

The Impact of Digital Transformation on Project Cost Management

Prepared by:

Hussam Abubakr Zainalabidin

Student ID:

232002317

Supervised by:

Dr. Alfaisal Abdelhameed Mohamed

Dr. Fayez Ali Jrad

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ABSTRACT

This study examined how employee-observed digital capabilities relate to perceived project cost-management effectiveness in Saudi Arabia. A quantitative, cross-sectional survey generated 100 complete eligible responses from employees and managers with recent experience of digitally supported project-cost activities. The model assessed digital cost-data integration, real-time visibility and analytics, and digital workflow for change and cost control as predictors of cost-information reliability, early variance detection, forecast usefulness, change traceability, timely response and overall cost-management effectiveness. The four composite scales demonstrated acceptable to strong reliability (Cronbach's alpha = .741 to .903). The simultaneous regression model was significant, $F(3, 96) = 28.55$, $p < .001$, and explained 47.2% of the variance in perceived project cost-management effectiveness. Digital cost-data integration ($B = .267$, $p < .001$) and real-time visibility and analytics ($B = .549$, $p < .001$) were significant positive predictors. Digital workflow for change and cost control was positively related at the bivariate level but did not make a statistically significant unique contribution in the full model ($B = .116$, $p = .178$). The managerial-versus-non-managerial comparison was not significant ($p = .624$). The findings suggest that digitalization is most valuable when cost data are connected to wider project information and translated into timely forecasts and early warning. Recommendations focus on integrated data architecture, forecast governance, traceable change records, user capability, data ownership and post-project learning. The design supports association rather than causal attribution.

Keywords: Digital transformation; project cost management; cost-data integration; forecasting; change control; Saudi Arabia

AUTHOR'S DECLARATION

I declare that this thesis is my own academic work and that all ideas, evidence and words derived from other sources have been acknowledged through in-text citation and the reference list. The survey data, analysis and interpretation presented in this thesis are reported honestly and have not been fabricated or manipulated.

Student signature:  Date: 17/07/2026

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CHAPTER ONE: GENERAL FRAMEWORK OF THE STUDY

1.1 Introduction and Background

Project cost management transforms scope, schedule, resources, contracts, risks and approved changes into information that can be used to plan and manage costs. How well it works is as much a function of the speed, consistency and traceability of commitments, actual costs, progress and changes as of the initial estimate. While traditional spreadsheet and document-based systems can be used to support this, if data is spread across multiple files, and if it is not updated in real-time or if it requires manual reconciliation, the project team may not be able to detect the variance as it develops, and take the necessary action before it becomes too late.

Digital transformation provides capabilities that have the potential to change this control cycle. This study is not about a specific software product, but about digital transformation. It is about the use of digitally integrated data, timely analyses and digitally supported control workflows in the organization. The difference is based on digital-transformation research that considers technology as a component of a larger process, structure and value creation transformation (Vial, 2019; Verhoef et al., 2021). A cost application that runs independently of the schedule, procurement and change information can digitalize a task without changing the cost management.

Digital cost data integration is the first predictor. It's about whether cost data is related to pertinent project sources, kept up to date and available without too much duplicate information or reconciliation. Research in building-information and project-delivery indicates that digitization alters the relationship of information and coordination, rather than just the file format (Whyte, 2019). Finance, procurement, planning, project controls, engineering and operations employees can see if the right information is being shared between the right people, even if they don't have the complete confidential budget.

Real-time cost visibility and forecasting analytics is the second predictor. It is about the timely provision of cost/status information, early detection of variance and support for adjustment of the final cost expected. The research on earned value management (EVM) has shown that it is important to include cost and schedule status in the management process, as well as to estimate the probable results of the project, and not only relying on the historical cost incurred (Batselier and Vanhoucke, 2015; Bryde, Unterhitzenberger and Joby, 2018). The measure in the present is still technology neutral. A dashboard can only be helpful if the information that backs it is up to date, and the signals it provides are relevant to decisions.

Digital workflow and change-control support is the third predictor. Commitments, approvals, scope changes, contract modification and corrective actions impact project costs. Digital workflows can enhance traceability by capturing the person who submitted, reviewed, approved and communicated a decision. They can also send variance information and corrective tasks. Automation is not a cure-all that is assumed to be good: a poorly designed workflow can speed up the wrong process. The construct thus focuses on the functions of control that are visible to employees, and not just on the automation itself.

