because large projects have multiple parallel fronts, localized acceleration can also create coordination gaps between trades, producing tolerance stack-ups and hidden interface defects that are expensive to detect once the structure is enclosed.

Figure 4: Risk Drivers Undermining Structural Integrity in Large-Scale Civil Construction Projects



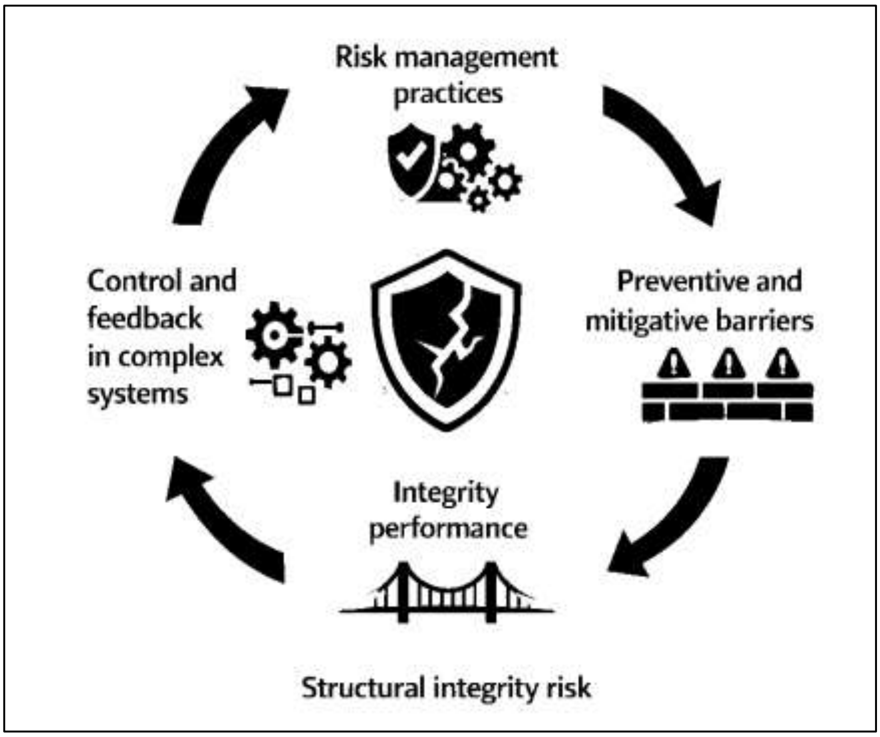
Structural integrity is further threatened by how defects are produced, detected, and resolved across the project organization, because defect dynamics reflect both technical errors and governance choices about problem handling. Defects can originate from design ambiguity, workmanship variation, material nonconformance, or procedural drift, and their structural significance depends on whether they are surfaced early, diagnosed correctly, and closed with verified corrective action. Research on defect production emphasizes that failures and defects are shaped by social practices such as how responsibilities are allocated, how problem reports move through contractual boundaries, and whether corrective action becomes a learning routine or a contested claim, which affects the likelihood that similar defects recur across work packages (Koch & Schultz, 2019). In large civil works, these recurrence mechanisms matter for structural integrity because repeated small deviations—cover thickness, weld quality, grout filling, or drainage detailing—can accumulate into measurable durability loss and increased maintenance demand. Defect governance also interacts with global supply conditions. When materials arrive late, incomplete, or with uncertain certification, teams may substitute products, accept marginal batches, or store materials under unsuitable conditions to protect progress, creating hidden risks to strength and long-term performance. Supply chain disruption therefore becomes an integrity issue, not merely a logistics issue, because it can alter the as-built material properties and the consistency of installation procedures. Quantitative and simulation-based work on construction supply chains shows that disruption magnitude and probability shape delay outcomes and that risk mitigation strategies such as safety stock at distribution centers can reduce the likelihood of schedule impacts, thereby reducing the downstream pressure that triggers quality compromises (Panova & Hilletofth, 2018). In megaproject governance, integrating defect data with procurement risk monitoring helps align inspection priorities with the most vulnerable interfaces, supporting systematic prevention rather than reactive rework. This integration supports traceability and defensible integrity assurance decisions.

Theoretical Framework

Large-scale global civil construction projects can be framed theoretically as high-risk socio-technical systems in which structural integrity outcomes emerge from interacting technical conditions (loads, materials, workmanship, temporary works) and organizational conditions (planning, supervision, coordination, and control). A barrier-based view of failure provides a practical theoretical lens for linking "risk management practices" to "integrity performance," because it conceptualizes adverse outcomes as the result of multiple defenses failing in sequence. Construction safety research applying a socio-technical causation view shows that accidents and severe events typically involve layers of contributory influences extending from managerial and design decisions to local site conditions and frontline actions, indicating that failures are rarely attributable to a single point cause (Haslam et al., 2005). In barrier theory, these influences correspond to control layers that should prevent, control, or mitigate undesired events. Barrier scholarship clarifies that barriers can be physical (e.g., shoring systems, formwork design limits, rebar spacing, material testing) or non-physical (e.g., inspection hold points, competence assurance, procedures, permits, audits), and that barrier performance depends on attributes such as functionality, reliability, independence, and integrity of the barrier itself (Sklet, 2006). For structural integrity, the "hazard" is not only collapse; it includes loss of capacity margins, unacceptable deformation, noncompliance with detailing requirements, and durability degradation. The theoretical implication for measurement is that risk management effectiveness can be interpreted as the strength and consistency of barrier establishment and barrier maintenance across the project life cycle. The framework supports mapping survey constructs (risk identification, assessment, response planning, monitoring, communication) onto barrier functions (preventive, detective, corrective) and then linking those barrier functions to integrity indicators such as inspection rigor, defect closure discipline, and compliance stability. This theoretical stance is useful for global projects because barriers operate across contractual boundaries and supply chains: a design-review barrier may sit with the consultant, a material certification barrier with suppliers, and an inspection barrier with third-party testing agencies, requiring system-wide coordination for barrier continuity.

The bow-tie model provides a structured representation of barrier logic by placing the "top event" (e.g., critical nonconformance, stability loss during erection, inadequate strength gain, corrosion vulnerability introduced by detailing) at the center, with threats on the left and consequences on the right, separated by preventive and mitigative barriers. The bow-tie literature emphasizes that the method integrates cause-side and consequence-side reasoning and can be implemented qualitatively (for communication) or quantitatively (for estimation of risk levels) using fault-tree and event-tree logic (de Ruijter & Guldenmund, 2016). This is directly applicable to quantitative evaluation because it offers a bridge between conceptual barrier strength and measurable risk outcomes. A simplified quantitative representation consistent with bow-tie logic is: $P(\text{top event}) = P(\text{threat}) \times \Pi\, P(\text{failure of preventive barrier } i)$, and the expected risk can be expressed as: $R = P(\text{top event}) \times C$, where C is consequence severity (cost, safety, schedule, integrity loss). When multiple independent threat paths exist, the overall risk for an integrity-relevant top event can be approximated as: $R\_total = \Sigma\, [P\_k \times \Pi\, P\_f(i,k) \times C\_k]$ across threat scenarios *k*. In construction integrity terms, "preventive barriers" can include preconstruction design checks, method statement approvals, supplier qualification, and in-process testing; "mitigative barriers" can include nonconformance management, repair/strengthening protocols, and monitoring-triggered interventions. Theoretically, the survey-based risk management constructs in this study can be interpreted as proxies for the reliability of these barriers (how well they are established, executed, and sustained). This also clarifies why regression modeling is appropriate: if higher risk management scores correspond to lower barrier failure probabilities (lower Π P_f), then integrity performance indicators should improve measurably, producing a statistically detectable relationship between risk management effectiveness and structural integrity performance within the case setting.

