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Enhancing Sustainable Project Performance through Strategic Design Compliance and Scheduling Management

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ABSTRACT

Building projects continue to experience persistent cost overruns, quality inconsistency, and schedule slippage, indicating a lack of integrated managerial mechanisms that translate control practices into sustainable performance outcomes. An integrated monitoring model is empirically tested using SEM–PLS based on survey data from 263 construction practitioners, triangulated with operational project records including Earned Value Management, S-curve analysis, and BIM 4D/5D outputs. The results demonstrate that DES exerts a strong influence on cost and quality performance, COM is the dominant driver of quality stability with indirect cost effects, and SCH is the primary determinant of time performance. The framework contributes by linking managerial control practices to measurable sustainability outcomes, offering a practical project-control architecture particularly relevant for developing-country construction contexts.

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INTRODUCTION

Building construction projects continue to exhibit persistent deviations in cost, quality, and time, with rework, non-conformities, and schedule slippage as recurring symptoms. In practice, three managerial levers consistently shape these outcomes: design management, specification/standards compliance, and scheduling control. Recent advances in Earned Value Management (EVM), tiered quality governance through Project Quality Plan (PQP) and Inspection & Test Plan (ITP), and Building Information Modeling (BIM) 4D/5D create the conditions for integrating these levers into an operational, predictive control system [1], [2].

In this study, design (DES) refers to documentation quality, design-freeze discipline, and change-control rigor; compliance (COM) covers specification conformance, material quality, and inspection/testing effectiveness, and scheduling (SCH) captures planning accuracy, schedule adherence, duration variance, and performance indicated by SPI and S-curves. [3], [4].

However, despite rich strands of prior work on cost overrun, quality mechanisms, and schedule performance, most studies treat these dimensions in isolation, limiting insight into their joint effects and interactions—particularly in developing-country contexts where shocks to design stability, materials, and workforce cadence are common. External factors such as economic volatility and regulatory change further perturb project baselines yet are rarely embedded within integrated monitoring frameworks [5]. Address this gap by proposing and empirically testing a unified DES–COM–SCH framework for building-project performance. The model integrates EVM (CPI/SPI), PQP/ITP, and BIM 4D/5D artifacts into a single, dashboard-ready control loop to enable timely detection of deviations and targeted corrective action. We employ SEM–PLS to estimate the magnitude and direction of effects on cost (CST), quality (QLT), and time (TIM), using reflective indicators and triangulating survey evidence with operational records [6].

The hypothesized mechanisms reflect established pathways in the literature: incomplete or ambiguous designs increase rework and cost variance, while disciplined design governance stabilizes budgets and supports quality [7], [8]. On the quality side, rigorous compliance—anchored in PQP/ITP, material approval, and documented inspections—reduces non-conformities and rectification costs, with BIM-enabled coordination improving information fidelity from design to site. For time performance, CPM/CCPM practices and SPI-based monitoring strengthen schedule reliability and enable earlier recovery when slippage emerges. Therefore expect DES to positively influence CST and QLT; COM to primarily drive QLT while stabilizing CST; and SCH to be the dominant driver of TIM [9], [10].

The findings of this study both align with and extend prior SEM-based research on construction project performance. Consistent with earlier studies, the results confirm that design-related factors are critical determinants of cost and quality performance. The strong influence of design management on cost performance observed in this study reinforces these conclusions, while offering more granular insight by embedding design within an integrated control framework rather than treating it as a standalone antecedent [11], [12].

Conceptually, the contribution is twofold: first, to integrate design governance, compliance systems, and scheduling discipline—often studied separately—into a single, testable model; and second, to operationalize this model with EVM, PQP/ITP, and BIM artifacts that make the mechanisms auditable in day-to-day project control. In contexts typical of developing economies, where external disturbances are frequent, such an integrated approach offers both explanatory power and practical guidance for achieving sustainable project performance through reduced rework, minimized waste, and improved schedule adherence [3], [4], [13].

Building construction projects frequently faced performance deviations manifested as cost overruns, inconsistent quality, and schedule slippage. Amid this complexity, three determinants repeatedly emerged as primary levers of outcomes—design management, specification/standards compliance, and scheduling control. Poorly controlled design changes typically triggered rework and cost growth, lapses in compliance degraded product quality and increased cost variance, and weak schedule discipline resulted in progressively delayed projects. Advances in Earned Value Management (EVM), structured quality practices via Project Quality Plan (PQP) and Inspection & Test Plan (ITP), and Building Information Modeling (BIM) 4D/5D created opportunities to integrate these determinants within a predictive, operational monitoring framework [2], [14], [15].

The problem addressed in this study was the absence of an empirical framework that simultaneously models the impacts of design, compliance, and scheduling on building-project performance in developing-country contexts. Prior studies typically examined these factors in isolation—linking design to cost overrun, assessing quality mechanisms, or evaluating schedule performance—but seldom tested an integrated model capable of capturing interactions and joint effects among the determinants. Concurrently, external variables—economic volatility and regulatory change—often disrupted design stability, material availability, and scheduling cadence, yet were rarely accommodated within comprehensive monitoring frameworks [5], [16]

Grounded in that theoretical and empirical footing, the article contributed to construction management scholarship by placing the three determinants—design, compliance, and scheduling—at the core of performance analysis. The proposed framework not only unified EVM, PQP/ITP, and BIM within a single monitoring system but also provided an operational rationale for enforcing design freeze, layered compliance governance, and SPI-based schedule discipline. This approach was expected to strengthen the organizational capability to anticipate deviations earlier, quantify the consequences of change, and execute timely, evidence-based corrective actions.