Perceived project cost-management effectiveness (PCME) is the dependent variable. It is multi-dimensional and has cost-information reliability, early variance detection, forecast usefulness, change traceability, response timeliness, and overall effectiveness. The outcome is not the same as final cost variance. An authorized scope expansion is a legitimate way for a project to go over an early baseline, and deferred work or reduced quality is a legitimate way for a project to stay within budget. The effectiveness of a cost-management process is not about whether a project completes within the first approved amount, but the quality of the information and process itself.

Saudi Arabia is a relevant context as organisations are providing portfolios in construction, energy, infrastructure, manufacturing, information technology, healthcare and public services and are investing in digital platforms and data capabilities. In large and complex projects, there is a real need for timely and integrated cost information. However, executives and private final accounts are not easily accessible. A wide-ranging employee survey can gather evidence from users of systems, record-keepers, change processors and cost reporters. Eligibility screening guarantees that respondents have first-hand experience with a recent digitally-supported project.

1.2 Problem Statement

While delayed cost information and poor forecasting continue, organizations can still experience enterprise resource planning, project-management information systems, building information modelling, dashboards, automated approvals, or cloud collaboration. Technology may continue to be siloed within finance, schedule, procurement, design and contract. Manual reconciliation of data can be repeated, dashboard values may be stale, and changes can be made without the cost impact being recorded. The real-world issue is the difference between technology and a project's cost-management capability.

The empirical challenge was to measure digital cost-management practice without requiring confidential budgets, final accounts or forecast-error records that many employees could not legitimately access. The questionnaire therefore focused on observable practices: whether data were connected, updated and visible; whether emerging variance was identified; whether forecasts were supported; whether approvals and cost effects were traceable; and whether corrective actions were coordinated. This design enabled informed participation across role levels while keeping the outcome explicitly perceptual rather than presenting it as an audited financial result.

There are also individual strands of literature on digital transformation, project information systems, building information modelling, earned value and cost forecasting. A sector-specific Saudi model for employees is still helpful, as it combines three capabilities in one test and still has a cost-management outcome. The study investigates the relationship between digital cost data integration, real-time visibility/forecasting analytics and digital workflow/change-control support with perceived project cost-management effectiveness. While the cross-sectional prediction is discussed, no causal “impact” is asserted from a one-time non-probability survey.

1.3 Research Objectives

1. To examine the relationship between digital cost-data integration and perceived project cost-management effectiveness among project employees in Saudi Arabia.
2. To examine the relationship between real-time cost visibility and forecasting analytics and perceived project cost-management effectiveness.
3. To examine the relationship between digital workflow and change-control support and perceived project cost-management effectiveness.
4. To assess the combined explanatory contribution of the three digital cost-management capabilities.
5. To determine whether perceived project cost-management effectiveness differs between managerial and non-managerial respondents.

1.4 Research Questions

1. How is digital cost-data integration related to perceived project cost-management effectiveness?
2. What relationship exists between real-time cost visibility and forecasting analytics and perceived project cost-management effectiveness?

3. How is digital workflow and change-control support related to perceived project cost-management effectiveness?
4. How much variance in perceived project cost-management effectiveness is jointly explained by the three digital capabilities?
5. Is there a significant difference in perceived project cost-management effectiveness between managerial and non-managerial respondents?

1.5 Research Hypotheses

H01: Digital cost-data integration is not significantly associated with perceived project cost-management effectiveness.

H11: Digital cost-data integration is positively and significantly associated with perceived project cost-management effectiveness.

H02: Real-time cost visibility and forecasting analytics are not significantly associated with perceived project cost-management effectiveness.

H12: Real-time cost visibility and forecasting analytics are positively and significantly associated with perceived project cost-management effectiveness.

H03: Digital workflow and change-control support are not significantly associated with perceived project cost-management effectiveness.

H13: Digital workflow and change-control support are positively and significantly associated with perceived project cost-management effectiveness.

H04: The three digital capabilities do not jointly explain a statistically significant amount of variance in perceived project cost-management effectiveness.

H14: The three digital capabilities jointly explain a statistically significant amount of variance in perceived project cost-management effectiveness.