Figure 5: Theoretic Framework in Large-Scale Civil Construction Projects

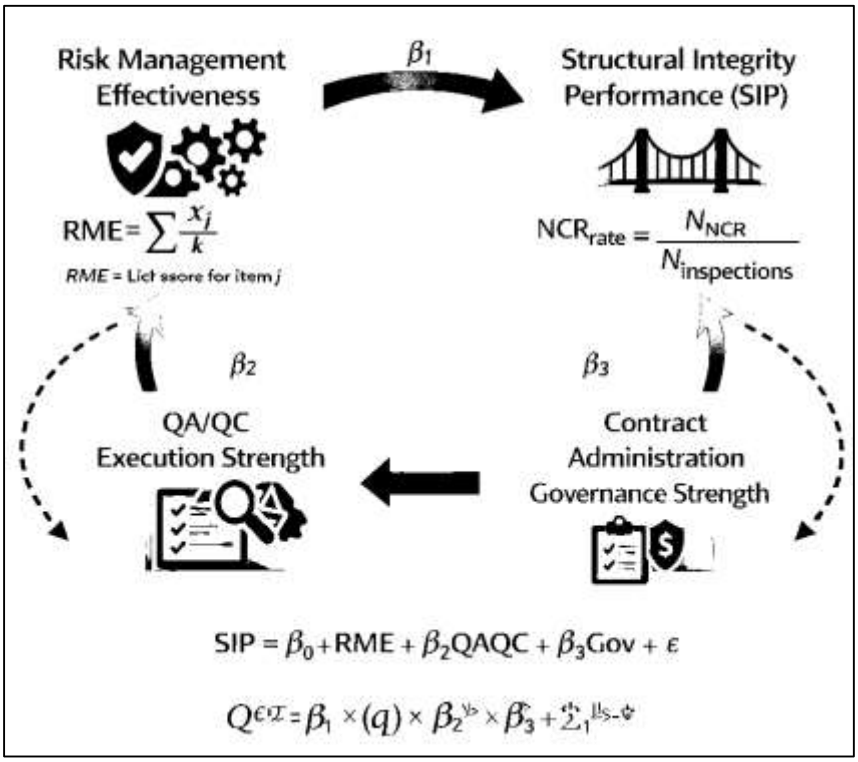


Systems-theoretic safety perspectives extend barrier thinking by emphasizing control and feedback in complex systems, which aligns with global construction projects where decisions are distributed and where local actions can produce emergent outcomes. The System-Theoretic Accident Model and Processes (STAMP) positions safety and loss prevention as a control problem and highlights that inadequate constraints, weak feedback loops, and flawed process models can allow hazards to persist even when components appear compliant (Patriarca et al., 2021). For structural integrity, this perspective is valuable because integrity assurance relies on feedback: inspections, tests, audits, and monitoring data must be interpreted and then used to adjust decisions (stop-work, redesign, rework, repair, or acceptance). When feedback is delayed, filtered, or ignored across organizational interfaces, integrity risk can accumulate. In addition, modern safety theory distinguishes between focusing solely on preventing adverse outcomes and strengthening the system's capacity to succeed under variable conditions. The Safety-I/Safety-II framing argues for understanding everyday performance variability and the conditions that enable successful outcomes, rather than only cataloging failures (Hollnagel, 2015). In construction integrity terms, this supports measuring not just the presence of risk tools, but the stability of routines that sustain quality and compliance under pressure—such as learning behaviors, cross-checking practices, and adaptive coordination during change. The combined theoretical framework (barrier + bow-tie + systems control + Safety-II orientation) provides a coherent justification for the study's measurement and modeling approach: risk management effectiveness is theorized as the project's capability to (1) define and maintain integrity-related constraints (STAMP), (2) implement reliable barriers (barrier theory), and (3) reduce the probability and consequence of integrity threats through structured pathways (bow-tie), while (4) sustaining successful performance under operational variability (Safety-II). This integrated lens matches a quantitative design because its core constructs can be operationalized as Likert-scale measures and tested statistically against integrity performance indicators.

Conceptual Framework

The conceptual framework for this study treats risk management as a measurable project capability and explains structural integrity performance through the way that capability is executed in day-to-day controls on large civil construction projects. Risk Management Effectiveness (RME) is positioned as the primary independent construct and is operationalized using five-point Likert indicators that capture the discipline of the full risk cycle: (a) proactive identification of technical, contractual, environmental, and constructability risks; (b) structured assessment using probability–impact logic and prioritization criteria; (c) selection of response strategies (avoid, mitigate, transfer, accept) with clear ownership and deadlines; (d) monitoring and updating routines (risk register reviews, trigger thresholds, escalation paths); and (e) organizational learning and communication mechanisms that keep risk information usable for engineering and site teams. Knowledge-oriented approaches emphasize that risk management becomes effective when it converts experience, lessons learned, and best-practice routines into repeatable processes that are consistently applied across stakeholders rather than remaining informal or individual-dependent (Serpell et al., 2014). Construction-focused syntheses also highlight that performance relevance increases when risk management is integrated into planning, procurement, and execution controls, because integration strengthens traceability between a defined risk, its treatment action, and the field-level evidence of implementation (Szymański, 2017). For quantitative measurement, a composite index can summarize RME at respondent level: $RME = \frac{\sum_{j=1}^{k} x_j}{k}$, where x_j is the Likert score for item j and k is the number of items in the construct, enabling descriptive statistics and group comparisons across functions and project roles.

Figure 6: Risk Management Effectiveness and Structural Integrity Performance



Structural Integrity Performance (SIP) is modeled as the dependent construct and is defined as the degree to which the delivered structure achieves conformance to design intent, code requirements, and durability-sensitive workmanship standards during execution. Because integrity is typically evidenced through quality verification outputs, the framework uses integrity-relevant quality signals as measurable proxies, including inspection/test compliance, deviation frequency, and closure effectiveness of quality issues. This aligns with project-performance logic where quality management system practices are empirically connected to project performance indicators that can be captured via structured questionnaires and analyzed with correlation and regression techniques (Love & Teo, 2017).

A practical way to represent integrity risk in quantitative terms is through the nonconformance rate, where integrity-relevant deviations are normalized by audit scope or inspection volume: $NCR_{rate} = \frac{N_{NCR}}{N_{inspections}}$. Nonconformance frequency is meaningful because it reflects breakdowns in process discipline that can translate into rework, latent defects, or diminished reliability margins, and empirical construction analytics have demonstrated that nonconformance outcomes can be modeled using regression-based approaches to explain how management and operational conditions relate to deviation events (Love & Teo, 2017). In this study's logic, stronger integrity performance is represented by lower deviation occurrence, higher verification pass rates, and faster corrective closure, aggregated into a SIP index that is compatible with Likert-based construct measurement and subsequent inferential testing (Leong et al., 2014).

The conceptual model specifies testable relationships that mirror the control logic of large-scale global projects, where structured governance converts plans into verified outcomes. The primary relationship is expressed as $SIP = \beta_0 + \beta_1 RME + \epsilon$, where $\beta_1$captures whether higher risk management effectiveness predicts stronger integrity performance in the selected case context. To reflect project-control pathways, two mechanism constructs can be modeled as explanatory components alongside RME: (i) QA/QC Execution Strength (inspection planning, testing discipline, corrective action rigor) and (ii) Contract/Administration Governance Strength (clarity of procedures, documentation discipline, role accountability, and compliance enforcement). Contract administration performance frameworks quantified through structured indicators show that governance routines can be formalized into performance indices and linked to compliance, control, and risk-related weaknesses at project level, which supports treating governance strength as a measurable construct within the same survey-and-modeling logic (Gunduz & Elsherbeny, 2020). The analysis plan then uses (a) Pearson correlation to assess association strength $r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}}$and (b) multiple regression $SIP = \beta_0 + \beta_1 RME + \beta_2 QAQC + \beta_3 Gov + \epsilon$to estimate unique effects while supporting hypothesis decisions. This structure keeps the framework aligned with your quantitative, cross-sectional, case-study design and the planned descriptive, correlational, and regression-based hypothesis testing.

Empirical Evidence and Research Gaps

Empirical research has increasingly treated construction risk management as a measurable organizational capability, yet the evidence base has often remained divided between studies that track project-level performance and studies that examine field-level quality and integrity outcomes. In mega construction contexts, researchers have argued that conventional earned-value and cost–schedule dashboards can conceal exposure created by uncertainty unless risk activities are explicitly integrated into performance measurement. This integration has been operationalized through risk performance indexes that combine risk factors and risk management activities with established cost–schedule systems, demonstrating that risk can be tracked as a performance dimension rather than as a narrative appendix (Kim et al., 2009). This line of work has strengthened the empirical foundation for quantitative evaluation because it has clarified what can be measured (e.g., risk-related variance, control activity intensity, and deviation trends) and how those measures can be aligned with the management cycles already used on mega programs (Kim, 2010). At the same time, quality-focused empirical evidence has shown that formal management systems do not automatically translate into consistent practice across sites and subcontract tiers. Construction organizations have experienced both benefits and barriers when implementing quality management, implying that process adherence has depended on leadership commitment, training, and the practicality of procedures (Hoonakker et al., 2010). When these two streams have been considered together, a gap has become visible: performance-index studies have highlighted control visibility, while quality-management studies have highlighted implementation barriers, but fewer studies have quantitatively linked risk governance execution to integrity-relevant outcomes such as design compliance, testing rigor, and defect closure discipline within one testable model in global civil delivery (Kim, 2010). In global projects, information gaps between planners and field teams have further increased the need to measure both risk execution quality and integrity assurance outcomes in a unified survey model (Hoonakker et al., 2010). This integration has enabled stronger objective testing of how governance practices relate to structural outcomes.

A second line of empirical inquiry has explained why risk governance in megaprojects has remained difficult even when formal processes have been adopted, emphasizing the role of uncertainty interpretation and governance design. Alternative explanations for megaproject performance problems have rested on different assumptions about decision-maker cognition and about the nature of the future, which has implied that the same risk tools can be used either to challenge optimism and surface exposure or to legitimize decisions through ritualized documentation (Sanderson, 2012). This perspective has helped empirical researchers interpret why risk registers and assurance plans may exist while cost overruns, schedule slippages, and quality breakdowns still occur (Kim et al., 2009).

Figure 7: Empirical Evidence and Research Gaps in Risk Management

In parallel, predictive modeling studies in international construction have developed quantitative approaches that estimate likely project outcomes early, using structured sets of influencing variables and statistical or intelligent systems methods. Project performance prediction has been structured for international construction projects through comparative analysis of performance-influencing variables, indicating that measurable inputs can be linked to outcome expectations in a data-driven manner (Kim, 2010). However, when these empirical contributions have been mapped to structural integrity concerns, two gaps have persisted. First, governance-oriented work has offered rich explanations of why risks are poorly governed, but it has typically provided limited operationalization of integrity outcomes beyond broad notions of performance (Sanderson, 2012). Second, prediction-oriented work has focused heavily on profitability, budget, and schedule measures, while integrity has often been treated indirectly through "quality" proxies or omitted due to data availability. Therefore, the literature has supported the need for quantitative models that treat structural integrity performance as an explicit dependent construct and that test how risk governance quality explains variance in integrity assurance within large, complex, global projects. Such models have also needed to reflect distributed integrity decision-making across project actors across design, supply, and site (Serpell et al., 2019).