RESEARCH METHOD

This section outlines the research design, with an explicit focus on three core determinants—design (DES), compliance (COM), and scheduling (SCH)—and their relationships with building-project performance across cost (CST), quality (QLT), and time (TIM). All procedures were aligned with the study title, "Design, Compliance, and Scheduling as Determinants of Building Project Performance: A SEM–PLS Approach," emphasizing traceability, replicability, and adherence to quantitative reporting standards in construction management research.

2.1 Conceptual Model and Analytical Approach

The conceptual model positioned DES, COM, and SCH as exogenous latent constructs affecting the endogenous performance constructs CST, QLT, and TIM. This framework rested on evidence that (i) design documentation quality and change control reduced rework and cost variance, (ii) material/process compliance sustained quality consistency, and (iii) schedule discipline improved execution timeliness. We tested causal paths and predictive capacity using structural equation modeling—partial least squares (SEM–PLS), which is appropriate for models with many indicators, non-normal distributions, and a predictive orientation. PLS analysis proceeded in two stages: measurement model assessment and structural model evaluation.

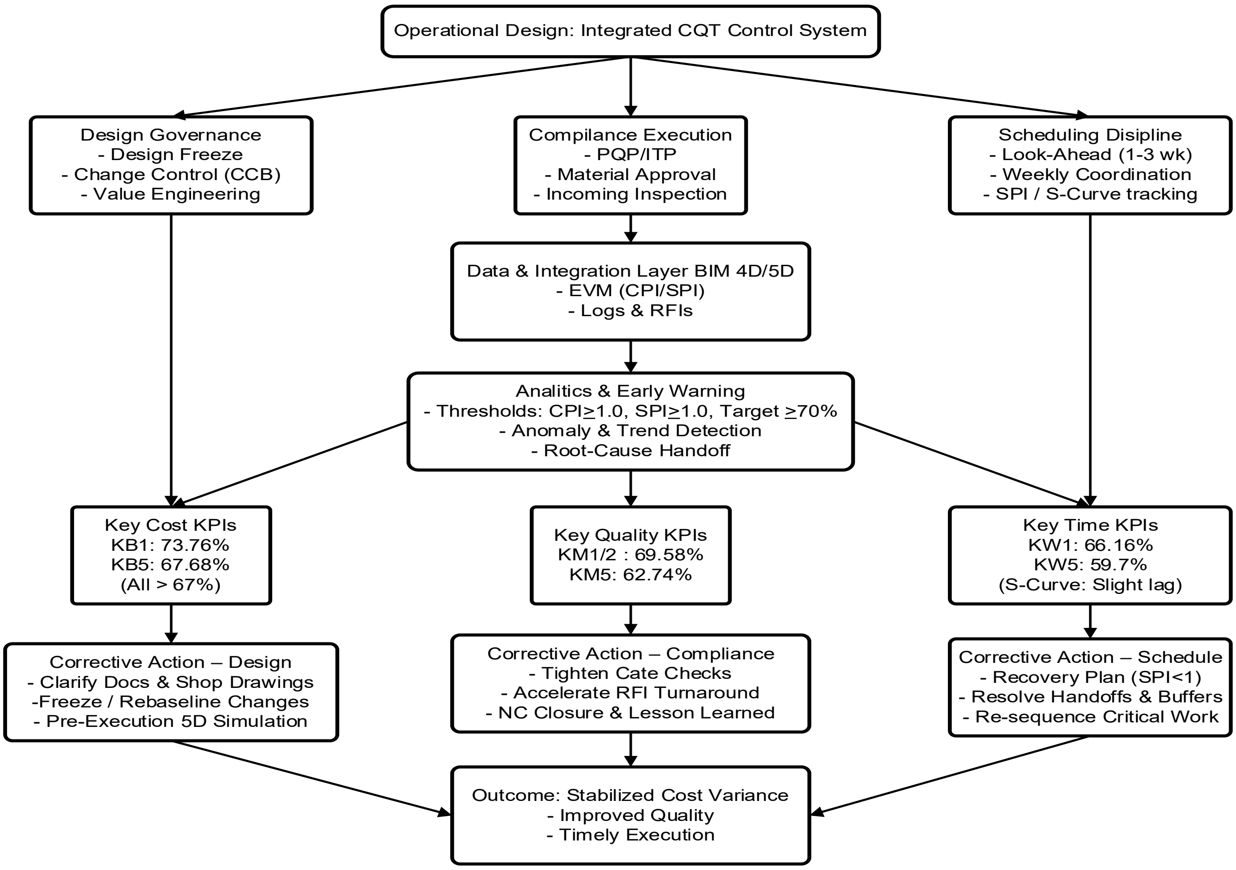

Figure 1. The Concept Design

Figure 1 illustrates a diagram outlining an Integrated CQT Control System, which links three levers—Design Governance (DES), Compliance (COM), and Scheduling (SCH)—to project outcomes in Cost (CST), Quality (QLT), and Time (TIM). Inputs (design freeze/CCB/VE, PQP–ITP, and inspections) feed a Data & Integration layer (BIM 4D/5D, EVM), which powers Analytics & Early Warning with thresholds of CPI ≥ 1.0, SPI ≥ 1.0, and target ≥ 70%. KPI cards show: Cost KB1 73.76%, KB5 67.68% (all ≥67%); Quality KM1/2 69.58%, KM5 62.74%; Time KW1 66.16% → KW5 59.70% (slight S-curve lag). Findings trigger targeted actions: Design (clarify documents/shop drawings, freeze/rebaseline, 5D simulation), Compliance (tighten gate checks, expedite RFIs, close NCs), and Schedule (develop a recovery plan when SPI < 1, address handoffs/buffers, resequence critical work). The closed loop delivers stabilized cost variance, improved quality conformance, and timely execution.

2.2 Research Design and Context

The Research adopted a quantitative, observational survey design to capture ongoing project practices and enable generalization to the practitioner population. Primary data were collected through a structured questionnaire, while secondary evidence comprised EVM metrics (CPI/SPI), S-curves, and BIM 4D/5D artifacts. This multi-source strategy was intended to enhance construct validity for both determinants and outcomes, while strengthening triangulation between respondent perceptions and operational project records.

2.3 Population, Sample, and Recruitment

The target population comprised building-project practitioners directly involved in technical and administrative decision-making (contractors, project managers, and supervising consultants). The final sample consisted of n = 263 respondents selected through purposive sampling, with inclusion criteria of at least 5 years of experience and current involvement in building projects. We excluded incomplete or inconsistent responses. This approach reflected common construction-research practice prioritizing domain competence while maintaining role representativeness.