H05: Mean perceived project cost-management effectiveness does not differ significantly between managerial and non-managerial respondents.

H15: Mean perceived project cost-management effectiveness differs significantly between managerial and non-managerial respondents.

1.6 Significance of the Study

Scientific significance

The research relates the digital-transformation capability to an explicit project-management role. It is easy to get lost in the hype of “project performance” with digital transformation. Separating data integration, visibility/analytics and workflow/change control makes the proposed pathways testable. After accounting for overlap among capabilities, simultaneous regression can be used to determine if each dimension has a unique association with PCME.

The outcome construct also provides conceptual discipline. Effective cost management cannot be reduced to staying within an original budget, because authorized scope change, revised baselines, deferred work and quality trade-offs can all affect the final amount. The study therefore assessed information reliability, early warning, forecast usefulness, change traceability and response timeliness. This wider definition is more suitable for employees who work with the process but do not necessarily have access to audited final accounts.

Having employees of all ranks involved gives proof for implementation. Executives and project directors can be familiar with the investment rationale, coordinators and planners can be familiar with whether records are current, and engineers, buyers, accountants and specialists can be familiar with whether workflows actually function. The proposed job-level comparison may show if there are different evaluations when access and responsibility is used. It does not presume that managers would report more positive results in advance.

Practical significance

The three predictors are actionable domains of diagnosis. Low DCDI scores indicate interface issues, data ownership, issues with duplicate entry and/or reconciliation. Low RVA

scores indicate a delay in updating, lack of warning or poor forecast support. Weak DWCC scores are associated with lack of traceable approvals, lack of change records or delayed assignment of corrective action. Organizations may use these signals as a means to compare with system logs, audit evidence, and objective project metrics.

The instrument is suitable for a public distribution on Google Forms, since it does not refer to company names or financial values. It is a cost-effective initial evaluation of the situation, sector-wide and still maintains respondents' accessibility. It is not a replacement for a formal cost system audit. Instead, it points out patterns that warrant further investigation.

1.7 Theoretical Framework and Conceptual Model

The main lens is information-processing theory. Projects are uncertain and interdependent, which means that they have information-processing needs (Galbraith, 1974). Digital data integration boosts the ability to put together the right information; visibility and analytics boost the ability to understand the status and predict results; workflow support boosts the ability to route decisions and responses. The three capabilities must be combined to enhance the fit between the information-processing requirements of the project and the project's control capacity.

This is complemented by management-control and feedback logic. A control cycle involves a reference, observations of current performance, interpretation of deviation, a forecast and action. Digital integration helps with the observation base, visibility and analytics help with interpretation and forecasting, and digital workflow helps with authorization and corrective response. As demonstrated by Bryde, Unterhitzenberger and Joby (2018), an implementation condition is required for earned value analysis to be effective, making it clear that a metric or application is not effective without a functioning organizational process.

The independent variables are digital cost-data integration (DCDI), real-time cost visibility and forecasting analytics (RVA), and digital workflow and change-control support (DWCC). Perceived project cost-management effectiveness (PCME) is the dependent variable. The regression is:

$$PCME = \beta_0 + \beta_1(DCDI) + \beta_2(RVA) + \beta_3(DWCC) + \varepsilon.$$

All coefficients are conditional associations in the achieved sample. The model does not establish temporal causality. The grouping variable for Objective 5 was job level. Sector was reported descriptively; it was not added as a regression control because several sector categories contained too few respondents for stable prespecified dummy-variable estimates.

1.8 Scope and Delimitations

The eligible respondents were adults working in Saudi Arabia who had been directly engaged in a project within the previous two years that involved digital tools or systems for cost, schedule, procurement, contracts, progress, reporting or change control. "Involved" meant creating or entering information, operating a system, reviewing outputs, processing approvals, managing affected work or making decisions from the information. Respondents were instructed to answer with reference to one of their most recent eligible projects to reduce project mixing.

The study covered multiple sectors and included managerial and non-managerial project employees. Formal membership of a project-management profession was not required, but direct process exposure was required. The questionnaire did not collect project names, organization names, contract values, approved budgets, actual costs, profits, vendor identities or confidential system architecture.