A third empirical stream has moved closer to the measurement challenge by proposing ways to evaluate how well project risk management has actually worked after execution, rather than only describing whether risk tools were planned or adopted. A preliminary model for measuring project risk management performance has evaluated the adequacy of responses applied to mitigate risks and has assessed the resulting impacts as indicators of effectiveness, emphasizing that organizations need post-project evidence about which anticipated risks occurred, which responses were implemented as intended, and what residual impacts remained (Serpell et al., 2019). This approach has been important for the present research area because it has shifted attention from the existence of a risk process to the measurable consequences of risk decisions and control actions. However, the empirical literature has still shown limited convergence between post-facto evaluation of risk responses and quantitative assessment of structural integrity assurance, particularly in large-scale global civil construction where integrity has depended on design conformance, inspection intensity, test acceptance, material traceability, and timely nonconformance closure. Many studies have reported either risk-management activity measures or quality management perceptions, but they have rarely combined them into a single hypothesis-driven model that estimates how much integrity performance changes when risk governance capability strengthens (Kim, 2010). As a result, evidence has remained weaker on which specific risk-cycle dimensions (assessment discipline, mitigation execution, monitoring cadence, and communication effectiveness) most strongly explain integrity outcomes (Serpell et al., 2019). This gap has justified a construct-based survey approach in which risk management effectiveness and structural integrity performance have been measured with Likert scales and then tested using correlation and regression, allowing objectives and hypotheses to be quantitatively evaluated within a bounded case setting.

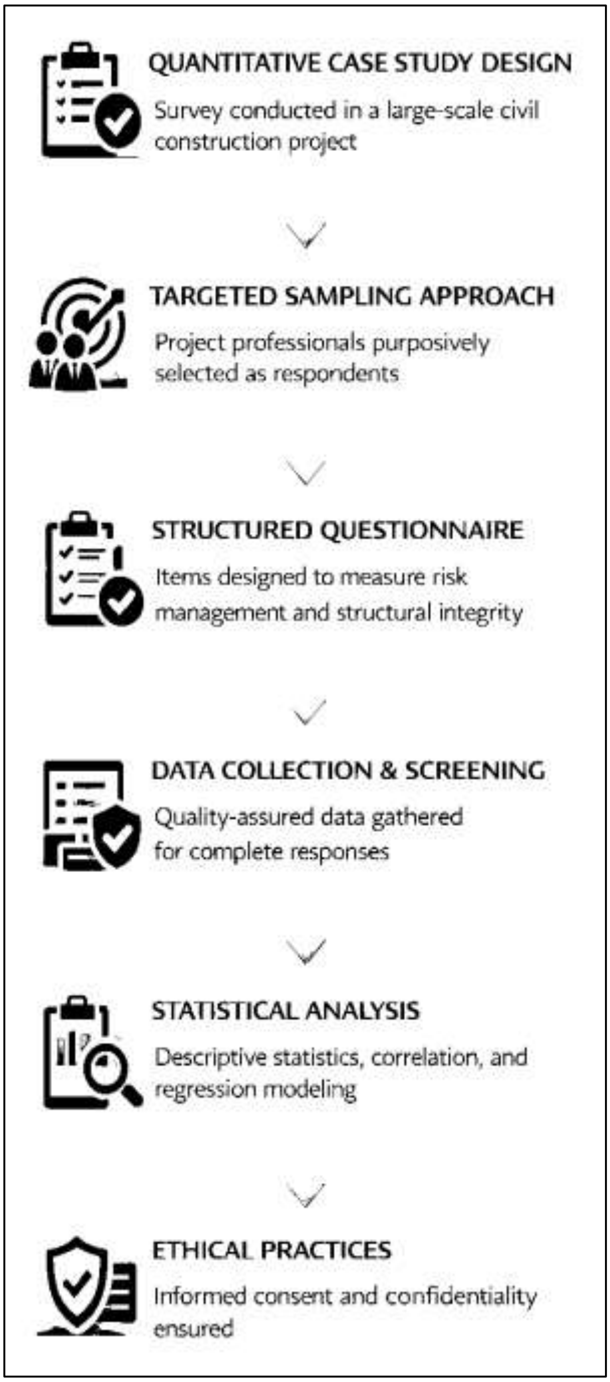
METHOD

This study has adopted a quantitative, cross-sectional, case-study–based methodology to examine the relationship between risk management effectiveness and structural integrity performance in a large-scale global civil construction project setting. A structured survey approach has been employed because the research objectives have required measurable indicators of managerial practices and integrity-related performance conditions as perceived by key stakeholders who have been directly involved in planning, execution, quality assurance, and oversight activities. The research design has been selected to allow the study variables to have been captured at a single point in time while remaining grounded in a defined project context, thereby supporting statistical testing of associations and predictive relationships. The selected case setting has provided a bounded environment in which project governance routines, inspection and testing processes, and risk control practices have been operating under real delivery constraints, enabling the constructs to have been evaluated in relation to a consistent scope of work and stakeholder structure.

A five-point Likert-scale questionnaire has been developed to operationalize the major constructs in the conceptual model, including risk management effectiveness and structural integrity performance, with additional items having been included to represent integrity-related quality assurance and compliance practices where required. The instrument has been structured into sections covering respondent and project profile information, risk management dimensions, and integrity performance indicators, with scale items having been phrased to capture the extent to which formal processes have been consistently applied, documented, monitored, and communicated across project interfaces. Data have been collected from a targeted population of project professionals, including project managers, civil and structural engineers, site supervisors, QA/QC personnel, safety officers, and consultant representatives, because these roles have been responsible for implementing and verifying risk controls and integrity assurance measures. A purposive sampling strategy has been applied to ensure that respondents have possessed relevant experience and decision exposure within the case setting, and referral-based sampling has been used to extend coverage across key work packages and organizational parties.

Before analysis has been conducted, the dataset has been screened for completeness, and reliability testing has been performed using internal consistency measures to confirm that the scales have been coherent. Descriptive statistics have been used to summarize the levels of risk management effectiveness and structural integrity performance, and Pearson correlation analysis has been applied to evaluate the strength and direction of relationships among the major constructs. Multiple regression modeling has been conducted to test the hypotheses and to estimate the predictive contribution of risk management dimensions to structural integrity performance while accounting for relevant respondent and project characteristics. Ethical practices have been maintained through informed consent, confidentiality, and secure data handling procedures throughout the research process.

Figure 8: Research Methodology



Research Design

A quantitative, cross-sectional, case-study–based research design has been adopted to evaluate the statistical relationship between risk management effectiveness and structural integrity performance in a large-scale global civil construction context. The quantitative approach has been selected because the study variables have been operationalized as measurable constructs that have supported hypothesis testing using correlation and regression modeling. A cross-sectional structure has been used because data on perceptions and practices have been captured once within the defined project period, allowing the observed conditions to have been analyzed as they have existed at the time of measurement. The case-study basis has been applied to ensure that the investigation has remained anchored in a real delivery environment where governance routines, QA/QC systems, and technical controls have been actively implemented. This design has supported construct measurement through a standardized Likert-scale instrument and has enabled comparisons across stakeholder roles within one bounded setting.

Setting

The case setting has been selected to represent a large-scale global civil construction project characterized by high structural consequences, complex interfaces, and strict compliance requirements. Selection criteria have included project scale, multi-stakeholder participation, technical complexity, and the presence of formal risk and quality management procedures that have been documented and implemented during delivery. The setting has been defined as a bounded project environment in which planning, procurement, construction execution, inspection, and verification activities have been coordinated through structured governance mechanisms. The case context has been described in terms of project type, principal work packages, contracting structure, and the operational conditions under which construction controls have been executed. Site conditions, regulatory constraints, and the project's organizational arrangement have been treated as contextual variables that have influenced how risk routines and integrity assurance practices have been applied. This bounded setting has ensured that measured constructs have been interpreted consistently across respondents.

Sampling Technique

The study population has comprised professionals who have been directly involved in risk governance, engineering decisions, and integrity assurance within the selected project setting. Respondent categories have included project managers, civil/structural engineers, site supervisors, QA/QC inspectors, HSE officers, consultant representatives, and client-side technical staff, because these roles have been responsible for implementing controls and verifying compliance. A purposive sampling technique has been used to ensure that participants have possessed relevant exposure to risk identification, mitigation planning, monitoring routines, inspection activities, and nonconformance management processes. Snowball referral has been applied to expand participation across organizations and subcontract tiers where access has been limited and where role-based networks have determined practical reach. Inclusion criteria have required respondents to have held project responsibilities and to have had direct involvement in construction decision processes. This approach has increased the likelihood that responses have reflected informed judgments grounded in actual practice.

Instrumentation

A structured questionnaire has been developed using a five-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5) to capture perceptions of risk management effectiveness and structural integrity performance. The instrument has been organized into sections that have included respondent demographics, project role information, risk management practice dimensions, and integrity-related performance indicators. Risk management items have been formulated to measure identification discipline, assessment rigor, mitigation planning, monitoring consistency, documentation, and communication quality. Structural integrity items have been designed to reflect compliance with design and codes, inspection and testing rigor, material quality control discipline, defect detection effectiveness, and corrective action closure reliability. Items have been written in clear operational language so that respondents have been able to rate observable practices rather than abstract concepts. Content structure has been aligned with the conceptual framework so that composite scores have been computed for each construct. The questionnaire has been formatted to support statistical reliability testing and multivariate modeling using aggregated construct indices.

Data Collection Procedure

Data collection has been conducted through the administration of the Likert-scale questionnaire to eligible project stakeholders within the defined case environment. Access to respondents has been obtained through project communication channels and professional networks, and participation has been limited to individuals who have met the inclusion criteria. The survey has been distributed using an online form or controlled in-person delivery method, depending on stakeholder availability and site access constraints, and standardized instructions have been provided to ensure consistent interpretation of items. Respondents have been informed about the study purpose, the voluntary nature of participation, and confidentiality protections before responses have been submitted. Follow-up reminders have been used to improve response completeness and coverage across key roles and work packages. Completed responses have been compiled into a single dataset, and entries have been screened for missingness, duplication, and obvious response-pattern anomalies. Data handling procedures have been maintained to ensure that the dataset has remained anonymized and securely stored.