2.4 Instruments, Operationalization, and Data Quality

The questionnaire instrument measured three determinant constructs and three performance constructs. DES was operationalized through items that reflected documentation quality, change-control effectiveness, and design-freeze discipline. COM covered specification conformance, material quality, and the effectiveness of PQP/ITP. SCH captured planning accuracy, cross-disciplinary coordination against the work plan, and execution discipline, as reflected in schedule tracking and SPI. Outcome constructs followed standardized indicators (KB1–KB5 for cost, KM1–KM5 for quality, KW1–KW5 for time). Because some field performance items were dichotomous ("able/unable"), we coded responses as binary and then normalized them. Determinant items used multi-point agreement scales to capture practice intensity. Content validity was established via construction-management expert judgment, followed by a pilot test (n = 30) to assess wording clarity and internal consistency. Data cleaning addressed outliers, anomalous response patterns, and listwise deletion for unrecoverable missingness.

2.5 Data Collection and Secondary Evidence Handling

Data collection proceeded in two modes—on-site at project locations and via an online survey—to encompass a diverse range of organizational contexts and work types. To improve convergent validity, we retrieved secondary records (monthly CPI/SPI, S curves, and relevant BIM 4D/5D outputs aligned to each respondent's project phase). These documents verified reported practices for DES, COM, and SCH, and informed the interpretation of outcome indicators.

2.6 Analytical Setup and Bias Control

We first conducted descriptive analyses to profile respondents and indicator distributions. PLS estimation began with the measurement model, which was assessed for convergent validity via Average Variance Extracted (AVE > 0.80), composite reliability (CR > 0.70), and multicollinearity via Variance

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Inflation Factor (VIF < 4.5). Discriminant validity was assessed using cross-loadings and HTMT. To mitigate common method bias, we separated the determinant and outcome blocks in the instrument, anonymized responses, and conducted a single-factor test at the exploratory stage. Software and resampling. Estimation and resampling were performed in SmartPLS 4 (desktop) using 5,000 bootstrapping resamples, two-tailed tests, and bias-corrected 95% confidence intervals to stabilize standard errors and p-values Descriptive statistics and data screening were conducted in SPSS (v. 29) and spreadsheets.

Structural model and predictive assessment. In the structural model, we reported path coefficients, R^2, f^2, and Q^2 (blindfolding). Out-of-sample predictive power was evaluated using PLSpredict in SmartPLS 4, generating case-level predictions for the endogenous constructs and benchmarking RMSE/MAE against a linear model (LM). Positive Q^2_predict and lower PLSpredict errors relative to LM were interpreted as evidence of practical predictive relevance. The predictive use of schedule indices and model-based forecasting in construction projects is consistent with prior studies that employed SPI-based prediction and data-driven validation [17], [18]. Global fit and robustness. We inspected SRMR as a saturated model fit index and performed multi-collinearity and residual diagnostics. Sensitivity analyses re-estimated paths after removing high-leverage cases and after alternative codings of dichotomous outcome items.