The design was cross-sectional and non-probability based. Results therefore apply to perceived practices and perceived effectiveness in the achieved sample; they are not national estimates or audited project-cost outcomes.

1.9 Limitations

The primary drawback is the lack of temporal order and causality. Projects that have a well-developed cost management process might be more likely to invest in integrated digital tools; capable organizations might be more likely to achieve both technology and cost effectiveness; and projects that are more challenging might be given more intense digital controls. These possibilities can be distinguished using longitudinal or quasi-experimental research.

Associations can be overestimated or masked with common-source self-report data. Some risks are mitigated by anonymity, neutral wording, a recent-project reference frame, the separation of the predictor and outcome sections, and by not evaluating the employers by name (Podsakoff et al., 2003). They can't close role-based information gaps. Perception scores should not be renamed as system audit scores.

Three item predictor scales maintain brevity while sacrificing content breadth. The target sample is suitable for a simple regression model for medium effects but not for a complex structural model. It is therefore crucial to have reliability, expert review, pilot testing, and careful factor analysis. Future studies need to integrate multiple respondents per project, system-log measures, forecast-accuracy records and final-cost data.

1.10 Operational Definitions

Digital cost-data integration (DCDI): the degree to which digital project-cost information is linked to relevant schedule, progress, procurement or change information and is updated, consistently and accessible without unnecessary duplicate entry or reconciliation, answered by Questions 6–8.

Real-time cost visibility and forecasting analytics (RVA): extent to which digital tools give employees timely and adequate cost/status information, and determine emerging variance and updates to expected final cost; measured by Questions 9-11. Real-time is not instantaneous sensor data, it's timely enough for the decision.

Digital workflow and change-control support (DWCC): the extent to which the employee reported that digital workflows document cost-related approvals, link approved changes to relevant records and support assignment/tracking of corrective action (Questions 12 – 14).

Perceived project cost-management effectiveness (PCME): the respondent's perception of the reliability of the cost information, the ability to detect variance, the usefulness of the cost forecasts, the ability to trace changes, the timeliness of the project's cost information, and the overall effectiveness of the project's cost-management, measured by Questions 15–20.

Managerial respondent: a supervisor/team leader, project or functional manager, project director, senior manager or executive. Other positions that are eligible for the planned comparison are considered non-managerial.

1.11 Chapter Summary

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter investigates the possible impact of digital transformation on project cost management in Saudi companies, with a critical view. The connection is significant, but is often exaggerated. Digital technologies can help to gather project information more quickly, facilitate the merging of information and increase visibility for decision makers, but none of these attributes ensures an accurate estimate, an authorized baseline, timely intervention, or disciplined change control. The literature thus needs to differentiate between technological capability and cost-management effectiveness. It also must differentiate evidence of a tool's ability to do a job from evidence of embedding that job into routine practice by an organization. It is this distinction that is followed throughout the review. Digital transformation is seen as a socio-technical capability that includes integrated data, interoperable systems, automation and analytics, real-time visibility and human/process readiness. Project cost management effectiveness is considered the quality and timeliness of cost estimation, cost budgeting, cost monitoring, cost forecasting, cost change control and cost-informed decision making.

The review moves from general digital-transformation theory, to construction and project-specific technologies, to mechanisms that are likely to impact cost work. It includes building information modelling (BIM), specifically model-linked or “5D” cost applications, cloud and platform integration, digital twins, artificial intelligence (AI) and data analytics, and digitally enabled earned value and forecasting. It also takes into account implementation conditions as a nominally advanced technology can be undermined by a weak or non-existent cost coding, inadequate competencies and unclear responsibility. Saudi and Gulf Cooperation Council (GCC) studies are then used to assess the transferability of international findings. This sequence avoids a widely reported mistake in the literature, which is attributing a general technology benefit to a specific project cost benefit in Saudi companies.

Conceptual articles, systematic and critical reviews, technical prototypes, case studies, surveys and archival forecasting evaluations were included in the evidence base. These designs answer different questions. A prototype can show feasibility but not organizational benefit. A perception survey can identify perceived usefulness and barriers but not necessarily cause and effect over time. A forecasting test permits comparison of predictive accuracy on past projects, but does not show that managers acted on a forecast. The chapter consequently uses cautious verbs such as “supports,” “enables,” “is associated with,” and “provides a mechanism.” Strong causal language is inappropriate because the completed survey estimates cross-sectional relationships rather than a controlled treatment effect.