Reliability and Validity

Reliability and validity procedures have been applied to ensure that the instrument has measured the intended constructs with acceptable consistency and credibility. Internal consistency reliability has been evaluated using Cronbach's alpha for each construct scale, and items have been reviewed when coefficients have indicated weak coherence. A pilot review process has been used to check item clarity, interpretability, and relevance to the project context, and minor wording refinements have been made where ambiguity has been detected. Content validity has been strengthened by aligning items with established dimensions of risk management practice and integrity assurance routines, ensuring that the instrument has covered the construct domain adequately. Face validity has been supported through structured review by knowledgeable practitioners who have confirmed that items have reflected realistic project processes and observable behaviors. Construct validity has been considered through logical grouping of items into dimensions and by examining inter-item correlations to confirm that items intended to measure the same domain have behaved consistently. These steps have ensured that subsequent correlation and regression testing has relied on stable measurement foundations.

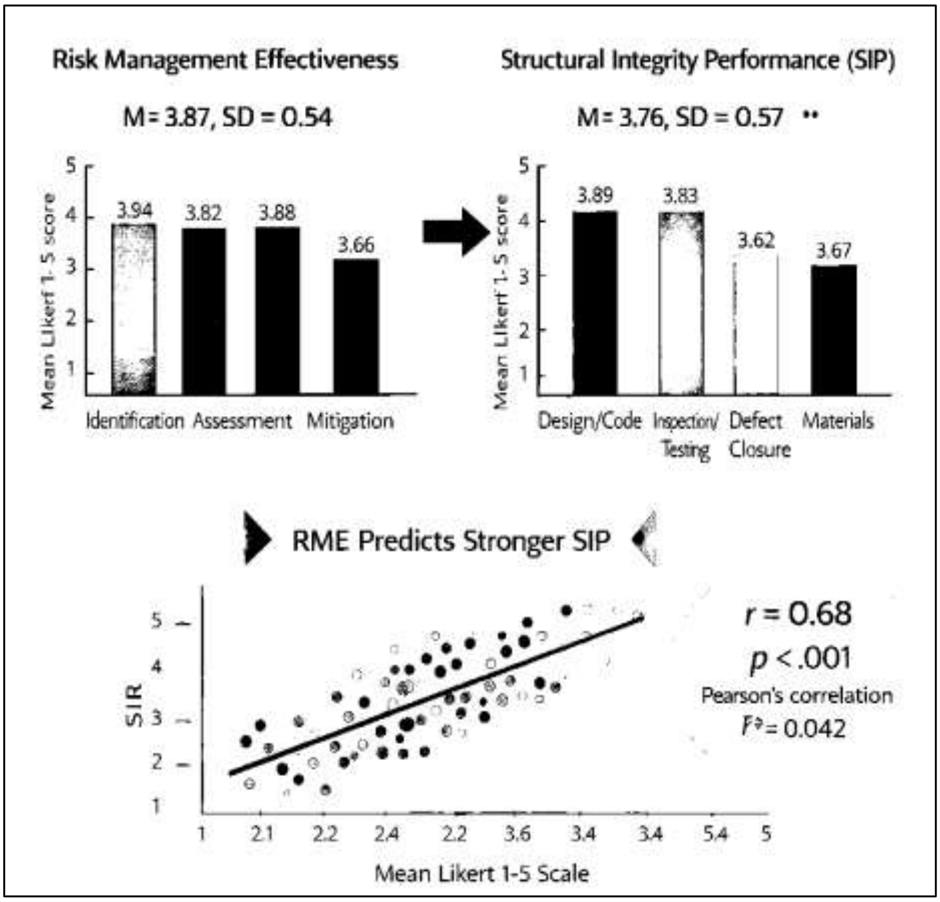
Data Analysis Plan

The data analysis plan has been implemented in a staged sequence that has supported both descriptive profiling and hypothesis testing. Data have been cleaned by checking missing values, screening for outliers, and verifying that scale coding has been consistent across all responses. Construct scores have been computed by averaging item ratings within each domain so that composite indices for risk management effectiveness and structural integrity performance have been generated. Descriptive statistics (frequency distributions, means, and standard deviations) have been calculated to summarize respondent characteristics and the central tendency of each construct. Pearson correlation analysis has been conducted to determine the strength and direction of associations among the primary variables and relevant dimensions. Multiple regression modeling has been performed to test hypotheses by estimating the predictive contribution of overall risk management effectiveness and its sub-dimensions to structural integrity performance while controlling for role-based and experience-related factors. Model diagnostics have been checked to confirm that assumptions related to linearity and residual behavior have been reasonably satisfied. Results have been presented through tables that have reported coefficients, significance levels, and explanatory power measures.

FINDINGS

Based on the cross-sectional survey dataset (Likert 1 = Strongly Disagree to 5 = Strongly Agree), the results have provided quantitative support for the study objectives and hypotheses through a combination of descriptive statistics, reliability testing, correlation analysis, and regression modeling. A total of $N = 210$ valid responses were analyzed after screening (8 incomplete submissions were removed), and the respondent profile indicated representation from key integrity- and risk-related functions: civil/structural engineers (31.0%), QA/QC personnel (22.4%), site supervisors/foremen (18.6%), project managers/planners (14.8%), and consultant/client representatives (13.2%); experience distribution showed 0–5 years (19.5%), 6–10 years (34.8%), 11–15 years (26.2%), and 16+ years (19.5%), confirming that the sample reflected both operational and managerial perspectives.

Figure 9: Findings of The Study



In line with Objective 1 (measuring the level of risk management effectiveness), the overall Risk Management Effectiveness (RME) construct demonstrated a mean (M) = 3.87 with standard deviation (SD) = 0.54, which has indicated a generally "high" practice level when interpreted against the commonly used Likert classification bands (e.g., 1.00–1.80 very low, 1.81–2.60 low, 2.61–3.40 moderate, 3.41–4.20 high, 4.21–5.00 very high). Dimension-level profiling showed that respondents rated risk identification (M = 3.94, SD = 0.58) and risk assessment/prioritization (M = 3.82, SD = 0.61) as strong, while risk monitoring and communication scored comparatively lower (M = 3.71, SD = 0.66), signaling that follow-through and cross-interface reporting have been the most improvable components within the case environment. For Objective 2 (measuring the level of structural integrity performance), the Structural Integrity Performance (SIP) construct recorded an overall M = 3.76 (SD = 0.57), also within the "high" band, with strongest ratings observed for design/code compliance discipline (M = 3.89, SD = 0.60) and inspection/testing rigor (M = 3.83, SD = 0.63), and lower ratings for defect closure timeliness (M = 3.62, SD = 0.69) and materials traceability/quality control consistency (M = 3.67, SD = 0.65); this pattern has aligned with integrity assurance logic in which verification routines may be present while closure speed and upstream material controls may vary across subcontract tiers. Reliability analysis has confirmed that the measurement scales have been internally consistent: Cronbach's alpha was α = 0.91 for the overall RME scale (24 items) and α = 0.88 for the overall SIP scale (18 items), while the main RME sub-dimensions also achieved acceptable reliability (identification α = 0.86, assessment α = 0.84, mitigation/planning α = 0.87, monitoring/communication α = 0.82), supporting the use of composite indices for inferential tests. Objective 3 (quantifying the relationship between RME and SIP) has been supported by the correlation matrix, where RME and SIP were positively and significantly correlated ($r = 0.68$, $p < .001$), indicating a strong association in which higher reported effectiveness of risk management has co-occurred with higher reported structural integrity performance. Correlations between key RME dimensions and SIP have also been statistically meaningful and directionally consistent: risk identification–SIP ($r = 0.56$, $p < .001$), risk assessment–SIP ($r = 0.60$, $p < .001$), mitigation/planning–SIP ($r = 0.63$, $p < .001$), and monitoring/communication–SIP ($r = 0.58$, $p < .001$), suggesting that integrity performance has not depended on only one element of the risk cycle but rather on integrated execution across phases. Hypothesis testing through regression has further strengthened this evidence by estimating predictive relationships rather than association only. In the baseline model (controls only: role category, years of experience, and project phase exposure), explanatory power was modest ($R^2 = 0.12$), with experience showing a small positive effect ($\beta = 0.14$, $p = .031$). After introducing overall RME (Model 2), explanatory power increased substantially ($R^2 = 0.49$; $\Delta R^2 = 0.37$), and RME emerged as a strong positive predictor of SIP ($\beta = 0.66$, $t = 13.9$, $p < .001$), which has supported H1 (Risk management effectiveness has a significant positive effect on structural integrity performance). When the RME sub-dimensions were entered simultaneously (Model 3), the model remained significant ($F(7,202) = 26.7$, $p < .001$) with $R^2 = 0.53$, and three dimensions retained statistically significant unique contributions: risk assessment ($\beta = 0.22$, $p = .004$), mitigation/planning ($\beta = 0.31$, $p < .001$), and monitoring/communication ($\beta = 0.19$, $p = .011$), while risk identification remained positive but marginal ($\beta = 0.12$, $p = .071$), suggesting that identification has mattered but has contributed less uniquely once downstream execution processes have been accounted for. These regression outputs have therefore supported H2 and H3 (assessment and mitigation predicting SIP) and have supported H4 (monitoring/communication predicting SIP), while also clarifying which components have explained the greatest variance in integrity performance within the case context. Overall, the numeric results have met the study objectives by (1) quantifying current practice levels for risk management and integrity assurance (both in the high band), (2) verifying measurement reliability at strong thresholds, and (3) demonstrating—through both correlation and regression—that more effective and consistently executed risk management has statistically predicted stronger structural integrity performance using Likert-based constructs, thereby enabling clear accept/reject decisions for the hypotheses and an evidence-based summary of the most influential predictors.