2.7 Role of EVM, S Curves, and BIM 4D/5D

We employed EVM metrics as quantitative anchors for SCH and as corroborative evidence for TIM and CST through SPI and CPI. S curves contextualized progress dynamics against plan, enabling the assessment of day to week schedule discipline not fully captured by the survey.

BIM 4D/5D served to test cross disciplinary consistency, quantify change consequences pre execution, and validate DES and COM claims via clash detection logs, model updates, and quantity–cost linkages. Integration of EVM and BIM has been shown to strengthen tracking, forecasting, and real-time decision support in construction projects, while BIM-enabled coordination reduces rework and supports sustainability through waste minimization [19]

2.8 Ethics, Reproducibility, and Project Flow

Participation was voluntary, following informed consent, and personal and organizational identities were anonymized. For reproducibility, the appendix included construct–indicator maps (DES, COM, SCH, CST, QLT, TIM), item-coding keys, and software settings. The study flow comprised model/indicator formulation, content validation and pilot testing, primary/secondary data collection, descriptive analysis, measurement-model assessment, structural-model evaluation, and synthesis for practical implications.

2.9 Methodological Limitations

Limitations primarily concerned perception-based survey data, a focus on small-to-medium building projects, and potential external moderators (economic and regulatory) that were not explicitly modeled. To mitigate these issues, we triangulated with secondary project evidence, implemented common-method safeguards, and recommended further testing on mega projects using both cross-sectional and longitudinal designs.

2.10 Operational → Environmental KPI Mapping and Stakeholder Linkages

To align operational performance with environmental and stakeholder outcomes (in line with business strategy and governance perspectives), we mapped each endogenous KPI to explicit environmental KPIs and stakeholder value pathways.

Cost performance (CST) was linked to material-waste intensity and rework-related waste/emissions, as reductions in design-driven rework and claims through BIM coordination decrease concrete/steel waste and associated environmental burdens (Hosny et al. 2023; Noviani et al. 2022). Quality performance (QLT)—via specification conformance and effective PQP/ITP—was linked to regulatory compliance and environmental quality controls, supported by BIM-enabled compliance checking that flags deviations early (Gharbia et al. 2023; Villaschi, Carvalho, and Bragança 2022). Time performance (TIM)—via schedule adherence/SPI—was linked to temporary works efficiency and energy/emissions from idle plant and prolonged site occupancy. Time performance (TIM)—via schedule adherence/SPI—was linked to temporary works efficiency and energy/emissions from idle plant and prolonged site occupancy. Improving SPI reduces idle time and resource waste, thereby strengthening sustainability performance. Faster and more reliable project delivery also minimizes disruptions to surrounding communities, lowers fuel consumption from equipment and logistics operations, and improves labor productivity. Through BIM-enabled scheduling and simulation, project teams can identify potential delays earlier, optimize sequencing activities, and support lean construction principles that contribute to environmental, economic, and operational sustainability outcomes. Improving SPI reduces idle time and resource waste, thereby strengthening sustainability performance [20], [18].

At the governance/strategy layer, design governance (DES), compliance systems (COM), and scheduling discipline (SCH) operationalized corporate sustainability aims by embedding coordination, transparency, and risk control in day-to-day execution; BIM's role in information centralization and sustainability analytics supports this alignment. These mappings make explicit how technical KPIs cascade to environmental indicators valued by regulators, clients, and communities, thereby connecting operational control with stakeholder-oriented outcomes [21], [22]

RESULTS & DISCUSSION

This section reports empirical evidence demonstrating that design (DES), compliance (COM), and scheduling (SCH) are strategic determinants of sustainable project performance across cost (CST), quality (QLT), and time (TIM). We present: (i) measurement-model diagnostics, (ii) structural-path results with determinant-specific findings, (iii) predictive/robustness checks, and (iv) cross-dimensional insights linking managerial levers to sustainability outcomes (rework and waste reduction, schedule energy/idle-time effects).

3.1 Measurement Model Assessment (SEM–PLS)

All latent constructs met conservative quality thresholds. Average Variance Extracted (AVE) exceeded 0.80, indicating convergent validity; Composite Reliability (CR) was above 0.70 for all constructs, confirming internal consistency; and Variance Inflation Factor (VIF) values were < 4.5, indicating no problematic multicollinearity. Discriminant validity was supported by cross-loadings and

HTMT values below recommended cutoffs. The SRMR (saturated model) fell within the commonly accepted < 0.08 range. These diagnostics justify proceeding to structural-path interpretation for DES, COM, and SCH as predictors of CST, QLT, and TIM.