The final goal of the chapter was to develop a defensible model that respondents at different organizational levels could answer. Lower- and middle-level employees may not know confidential final budgets, but project participants can observe whether data are entered once or repeatedly, whether systems share information, whether reports arrive on time, whether variances prompt action and whether change impacts are traceable. These observable practices are closer to the mechanisms of digital cost management than disclosure of confidential financial data. The literature was therefore synthesized into measurable dimensions of practice rather than a list of technologies.

2.2 Meaning and scope of digital transformation

Digital transformation is more than digitization. Verhoef et al. (2021) differentiate the conversion of analogue information into digital, the use of digital tools to enhance processes and the more fundamental change in organizational structures and value creation. This hierarchy is important for cost control. The digitization of invoices or the export of a

spreadsheet is digitization, the linking of procurement commitments, progress quantities and the approved cost baseline is digitalization, redesigning decision rights and workflows around a shared, continuously updated data environment is closer to transformation. A study that focused solely on whether or not a company has software, however, would be mixing adoption with maturity. It may consider a disjointed and manually reconciled setting to be transformed even if the cost management process is the same.

Vial (2019) presents digital transformation as an organizational response to disruption created by digital technologies. In project cost management, the relevant change is not simply faster calculation. It is the possibility that designers, planners, quantity surveyors, procurement staff, site teams and managers can work from connected information rather than periodic function-specific files. This may change who generates cost data, when forecasts are updated and what evidence is available when a change is approved. The framework therefore provides causal logic for interpretation, but it does not itself supply project-level cost measures or prove the causal direction tested in this survey.

Gong and Ribiere (2021) propose a common definition that focuses on the fundamental change that is made possible through innovative combinations of information, computing, communication and connectivity technologies. The emphasis on combinations corrects another measurement problem. Each of the three – BIM, an enterprise resource planning system, a cloud platform or an AI model – can play a part in cost work, but transformation typically requires the connection between them. Even though a model generates quantities, it cannot share cost codes with the accounting or project-control system, manual reconciliation is still needed. Poorly governed integrated systems, on the other hand, can propagate an error at a rapid pace. All of these are therefore complementary dimensions of a valid construct and not a list of individual tools, and must be measured in terms of integration, automation, visibility and readiness.

Matt, Hess and Benlian (2015) suggest that the approach towards digital-transformation should be connected to the use of technology, value creation changes, structural changes and the financial aspects. Their framework is especially relevant to cost management, as the financial aspect is not taken for granted, but integrated into transformation strategy. A project organization can spend more money on advanced modelling without changing the thresholds for approval, work breakdown structures or cost-accountability rules. If so, the technology strategy/cost-governance design is off track. While the paper is conceptual and should not be interpreted as evidence that strategic alignment will always lead to savings, Matt et al. do offer a concise strategic framework.

Similarly, Bharadwaj et al. (2013) argue that digital strategy is not an independent strategy, but rather a strategy that affects scope, scale, speed and sources of value. In the case of temporary projects, it means that cost information architecture is not just an information-technology issue. The speed at which commercial and technical teams can identify cost exposure depends on decisions made regarding coding structures, data ownership, interfaces, update frequency and access. The article is not construction-specific, but it does make the point that departmental optimization can be problematic because procurement, schedule and site-progress data may remain incompatible with a fast estimating application.

Nambisan et al. (2017) articulate the way that digital technologies have changed innovation processes to be unbounded, distributed, and generative. Distributed participation can enhance the scope of information for a cost decision in project environments, but it can also introduce version control and accountability issues. An increase in the number of contributors does not necessarily lead to improved estimates. A cost manager should be aware of which model version, quantity set, productivity assumption and price date is authoritative. Nambisan et al. thus argue both sides of the coin: digitalization can expand the availability of information, but also raises the demand for governance that secures decisions.

The most robust organizational mechanism is offered by Warner and Wäger (2019) in their dynamic-capabilities account. They tell their stories as a process of strategic renewal that is

ongoing, and that involves developing the ability to detect opportunities and threats, and to seize opportunities by making decisions and using resources, and to change structures and culture. In project cost management terms, sensing is the recognition of patterns of variance or emerging changes, seizing is the reallocation of resources and/or approval of corrective action, and transforming is the redesign of workflows and the development of competencies. A dashboard that detects a variance but is not connected to decision rights does only half the job. The case design of the study does not measure cost performance, but it helps to understand how the same technology can be effective in one company and ceremonial in another.