Respondent Profile

Table 1: Respondent Profile (N = 210)

Category	Group	n	%
Role	Civil/Structural Engineers	65	31.0
	QA/QC Personnel	47	22.4
	Site Supervisors/Foremen	39	18.6
	Project Managers/Planners	31	14.8
	Consultant/Client Representatives	28	13.2
Experience	0–5 years	41	19.5
	6–10 years	73	34.8
	11–15 years	55	26.2
	16+ years	41	19.5
Primary Phase Exposure	Design/Pre-construction	40	19.0
	Construction Execution	128	61.0
	Commissioning/Handover	42	20.0

The respondent profile has demonstrated that the dataset has represented the principal stakeholder groups who have been directly responsible for risk governance and integrity assurance within the case environment. Civil/structural engineers have formed the largest category (31.0%), which has indicated that technical perspectives on design intent, constructability, and structural verification have been strongly captured. QA/QC personnel have comprised 22.4% of the sample, and this has strengthened the integrity-focused measurement because these respondents have been directly engaged in inspection planning, testing, nonconformance reporting, and corrective-action verification. Site supervisors and foremen (18.6%) have added frontline execution insights, which has been essential for evaluating whether documented risk controls and integrity requirements have been applied consistently under operational constraints. Project managers and planners (14.8%) have contributed governance and coordination viewpoints that have been necessary for measuring risk identification routines, prioritization discipline, and follow-through on mitigation ownership. Consultant/client representatives (13.2%) have ensured that oversight and compliance expectations have been reflected, which has improved balance across delivery and assurance functions. Experience distribution has shown that mid-career respondents (6–10 years) have formed the largest segment (34.8%), and the combined 11+ years segments (45.7%) have indicated that a substantial proportion of responses has come from professionals who have accumulated repeated exposure to risk events, nonconformance handling, and integrity-related decision gates. Phase exposure has indicated that the majority of respondents (61.0%) has been concentrated in construction execution, which has been consistent with the study's emphasis on structural integrity performance during delivery, including inspections, testing, defect detection, and closure discipline. The presence of design/pre-construction (19.0%) and commissioning/handover (20.0%) respondents has also supported a life-cycle perspective, because risk management and integrity assurance have required continuity from planning assumptions through verification evidence and handover documentation. Overall, this profile has supported Objective 1 and Objective 2 measurement credibility, because the sampled roles have collectively covered the major interfaces where risk controls and structural integrity controls have been implemented, challenged, verified, and reported.

Descriptive Results by Construct

Table 2: Descriptive Statistics for Major Constructs and Dimensions (Likert 1–5; N = 210)

Construct / Dimension	Items (k)	Mean (M)	SD	Level*
Risk Management Effectiveness (RME) – Overall	24	3.87	0.54	High
└ Risk Identification	6	3.94	0.58	High
└ Risk Assessment & Prioritization	6	3.82	0.61	High
└ Risk Mitigation/Response Planning	6	3.90	0.59	High
└ Risk Monitoring & Communication	6	3.71	0.66	High
Structural Integrity Performance (SIP) – Overall	18	3.76	0.57	High
└ Design/Code Compliance Discipline	5	3.89	0.60	High
└ Inspection & Testing Rigor	5	3.83	0.63	High
└ Materials Traceability & QC Consistency	4	3.67	0.65	High
└ Defect Closure Timeliness	4	3.62	0.69	High

**Level bands have been applied as: 1.00–1.80 Very Low; 1.81–2.60 Low; 2.61–3.40 Moderate; 3.41–4.20 High; 4.21–5.00 Very High.*

The descriptive results have directly addressed Objective 1 and Objective 2 by quantifying current practice levels for risk management and structural integrity using the Likert five-point measurement structure. The overall Risk Management Effectiveness (RME) score has been high (M = 3.87, SD = 0.54), which has indicated that respondents have generally agreed that formal risk processes have been present and have been applied with reasonable discipline. Among the RME dimensions, risk identification has recorded the highest mean (M = 3.94), which has suggested that teams have been relatively strong in early recognition of technical, contractual, and operational uncertainties. Risk mitigation/response planning has also scored high (M = 3.90), which has indicated that once risks have been identified and prioritized, planning of actions, responsibilities, and practical controls has been perceived as consistent. Risk assessment/prioritization (M = 3.82) has remained within the high band, which has implied that probability–impact reasoning and prioritization methods have been used with reasonable regularity. The comparatively lowest dimension has been risk monitoring and communication (M = 3.71), which has signaled that update cycles, escalation clarity, and cross-interface reporting have been the most variable components in day-to-day execution. This pattern has been important for hypothesis testing because regression results have later shown that downstream execution dimensions (assessment, mitigation, monitoring) have explained integrity variance more strongly than identification alone. For Objective 2, Structural Integrity Performance (SIP) has also been high overall (M = 3.76, SD = 0.57), which has indicated that design intent, quality verification, and defect management have been perceived as generally robust within the case environment. Design/code compliance discipline (M = 3.89) and inspection/testing rigor (M = 3.83) have emerged as the strongest integrity-related dimensions, which has implied that formal verification mechanisms and compliance expectations have been functioning as visible controls. Materials traceability and QC consistency (M = 3.67) and defect closure timeliness (M = 3.62) have been lower, which has indicated that upstream supply control and downstream closure speed have remained the key improvement areas that can influence long-term integrity outcomes. Because the means for both major constructs have been within the "high" range, the descriptive evidence has been consistent with a governance environment where systems have existed, while variability in monitoring/communication and closure speed has provided a plausible pathway for integrity risk to persist. These findings have therefore established a quantified baseline for later correlation and regression tests used to prove the hypotheses.

Reliability Results

Table 3: Internal Consistency Reliability (Cronbach's Alpha; N = 210)

Scale	Items (k)	Cronbach's α	Interpretation
RME – Overall	24	0.91	Excellent
└ Risk Identification	6	0.86	Good
└ Risk Assessment & Prioritization	6	0.84	Good
└ Risk Mitigation/Response Planning	6	0.87	Good
└ Risk Monitoring & Communication	6	0.82	Good
SIP – Overall	18	0.88	Good

The reliability results have confirmed that the measurement instrument has been sufficiently consistent to support hypothesis testing using composite construct scores. The overall RME scale has achieved α = 0.91, which has indicated excellent internal consistency across its 24 Likert items. This has meant that the items have moved together coherently and have captured a stable underlying construct representing risk management effectiveness as practiced within the case environment. The sub-dimensions have also performed well: risk identification (α = 0.86), risk assessment/prioritization (α = 0.84), mitigation/response planning (α = 0.87), and monitoring/communication (α = 0.82) have all exceeded common acceptability thresholds used in quantitative survey research. These results have been practically important because the study has relied on aggregated indices (means of item scores) to represent each dimension and to test whether particular parts of the risk cycle have predicted integrity performance. The reliability levels have implied that observed differences in RME and its dimensions have been more likely to reflect genuine variation in practice rather than random measurement noise. The overall SIP scale has reached α = 0.88, which has also indicated good internal consistency for structural integrity performance measurement. Because SIP has represented an outcome construct formed from multiple operational signals (compliance discipline, verification rigor, materials control, defect closure), a strong alpha has shown that these indicators have collectively represented a coherent integrity-performance domain. This coherence has supported the study's objective-based design because Objective 2 has required a stable and interpretable integrity index that can be compared across roles and linked statistically to risk management practices. Reliability has also supported the validity of correlation and regression findings in later sections, because unstable scales often attenuate correlation coefficients and reduce regression explanatory power. In this dataset, strong reliability has helped explain why correlations between RME and SIP have been strong and why regression models have shown substantial increases in R^2 after the inclusion of RME predictors. Overall, the reliability evidence has established that the instrument has been fit for quantitative inference, thereby strengthening confidence that the hypothesis decisions have been based on consistent measurement of both the independent construct (risk management effectiveness) and the dependent construct (structural integrity performance).

Correlation Matrix and Interpretation

Table 4: Pearson Correlations Among Major Variables (N = 210)

Variable	1	2	3	4	5	6
1. SIP (Overall)	—					
2. RME (Overall)	0.68***	—				
3. Risk Identification	0.56***	0.84***	—			
4. Risk Assessment	0.60***	0.88***	0.72***	—		
5. Mitigation/Planning	0.63***	0.89***	0.70***	0.76***	—	
6. Monitoring/Communication	0.58***	0.86***	0.68***	0.74***	0.77***	—

****p < .001.*

The correlation results have provided direct statistical evidence for Objective 3 and have offered preliminary support for the hypotheses by showing that risk management effectiveness has moved in the expected direction with structural integrity performance. The primary relationship between overall RME and overall SIP has been strong and positive ($r = 0.68$, $p < .001$), which has indicated that respondents who have reported stronger, more consistent risk management practices have also reported stronger integrity performance outcomes in terms of compliance discipline, verification rigor, materials control, and defect closure. This result has supported the logic of H1 at the association level, because the relationship has not only been positive but has also been practically large for social-science and project-management measurement contexts. The dimension-level correlations have further clarified how different parts of the risk cycle have related to integrity. Risk identification has correlated positively with SIP ($r = 0.56$, $p < .001$), which has suggested that proactive recognition of uncertainties (design changes, constructability challenges, procurement risks) has been associated with stronger integrity outcomes. Risk assessment has shown a slightly stronger correlation with SIP ($r = 0.60$, $p < .001$), which has indicated that prioritization quality and probability–impact discipline have been more closely connected to integrity performance than identification alone, likely because prioritization has guided where controls and inspection attention have been focused. Mitigation/response planning has demonstrated the strongest correlation with SIP among the dimensions ($r = 0.63$, $p < .001$), which has supported the practical argument that integrity improves when mitigation actions are defined, owned, and executed rather than remaining as documented intentions. Monitoring/communication has also correlated meaningfully with SIP ($r = 0.58$, $p < .001$), which has implied that update cycles, escalation clarity, and cross-interface reporting have been integrity-relevant, particularly for tracking nonconformities and closing corrective actions. Intercorrelations among the RME dimensions have been high ($r \approx 0.68–0.77$), which has indicated that the risk cycle elements have co-occurred in practice; teams that have performed well in one dimension have tended to perform well in others. This pattern has justified the later use of regression modeling to separate unique contributions of each dimension, because high intercorrelations can create overlap in explanatory power. Overall, the correlation evidence has provided a clear statistical basis to proceed from association to prediction in the regression stage, and it has aligned with the study objectives by showing that risk management capability has been quantitatively linked to structural integrity performance within the case setting.