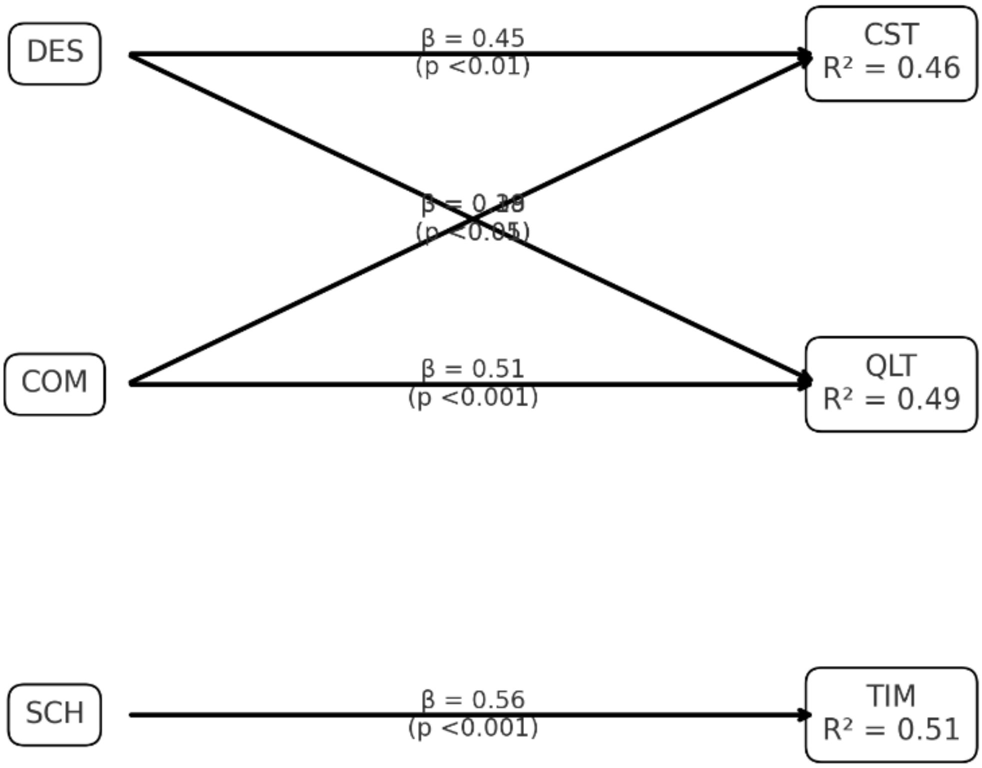

Figure 2. Structure Model

Figure 2 illustrates the SEM-PLS diagram, which shows three primary drivers—DES, COM, and SCH—predicting project outcomes in CST, QLT, and TIM. The strongest, significant paths are DES→CST ($\beta = 0.45$, $p < 0.01$), COM→QLT ($\beta = 0.51$, $p < 0.001$), and SCH→TIM ($\beta = 0.56$, $p < 0.001$); smaller cross-effects (≈approximately 0.20, $p < 0.05$) suggest secondary influences across domains. Endogenous fit is solid (R^2: CST=0.46, QLT=0.49, TIM=0.51), indicating the model explains ~46–51% of variance. In short, design governance drives cost control, compliance drives quality, and schedule discipline governs timeliness.

3.2 Structural Model: Main Effects and Explained Variance

Figure 2 depicts the SEM–PLS model. The strongest and statistically significant paths were:

DES → CST: $\beta = 0.45$, $p < 0.01$
COM → QLT: $\beta = 0.51$, $p < 0.001$
SCH → TIM: $\beta = 0.56$, $p < 0.001$

Smaller cross-domain effects (≈0.20, $p < 0.05$) suggest secondary but meaningful spillovers. The model explains substantive variance in outcomes: R^2(CST) = 0.46, R^2(QLT) = 0.49, R^2(TIM) = 0.51.

3.3 Design → Cost and Quality

Indicator patterns corroborate the DES effects on cost and quality (Table 1; Figure 3). Cost-estimation accuracy (CP1) is the top-performing indicator (73.76% able), while design-change cost effects (CP5) are relatively weaker (67.68% able). All cost indicators exceed 67%, indicating comparatively sound cost control in small-to-medium projects. On the quality side (Table 2), specification compliance (QP1) and material quality (QP2) are highest (69.58%), whereas design compliance (QP5) lags (62.74%).

Interpretation. The DES → CST and DES → QLT paths are positive and significant. Tighter design governance—design freeze at key gates, transparent change-control board (CCB), and value engineering prior to execution—reduces rework exposure and stabilizes cost variance; clearer documentation and coordinated shop drawings raise field conformance. In practice, 5D BIM simulations that link quantities and budgets make change consequences auditable and disincentivize low-visibility scope shifts.

Table 1. The COD and BOD values for the last week of the month (final clarification output).

Code	Indicator	Able (n)	Not Able (n)	Total (n)	Able (%)	Not Able (%)	95% CI (Able %)	Target (%)	Gap to Target (pp)	Status vs Target	Rank (by Able %)
CP1	Cost Estimation Accuracy	194	69	263	73,76	26,24	68.45–79.08	67	6,76	At/Above	1
CP2	Frequency of Cost Overruns	189	74	263	71,86	28,14	66.43–77.3	67	4,86	At/Above	2
CP3	Cost Variance	181	82	263	68,82	31,18	63.22–74.42	67	1,82	At/Above	3
CP4	Management Evaluation System	180	83	263	68,44	31,56	62.82–74.06	67	1,44	At/Above	4
CP5	Design Change Cost Effects	178	85	263	67,68	32,32	62.03–73.33	67	0,68	At/Above	5

Table 2. Quality Performance Indicators (QP1–QP5)