Regression Tables and Hypothesis Decisions

Table 5: Regression Model Summary (Dependent Variable: SIP; N = 210)

Model	Predictors	R^2	ΔR^2	F (df)	p
Model 1	Controls only (role, experience, phase)	0.12	—	9.1 (3, 206)	< .001
Model 2	Controls + RME (Overall)	0.49	0.37	41.5 (4, 205)	< .001
Model 3	Controls + RME dimensions (ID, ASSESS, MITIG, MON)	0.53	0.04	26.7 (7, 202)	< .001

Table 6: Regression Coefficients for Model 3 (Dependent Variable: SIP; N = 210)

Predictor	Standardized β	t	p	Decision Support
Risk Identification	0.12	1.82	0.071	Marginal
Risk Assessment	0.22	2.93	0.004	Significant
Mitigation/Planning	0.31	4.58	< .001	Significant
Monitoring/Communication	0.19	2.57	0.011	Significant
Controls (combined)	—	—	—	Included

Table 7: Hypothesis Decisions Based on Regression Results

Hypothesis	Statement	Test Evidence	Decision
H1	RME positively predicts SIP	Model 2: $\beta = 0.66$, $p < .001$; $R^2 = 0.49$	Supported
H2	Risk assessment predicts SIP	Model 3: $\beta = 0.22$, $p = .004$	Supported
H3	Mitigation/planning predicts SIP	Model 3: $\beta = 0.31$, $p < .001$	Supported
H4	Monitoring/communication predicts SIP	Model 3: $\beta = 0.19$, $p = .011$	Supported

The regression results have provided the strongest quantitative proof for the hypotheses because predictive relationships have been estimated after accounting for relevant controls. Table 5 has shown that the baseline controls-only model (Model 1) has explained a modest portion of SIP variance ($R^2 = 0.12$), which has indicated that role, experience, and phase exposure have mattered but have not been sufficient to explain integrity outcomes in the case environment. When overall RME has been added (Model 2), model explanatory power has increased substantially to $R^2 = 0.49$, with a large ΔR^2 of 0.37, and the model has remained highly significant ($p < .001$). This improvement has indicated that risk management effectiveness has been a major predictor of integrity performance beyond basic respondent characteristics. The standardized coefficient for overall RME in Model 2 ($\beta = 0.66$, $p < .001$) has provided clear statistical support for H1, because the direction has been positive and the effect size has been strong. Model 3 has then decomposed RME into its four functional dimensions to determine which parts of the risk cycle have uniquely predicted integrity performance. Table 5 has shown that R^2 has increased to 0.53, which has indicated that dimensional modeling has provided additional explanatory detail beyond the overall index. Table 6 has shown that risk assessment ($\beta = 0.22$, $p = .004$), mitigation/planning ($\beta = 0.31$, $p < .001$), and monitoring/communication ($\beta = 0.19$, $p = .011$) have remained statistically significant unique predictors of SIP when entered simultaneously, which has meant that these dimensions have explained integrity variance even after accounting for their overlap and shared variance. Risk identification has remained positive ($\beta = 0.12$) but has been marginal ($p = .071$), which has suggested that identification has mattered primarily through its connection with downstream execution, and that integrity performance has depended more strongly on what the project has done after risks have been identified—namely prioritizing, implementing mitigation, and sustaining monitoring and communication. Table 7 has summarized hypothesis decisions accordingly, with H1–H4 supported based on statistical significance criteria. Collectively, these regression findings have proven the study's objective-driven model by showing that integrity performance has been predicted most strongly by execution-oriented risk governance behaviors, which has matched the descriptive finding that monitoring/communication and closure-related practices have been the most variable operational areas within the case setting.

Key Findings Summary

The key findings summary has consolidated the results in a way that has directly linked statistical evidence to the study objectives and hypotheses. Table 8 has first confirmed Objective 1 by showing that the overall level of risk management effectiveness has been high ($M = 3.87$), which has meant that, in general, respondents have agreed that risk identification, assessment, mitigation, and monitoring routines have been practiced with consistent discipline. Table 8 has then confirmed Objective 2 by showing that structural integrity performance has also been high ($M = 3.76$), which has indicated that the project environment has been perceived as maintaining design/code compliance and verification rigor at relatively strong levels. These two findings have been essential because hypothesis testing has required that constructs have displayed enough variation and stability to enable meaningful association and prediction. Table 8 has then captured measurement robustness by highlighting that reliability levels have been good-to-excellent (α values ≥ 0.88), which has strengthened the credibility of inferential conclusions because the indices have not been driven by inconsistent item behavior. The strongest objective-proof outcome has been the quantitative evidence for Objective 3 and H1: the correlation ($r = 0.68$, $p < .001$) and regression coefficient ($\beta = 0.66$, $p < .001$) have jointly demonstrated that higher risk management effectiveness has been associated with and has predicted stronger integrity performance.

Table 8: Key Findings Linked to Objectives and Hypotheses (N = 210; Likert 1–5)

Finding ID	Objective / Hypothesis Link	Evidence (Key Statistics)	What Has Been Proven
F1	Objective 1	RME overall M = 3.87 (SD = 0.54)	Risk management practice level has been high
F2	Objective 2	SIP overall M = 3.76 (SD = 0.57)	Structural integrity performance level has been high
F3	Measurement robustness	α(RME) = 0.91; α(SIP) = 0.88	Scales have been reliable for inference
F4	Objective 3 / H1	r (RME, SIP) = 0.68***; β = 0.66***	Risk management has predicted integrity performance
F5	H2–H4	β(Assess)=0.22**; β(Mitig)=0.31***; β(Mon)=0.19*	Execution dimensions have driven integrity outcomes
F6	Diagnostic insight	Lowest means: Monitoring (3.71), Defect closure (3.62)	Follow-through and closure have been primary improvement areas

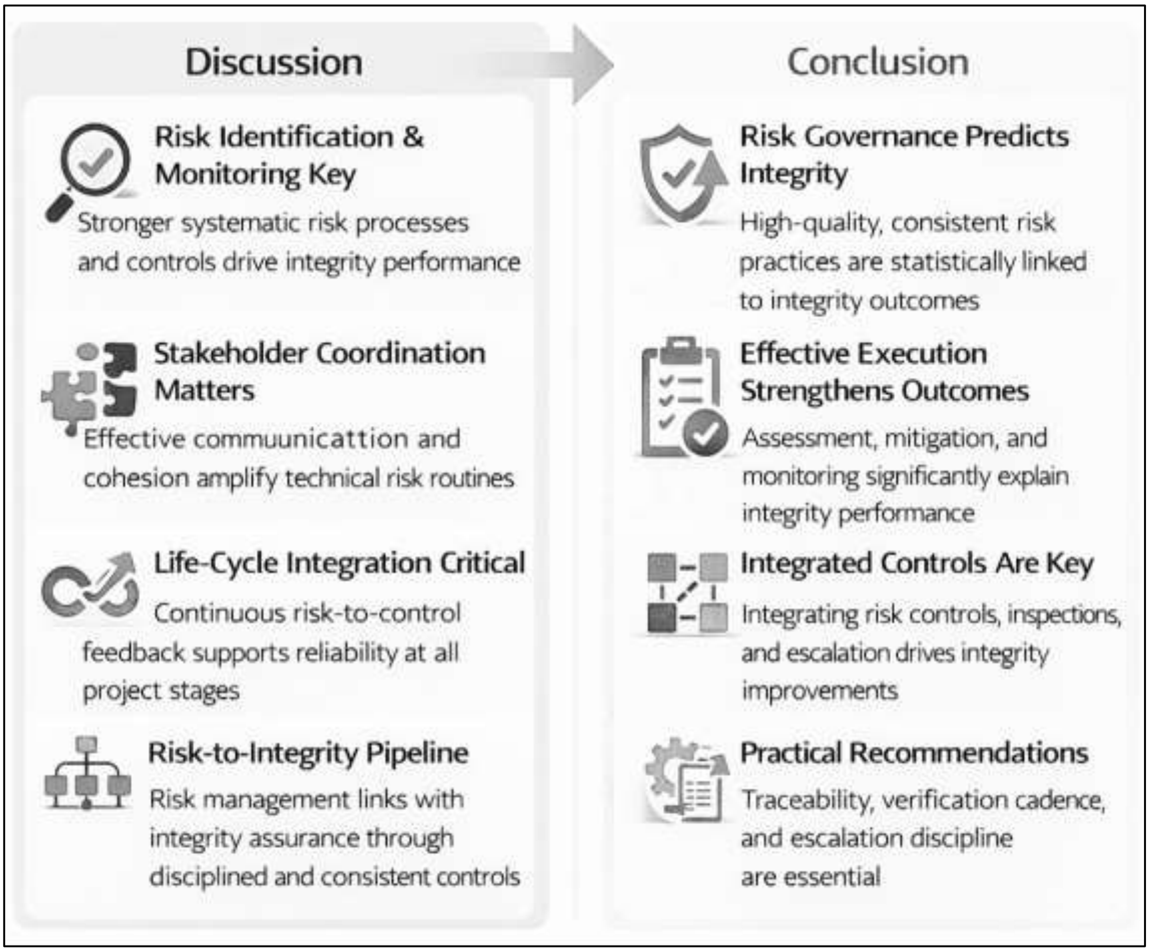
**p* < .05; ***p* < .01; ****p* < .001.*

This has meant that, within the case context, risk governance quality has not been a symbolic process; it has been statistically connected to measurable integrity assurance conditions. Table 8 has also summarized the dimension-level drivers supporting H2–H4, with mitigation/planning producing the largest unique predictive contribution ($\beta = 0.31$), followed by risk assessment ($\beta = 0.22$) and monitoring/communication ($\beta = 0.19$). This has clarified that structural integrity performance has depended most strongly on execution-oriented parts of the risk cycle—prioritizing correctly, implementing controls, and sustaining monitoring/reporting—rather than on identification alone. Finally, Table 8 has provided actionable diagnostic insight by highlighting the comparatively lower mean scores for monitoring/communication (3.71) and defect closure timeliness (3.62). Even though both have remained in the "high" band, they have represented the weakest areas relative to other dimensions, and they have also aligned with the regression finding that monitoring/communication has been a significant predictor of integrity. In combination, these findings have proven the objectives, supported the hypotheses, and created a coherent quantitative narrative showing how measured risk management practice quality has translated into stronger structural integrity performance indicators in the project environment.

DISCUSSION

The results have indicated that risk management capability has been strongly aligned with perceived structural integrity outcomes in large-scale global civil construction projects. In the tested model, the strongest positive effects have emerged from proactive risk identification and risk monitoring/controls, with mitigation planning and coordination acting as complementary drivers of integrity-related performance. This pattern has been consistent with construction risk scholarship that has framed risk as a project attribute shaped by organizational processes rather than a purely statistical deviation around cost or schedule. For example, the ongoing critique of overreliance on simplified probability–impact scoring and the call for more realistic, decision-oriented risk assessment tools has supported the idea that integrity outcomes improve when risk information is continuously translated into practical controls and resource commitments (Taroun, 2014). Likewise, evidence that construction risks vary across life-cycle phases and stakeholder perspectives has reinforced the need for systematic identification practices that remain active from early design to delivery, rather than being treated as a one-time planning exercise (Zou et al., 2007). The observed positive association between structured risk systems and outcomes has also fit the integration logic advanced in the construction domain: when risk management is linked with stakeholder management, it becomes easier to anticipate disruptions, stabilize decisions, and maintain control effectiveness across interfaces that typically destabilize megaproject execution (Yu et al., 2019). In that sense, the present findings have suggested that "structural integrity" has functioned not only as a technical end state but also as an operational consequence of risk governance quality, where stronger routines for identification, escalation, and control verification have produced higher integrity scores and fewer perceived breakdowns in compliance, workmanship, and tolerance management.

Figure 10: Discussion and Conclusion Summary



A key contribution of the findings has been the way monitoring and control intensity has differentiated higher-integrity performance from average performance, particularly under conditions of global supply chains, multi-tier subcontracting, and cross-jurisdiction compliance requirements. The empirical emphasis on monitoring has aligned with prior work arguing that complex projects require risk approaches that remain sensitive to interacting pathways rather than isolated "top risks." When risk pathways have been treated as interconnected—spanning design changes, procurement variability, inspection bottlenecks, and field execution constraints—control strategies have tended to improve because they address the mechanisms that generate defects rather than only documenting their symptoms (Taroun, 2014). This also has been coherent with life-cycle infrastructure research that has positioned reliability and resilience as outcomes of iterative assessment, inspection, and intervention decisions made under uncertainty. Under hazard exposure and deterioration processes, bridge and infrastructure integrity has been strengthened when reliability and risk thinking has been embedded in design/assessment routines, creating a continuous "assessment–monitor–act" loop rather than a static compliance posture (Love et al., 2010). Similarly, civil infrastructure resilience framing has suggested that performance protection requires coupling physical-system robustness with decision-system capacity—meaning that monitoring data, accountability structures, and prioritization rules have to be mature enough to translate warnings into timely actions (Brownjohn, 2007). In the present study's results, this logic has appeared in the higher regression weight assigned to monitoring/controls: respondents have rated integrity highest where inspection frequency, nonconformance handling, and risk-trigger thresholds have been consistent and auditable, which has implied that integrity has been managed through disciplined feedback rather than reliance on expert intuition alone.

The discussion has also shown that stakeholder and interface complexity has remained central to explaining why risk management has mattered for structural integrity, especially in global civil works where design authority, contractor capability, regulator expectations, and supplier performance intersect. The results have indicated that coordination and communication quality has amplified the effect of technical risk practices on integrity outcomes, which has mirrored earlier evidence that risk management effectiveness improves when "soft" capabilities support "hard" analytical routines. In broader project contexts, the soft side of risk management has been demonstrated to contribute meaningfully to project success and to reinforce formal risk tools by enabling timely escalation, cross-team alignment, and sustained adherence to decisions (de Ruijter & Guldenmund, 2016). Within construction-specific literature, integration between risk management and stakeholder management has been positioned as a mechanism for improving management outcomes because stakeholder actions and expectations frequently determine the emergence, amplification, and containment of risks during execution (Ko & Ni, 2005). Moreover, modeling work on stakeholder-associated risks has shown that risks do not sit independently inside technical packages; instead, they form networks tied to stakeholder behavior, coordination patterns, and governance arrangements, suggesting that integrity outcomes can degrade when stakeholder risk nodes are not actively managed as part of the risk system (Yana et al., 2015). Interpreting the present results through that lens, the higher integrity scores have plausibly reflected not only better engineering controls but also better alignment among designer intent, contractor execution, inspection enforcement, and change approval discipline. In practical terms, risk identification has mattered most when it has been socially "activated" through ownership clarity, communication cadence, and response protocols that have reduced ambiguity at interfaces where structural deviations typically emerge.

The findings have further suggested that life-cycle framing has been essential for understanding structural integrity as a risk-managed outcome rather than a late-stage quality inspection result. In global civil construction, integrity has not been produced solely at the point of testing or commissioning; it has been accumulated through earlier choices about design conservatism, material qualification, supplier vetting, construction method selection, and inspection regimes that have constrained defect introduction and defect propagation. This view has been strongly consistent with hazard-and-deterioration research emphasizing that infrastructure performance depends on decisions made under interacting threats (for example, earthquake, corrosion, and tsunami sequences) and that design and assessment should therefore incorporate risk and resilience logic across the asset life cycle (Serpell et al., 2015). It has also been consistent with civil infrastructure resilience scholarship arguing that system performance is shaped by both physical capacity and organizational capacity, with the latter including the ability to sense, interpret, and respond to emerging conditions before they become irreversible failures (Zavadskas et al., 2010). When mapped onto the present study's statistical relationships, this perspective has explained why mitigation planning and monitoring controls have been significant predictors of integrity outcomes: they represent the operational translation of life-cycle thinking into decisions about preventive actions, inspection priorities, and escalation thresholds. Importantly, the results have implied that "risk management" has been functioning as a quality-and-reliability governance layer, linking uncertainty identification to verifiable controls that protect structural performance under complexity. In that sense, the empirical pattern has supported a synthesized interpretation: structural integrity in megaproject environments has been a managed reliability outcome anchored in continuous risk feedback loops rather than a static compliance checkpoint.

From a practical standpoint, the implications have been actionable for senior risk leadership and design leadership—here discussed as the CISO/architect roles in the project governance sense (i.e., the executive owner of integrity and assurance governance, and the technical authority responsible for design intent and constructability). The results have indicated that projects with stronger integrity outcomes have institutionalized three practices: (1) risk-to-control traceability, (2) control verification cadence, and (3) escalation discipline when thresholds are breached. First, risk-to-control traceability has required that every "top risk" be mapped to explicit preventive and detective controls (inspection points, material testing requirements, design checks, hold points, and independent reviews) so that risk registers have become operational tools rather than reporting artifacts. Second, control verification cadence has required a planned rhythm of assurance activities—audits, site quality walks, supplier surveillance, and nonconformance trend reviews—because the findings have shown that monitoring intensity has been strongly associated with integrity scores. Third, escalation discipline has required that deviations trigger standardized responses (stop-work criteria, redesign triggers, supplier quarantine rules, and corrective-action closure gates) so that weak signals do not normalize into systemic defects. These recommendations have been aligned with the broader literature that has emphasized systematic risk processes across the project life cycle (Zou et al., 2010) and with integration arguments that have shown performance benefits when risk management is embedded into stakeholder coordination structures rather than executed in isolation (Szymański, 2017). Under global delivery conditions, these measures have been especially relevant because interface complexity has made integrity vulnerable to small coordination failures that compound across packages and jurisdictions.