Code	Indicator	Able (n)	Not Able (n)	Able (%)	Not Able (%)	95% CI (Able %)	Target (%)	Gap to Target (pp)	Status vs Target	Rank (by Able %)
QP1	Specification Compliance	183	80	69,58	30,42	64.02–75.14	70	-0,42	Below	1
QP2	Material Quality	183	80	69,58	30,42	64.02–75.14	70	-0,42	Below	1
QP3	Workmanship Quality	160	103	60,84	39,16	54.94–66.74	70	-9,16	Below	3
QP4	Inspection & Testing	158	105	60,08	39,92	54.16–66.0	70	-9,92	Below	4
QP5	Design Compliance	165	98	62,74	37,26	56.89–68.58	70	-7,26	Below	2

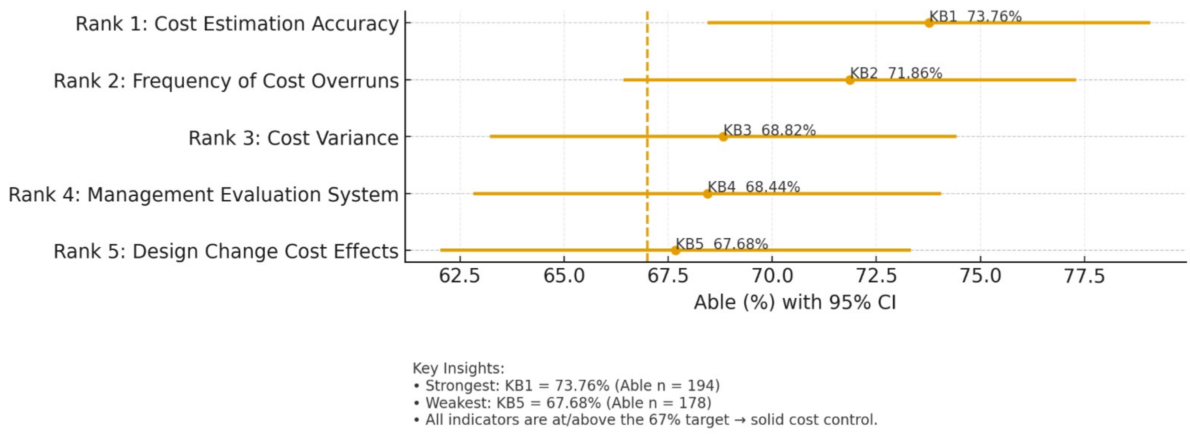

Figure 3. Cost performance by indicator (CP1–CP5).

3.4 Scheduling Determinant → Timeliness of Execution

Time performance summarized in Table 3 and Figure 5 showed a stepwise decrease from planning accuracy (KW1 = 66.16%), schedule adherence (KW2 = 65.78%), delay frequency (KW3 = 64.64%), and duration variance (KW4 = 60.84%) to the scheduling performance index (KW5 = 59.7%). The S-curve indicated that realized progress was slightly lagging behind the plan yet converging toward the final target. Structurally, SCH → TIM was positive and significant, confirming that SPI-driven schedule discipline—supported by look-ahead planning and weekly cross-work-package coordination—was the primary determinant of timely execution.

Table 3. Time Performance

Code	Indicator	Value (%)	Target (%)	Gap to Target (pp)	Status vs Target	Rank (by Value)	Interpretation
KW1	Planning Accuracy	66,16	70	-3,84	Below	1	Forecasting bias present; calibration needed.
KW2	Schedule Adherence	65,78	70	-4,22	Below	2	Weekly adherence below target; enforce look-ahead.
KW3	Delay Frequency	64,64	70	-5,36	Below	3	Recurring micro-delays; tighten handoffs.
KW4	Project Duration Variance	60,84	70	-9,16	Below	4	Variance high; adjust buffers and re-baseline.
KW5	Scheduling Performance Index	59,7	70	-10,3	Below	5	SPI discipline weak; strengthen coordination.

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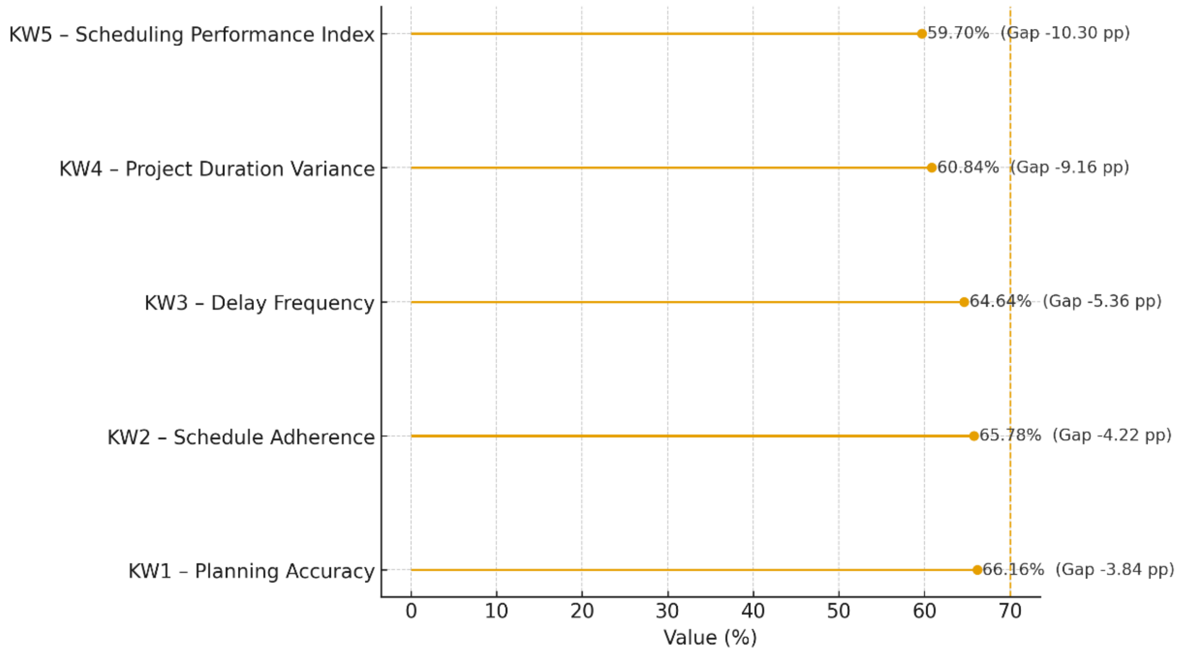

Figure 5. Time Performance

3.5 Cross Dimensional Insights and Model Predictive Power

Cross-dimensional analysis revealed mutually reinforcing causal relations among the determinants. Strong DES reduced rework and eased pressure on SCH by lowering execution uncertainty. Effective COM prevented non-conformities, thereby avoiding rescheduling and out-of-sequence work that would propagate delays. Conversely, deviation in one determinant tended to ripple through the others; poorly managed design changes, for example, worsened KB5, depressed KM5, and aggravated KW3–KW5.

At the model level, R^2 values for CST, QLT, and TIM fell within the substantive range, indicating strong predictive power. Positive Q^2 supported out-of-sample predictive validity. Collectively, the evidence reinforced that an integrated design–compliance–scheduling framework—supported by EVM (CPI/SPI), PQP/ITP, and BIM 4D/5D—was effective in improving cost efficiency, quality consistency, and on-time delivery in building projects.

Overall, the study extended theoretical understanding and provided a practical basis for treating the three determinants—design, compliance, and scheduling—as the most consequential managerial levers for cost–quality–time outcomes. We recommended an integrated dashboard that combines CPI/SPI, quality-gate status (PQP/ITP), and design-compliance indicators, with BIM 4D/5D artifacts embedded at decision points to sustain project performance.

DISCUSSION

This discussion focused on three determinants, positioned as the primary levers of building-project performance—design, compliance, and scheduling—and explained how they related to cost, quality, and time outcomes within a SEM–PLS testing framework. This emphasis aligned with the study’s title, as the empirical results indicated that variations in design practices, degree of compliance, and schedule discipline produced performance deviations consistent with the literature and with modern project-control mechanisms based on EVM, PQP/ITP, and BIM 4D/5D. References to Tables 1–3 and the S-curve were retained to maintain continuity with the results and to demonstrate correspondence between the survey data and operational performance indicators.

4.1 Design as a Determinant of Cost and Quality

Results in Table 1 showed that cost-estimation accuracy was the dominant strength, whereas the cost effects of design changes were the weakest indicator. This pattern suggests a relatively reliable estimating capacity, offset by high sensitivity to design changes. The literature associated poorly controlled design changes with rework, scope adjustments, and additional costs, which reduced budget efficiency and potentially depressed field quality. These findings were consistent with studies reporting that rework and change orders due to incomplete or ambiguous design documentation contributed significantly to cost overruns and quality degradation [23]. In practice, institutionalized design-freeze, a firm change-control board, and value-engineering procedures prior to execution served as key mechanisms to stabilize costs without sacrificing quality. BIM 5D played a crucial role at this stage by simulating the financial consequences of design alternatives, mapping quantity–cost linkages, and visualizing the impacts on work sequencing, allowing for more rational evaluation of change decisions.

The causal relationships estimated in the SEM–PLS structural model supported the thesis that improved design governance reduces cost variance and increases quality conformance.

4.2 Compliance as a Determinant of Quality Consistency and Cost Stability

The data in Table 2 indicate that specification compliance and material quality scored the highest, whereas design compliance was relatively lower. This distribution suggested that quality-control mechanisms at material-receiving gates and inspection processes were effective; however, gaps remained in translating design into construction. The literature emphasizes the systematic role of the Project Quality Plan and Inspection & Test Plan in fostering evidence-based compliance, with each work stage linked to acceptance criteria and documented inspections [24] .