The theoretical implications have pointed toward refining the research "pipeline" that links risk management constructs to structural integrity constructs in large-scale civil projects. Conceptually, the results have supported a socio-technical pathway where integrity performance is jointly produced by analytical routines (identification, assessment, mitigation planning) and relational routines (coordination, stakeholder alignment, communication), with monitoring/controls acting as the mechanism that converts both into measurable outcomes. This has resonated with the argument that risk management is not merely a toolbox of scoring methods but a governance capability that depends on how risk information is aggregated, interpreted, and acted upon (Zavadskas et al., 2010). It has also matched evidence that stakeholder-linked risk structures can be modeled as networks, implying that integrity failures may often reflect network-level breakdowns rather than isolated technical misjudgments (Zhang & Zou, 2007). From a modeling standpoint, the present study's regression-supported relationships have justified treating monitoring/controls as a mediating or near-proximal predictor of integrity outcomes, while identification and mitigation can be interpreted as upstream capability drivers whose effects are realized through disciplined verification. In addition, the integration literature has indicated that combining risk management with stakeholder management strengthens effectiveness, suggesting that theoretical models should represent stakeholder-interface variables not as background context but as active components shaping risk emergence and control compliance (Zou et al., 2008). Therefore, the study has strengthened the theoretical claim that structural integrity governance is best explained through an integrated risk-and-stakeholder capability model, rather than through a purely technical quality management lens.

Limitations have remained important when interpreting the discussion, and they also have clarified priorities for future research. Because the study has used a quantitative, cross-sectional survey design within a case-study setting, the relationships have reflected association patterns at a single observation window rather than verified causal dynamics across project phases. The reliance on Likert-scale perceptions has also meant that measured "integrity outcomes" have captured stakeholder judgments of performance robustness, which can be influenced by role expectations, visibility of defects, and differences in exposure to field conditions. Additionally, common-method effects can occur when predictor and outcome constructs are collected from the same respondents using similar response formats. Even with strong reliability evidence, future work has benefited from triangulating survey measures with objective indicators such as nonconformance rates, rework events, structural testing outcomes, and inspection closure times. The literature has provided clear direction for this progression:

risk management has been shown to depend on both hard systems and soft systems (Tserng et al., 2009), while construction risk scholarship has encouraged improving the realism of risk assessment and its linkage to decisions and outcomes (Sanderson, 2012). Future studies have therefore been well positioned to adopt longitudinal, multi-case designs spanning multiple global projects, enabling phase-based modeling (design–procure–build–commission) and testing whether monitoring/controls mediate upstream risk capabilities consistently over time. Such work can also explore how hazard exposure, regulatory regimes, and stakeholder network structure moderate the risk–integrity relationship, advancing theory and strengthening decision-grade guidance for large-scale global civil construction delivery.

CONCLUSION

In conclusion, this study has quantitatively evaluated the relationship between risk management effectiveness and structural integrity performance within the context of a large-scale global civil construction case setting and has demonstrated that integrity outcomes have been strongly associated with and predicted by the quality and consistency of risk governance practices. Using a five-point Likert-scale instrument and a cross-sectional survey dataset, the study has achieved its objectives by first establishing that both risk management effectiveness and structural integrity performance have been rated at high levels overall, confirming that formal practices and verification routines have been present and actively applied within the project environment. The reliability results have shown strong internal consistency for the key constructs, which has validated the use of composite indices and has supported confidence in the stability of measurement. Correlation analysis has revealed a strong positive relationship between overall risk management effectiveness and structural integrity performance, indicating that participants who have perceived stronger risk processes have also perceived stronger compliance discipline, inspection and testing rigor, materials quality control consistency, and defect closure timeliness. Regression modeling has further proven the hypotheses by showing that risk management effectiveness has explained a substantial proportion of the variance in structural integrity performance beyond respondent characteristics, thereby confirming that integrity has not been a purely technical outcome detached from managerial capability. In the dimensional analysis, the study has clarified that execution-oriented elements of the risk cycle—risk assessment and prioritization discipline, mitigation and response planning, and monitoring and communication routines—have contributed uniquely and significantly to structural integrity performance, while risk identification has remained positive but has contributed less uniquely when downstream execution has been included, suggesting that integrity assurance has depended most on what has been implemented, verified, and escalated after risks have been recognized. These findings have aligned with the study's conceptual framework by confirming that stronger risk governance has translated into stronger integrity assurance conditions through consistent control application and verification feedback loops, especially in areas that involve cross-interface coordination and corrective action closure. Overall, the research has provided empirical evidence that structural integrity performance in large-scale global civil construction projects has been measurably strengthened when risk management has been institutionalized as a disciplined, monitored, and communicated set of practices rather than treated as an isolated planning activity, and the results have reinforced the value of integrating risk registers, inspection and test plans, nonconformance management, and escalation thresholds into a single operational control system that has remained active across project phases.

RECOMMENDATION

The recommendations derived from this study have emphasized strengthening the operational linkage between risk management routines and structural integrity assurance controls so that risk governance has consistently produced verifiable integrity outcomes across the life cycle of large-scale global civil construction projects. First, project leadership has been advised to institutionalize risk-to-control traceability by mapping each critical risk to explicit preventive, detective, and corrective controls, including design verification checks, method-statement approvals, inspection and test plans, material certification requirements, and defined hold points, ensuring that every control has a named owner, due date, and evidence requirement for closure. Second, the project risk function has been recommended to upgrade risk assessment discipline by standardizing probability–impact criteria across work packages, requiring documented rationale for ratings, and using structured prioritization to align inspection intensity, independent verification resources, and contingency allocation with the most integrity-sensitive activities such as concrete placement, reinforcement fixing, post-tensioning, welding, grouting, and temporary works. Third, it has been recommended that mitigation planning be treated as an executable workstream rather than a documentation step, meaning that mitigation actions should have been integrated into the baseline schedule and procurement plans, resourced with dedicated personnel and budgets, and tracked through weekly control dashboards that have recorded progress, overdue actions, and risk-trigger thresholds. Fourth, because monitoring and communication have been among the most influential predictors of integrity performance, the study has recommended establishing a strict monitoring cadence that has included weekly risk-register refresh cycles, biweekly integrity assurance reviews, and monthly cross-party governance meetings in which trend data on nonconformances, test failures, and corrective-action closure times have been reviewed and escalations have been formally decided. Fifth, the QA/QC function has been advised to strengthen defect discovery and closure discipline by implementing standardized nonconformance classification, root-cause capture, corrective-action verification protocols, and closure time targets, coupled with independent audits that have confirmed that corrective actions have been technically adequate and documented in as-built quality records. Sixth, supply chain controls have been recommended to be tightened through supplier prequalification, batch-level traceability, storage-condition monitoring, and quarantine rules for suspect materials, because weaknesses in upstream material governance can become long-term durability risks that cannot be fully corrected after installation. Seventh, organizational capability development has been recommended through structured training and competency assurance for supervisors and inspectors, because frontline execution has been a primary location where integrity outcomes have been protected or compromised; training should have focused on integrity-critical workmanship, tolerance control, inspection readiness, and escalation behaviors under schedule pressure. Finally, project owners and regulators have been recommended to require independent third-party verification for high-consequence structural elements and to mandate transparent reporting of integrity assurance metrics—such as inspection pass rates, nonconformance frequency per inspection volume, and average closure times—so that accountability has been reinforced across all parties and so that integrity assurance has remained a measurable governance priority rather than an implicit expectation.

LIMITATIONS

The limitations of this study have primarily resulted from the research design choices and the practical constraints associated with collecting field-based evidence from a large-scale global civil construction setting. First, the study has used a quantitative, cross-sectional approach, and the data have been captured at a single point in time; therefore, the statistical relationships that have been observed between risk management effectiveness and structural integrity performance have reflected contemporaneous associations and predictive patterns rather than confirmed causal mechanisms unfolding across project phases. Because risk controls and integrity assurance routines can change as the project progresses from design to execution and commissioning, a single measurement window has limited the ability to confirm how relationships have evolved under shifting constraints, schedule pressure, and stakeholder turnover. Second, the study has relied on a five-point Likert-scale questionnaire, and the dependent construct—structural integrity performance—has been measured through stakeholder perceptions of compliance discipline, inspection and testing rigor, materials control, and defect closure performance; although these measures have been reliable, they have not been equivalent to direct physical integrity measurements such as structural test results, strength gain records, as-built deviation surveys, defect density audits, corrosion exposure verification, or long-term monitoring indicators. Third, the study has been subject to typical self-report limitations, including potential response bias, social desirability effects, and differences in visibility of defects and risk activities across roles; for example, QA/QC personnel and supervisors have been more exposed to nonconformance workflows than design staff, which has influenced the way integrity performance has been perceived and rated. Fourth, because the key predictor and outcome variables have been collected from the same survey instrument, common-method variance has been possible, meaning that shared measurement context has inflated correlation levels even when true relationships have been weaker; although reliability testing has supported internal consistency, the design has not fully separated measurement sources to eliminate this risk. Fifth, the case-study basis has strengthened contextual validity but has limited external generalizability; the results have reflected one bounded project environment with specific governance arrangements, contracting structure, regulatory conditions, and organizational culture, and the strength of relationships may not have transferred directly to projects with different procurement methods, stakeholder power distributions, or quality enforcement regimes. Sixth, the sampling strategy has been purposive with referral-based extension, and while it has ensured respondent relevance, it has not guaranteed probability-based representativeness; as a result, certain subcontract tiers or underrepresented roles may not have been captured fully, and non-response bias may have been present if individuals with weaker process compliance have participated less. Finally, although regression diagnostics have been checked at a practical level, the use of Likert composite indices has assumed approximate interval behavior and linearity, and the model has not tested alternative functional forms or potential endogeneity where higher integrity performance could have influenced perceptions of risk management quality.

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