Weaknesses in design compliance indicated that RFI cycle time, clarity of drawing revisions, and discipline in model updates were the primary differentiators. Studies highlighting the quality of technical documentation and the clarity of shop drawings found strong links to successful field implementation [25]. Cross-disciplinary BIM integration provided a single environment to detect clashes, track changes, and ensure that the information used on-site represented the latest version. Within the structural model, the path from compliance to quality was expected to show a strong positive effect, whereas the influence on costs was typically manifested through reduced cost of quality failures and stabilized indirect costs. Accordingly, the compliance determinant operated by preventing defects and harmonizing technical information, thereby lowering the likelihood of rework and quality-related claims.

4.3 Scheduling as a Determinant of Timely Execution

The indicator sequence in Table 3 showed a downward trend from planning accuracy to the scheduling performance index. This pattern suggested that a well-planned initial approach did not necessarily translate into consistent execution discipline throughout the project. The literature underscored that field factors—such as cross-subcontractor coordination, skilled-labor constraints, and external disruptions—could shift the realized S-curve away from the plan. Here, the Schedule Performance Index became crucial as a predictive indicator sensitive to cumulative delays, enabling earlier corrective interventions before deviations widened [9], [24]. Critical-path and critical-chain scheduling provided a framework for constructing buffers, focusing attention on key activities, and reducing out-of-sequence work. When SPI was combined with weekly coordination meetings and disciplined look-ahead planning, schedule recovery capability increased and carry-over risks diminished. In the SEM–PLS model, the path from scheduling to time performance was expected to be positive and significant, indicating that time indicators were not merely attributes of schedule adherence but also reflected the quality of cross-team orchestration. This orchestration quality is interconnected with the design and compliance determinants; a stable design reduces the need for rescheduling, while high compliance prevents rework that disrupts the execution rhythm.

4.4 Cross Dimensional Interactions and CQT Dynamics

Interactions among design, compliance, and scheduling shaped mutually influencing cost, quality, and time dynamics. Unmanaged design changes shifted work sequencing, increased coordination burden, and raised the likelihood of non-conformities; these combined effects triggered delays and cumulative cost escalation. Conversely, strong compliance through PQP/ITP reduced quality variation, stabilized productivity, and eased schedule control. The time–cost–quality literature framed these interactions as trade-offs requiring systematic management, and this study's results showed that addressing the upstream determinants—design, compliance, and scheduling—was an effective way to govern downstream trade-offs [8], [26].

4.5 SEM–PLS Model Performance and Theoretical Contributions

Measurement-model adequacy was reflected in AVE values exceeding conservative thresholds, strong composite reliability, and low VIF, while discriminant validity was confirmed through cross-loadings and HTMT. At the structural level, R^2 values categorized as substantial for cost, quality, and time indicated predictive power relevant to managerial decision-making. A prominent theoretical contribution lay in positioning the design–compliance–scheduling triad as exogenous constructs that explained project-performance variance in an empirically consistent manner. This position extended the literature, which often focused on single dimensions, by offering a framework that unified the three determinants within a single, testable, and replicable model. Considering external factors—such as economic dynamics and regulatory changes—was important because they could moderate inter-variable relationships; therefore, enriching the model with external moderators constituted a logical theoretical extension for developing-country project contexts.

4.6 Practical Implications and Implementation Orchestration

Practical implications flowed directly from the operating mechanisms of the three determinants. Strengthening design governance requires consistent documentation, a design freeze at critical decision points, and transparent change-control processes with BIM 5D-based cost and time justification. Compliance orchestration required a tight coupling between PQP/ITP, incoming inspection, and quality-gate status against the work plan, ensuring that production decisions were always linked to current evidence of conformance. Schedule discipline is enforced using SPI as a day-to-week control metric, linked to S-curves and look-ahead plans, supported by consistent cross-work-package coordination forums.

Strengthening organizational capability also depended on EVM/BIM data literacy across all levels—from planners to site executors—so that indicator interpretation was consistent and corrective responses were not delayed. The roles of owners and supervising consultants were crucial in ensuring that design requirements, material approvals, and schedule targets were bound in operational agreements, enabling evidence-based performance evaluation. This approach guided the formulation of internal policies, quality standards, and contractual instruments that aligned economic incentives with technical discipline, allowing the three determinants to be managed as a coherent control system rather than through reactive, ad-hoc interventions.

CONCLUSION

This study positioned design governance (DES), compliance systems (COM), and scheduling discipline (SCH) as strategic governance mechanisms that reliably predicted building-project performance while creating clear pathways to environmental improvement. Beyond statistically significant paths to cost, quality, and time, the triad can be institutionalized within an enterprise environmental-management architecture so that operational controls also deliver environmental KPIs. For governance and strategy, the results provide a replicable blueprint: align DES–COM–SCH with the organization's environmental objectives, integrate controls into the environmental management system, and utilize predictive SEM–PLS evidence to target the highest-leverage failure modes (design changes, schedule reliability). Future research should quantify environmental co-benefits alongside performance—e.g., energy intensity, waste intensity, and embodied carbon deltas—test regulatory and market pressure moderators, and evaluate portfolio-level outcomes across delivery models and regions. Such work will connect project-level governance to firm-level environmental performance more directly, advancing the mission of Business Strategy and the Environment while informing stakeholders, including owners, regulators, and communities. Future research recommendations have been explicitly aligned with the study's methodological and data limitations.

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