When these studies are combined, they indicate that digital transformation should not be judged by money spent, software ownership or by a single maturity label. It can be operationalized in the employees experience of data integration, automation/analytics, real-time visibility, interoperability and readiness within the proposed thesis. This operationalization also lowers the risk of rank bias: employees don't have to be aware of the transformation budget, they just have to be aware of whether systems and processes enable them to do their work. Perception measures do, however, remain subject to common-method risk. Those who rate their company well could rate digital practice and cost effectiveness well. The methodology should then ensure that anonymity is protected, construct blocks separated, and the measurement model tested prior to regression, and be worded in a neutral way.

2.3 Digital transformation in project-based and construction environments

There are unique barriers to transformation in construction and other project-based industries. Projects bring together temporary, multi-organizational teams to work on shifting designs and contracts. Information flows between organizational units and incentives and liabilities can be barriers to open sharing. Oesterreich and Teuteberg (2016) list BIM, cloud computing, mobile technologies, automation, robotics and data analytics as part of Construction 4.0 but also skills, standardization, investment and organizational barriers. They have a triangulation research agenda which is helpful in avoiding a technology-only explanation. It mostly represents implications and opportunities for research, but it doesn't indicate that a collection of technologies has led to lower costs.

Whyte and Hartmann (2017) state that digitizing building information alters the built environment by altering the shape and use of project information and by questioning the current delivery systems. A digital model is at the same time a technical representation and a coordination object. The cost value is a function of the way in which contractual parties rely on it, the version on which they rely and who is responsible for the contents. Therefore, increased visibility may help to minimize confusion in one context, but increase liability issues in another. Their editorial synthesis is important, but provides no independent outcome test.

Interoperability is also a key concept in the project environment, which is also highly fragmented. Transformation should not be equated with the number of applications deployed. When design objects, schedule activities, cost accounts, procurement packages and accounting codes are not mapped, employees have to re-enter, classify and reconcile data. Each handoff introduces delay and error exposure. On the other hand, a common information structure can be used to support faster updates, but can also exacerbate misclassified information. The potential speed and consistency that interoperability brings to cost information is therefore contingent on data governance: the potential can become a reliable source of control.

The temporariness of the project poses another obstacle to learning. Organizations benefit from digital cost systems when they have historical amounts, rates, productivity, changes and forecast errors in a similar format. Typically, projects end up with data spread out among

contractors, spreadsheets and personal folders. The next team then starts with restricted reference information. The strategic and the dynamic capabilities literature suggests that institutional memory is needed beyond the project boundary (Bharadwaj et al., 2013; Warner & Wäger, 2019). This mechanism is especially important for estimating and reference-class forecasting, since algorithms can't fill in missing or incomparable histories.

The construction literature thus provides a layered model. On the technical level there are models, platforms, sensors and analytical tools. Coding, classification, metadata, versioning and interoperability are at the information layer. Estimating, progress measurement, forecasting, change control and payment are at the process level. Competence, leadership, contracts, incentives and decision rights are at the organizational level. The effectiveness of cost-management is created by interaction between layers. If only the technical layer is measured, the study may be interpreted as a measure of process maturity due to technology; if all layers are measured at once, the study may lose its diagnostic value. The proposed survey should then have separate but related dimensions and report the reliability of these dimensions separately.

2.4 BIM and the change of project cost information

Building information modelling is the oldest digital information model that is found in the project-cost literature. Unlike BIM as a three-dimensional drawing package, Succar (2009) outlines a broad BIM framework of fields, stages and maturity. This separation is important in the study of cost. A company can create visual models with no model based quantities, shared classification or controlled exchange. On the other hand, a cost team can link quantities and changes even if other departments are at a lower maturity level. While succar is a framework for maturity-sensitive measurement, it is not a demonstration of the framework that higher maturity leads to better cost outcomes.

Azhar (2011) collates the benefits, risks and challenges of BIM such as visualisation, clash detection, cost estimating, scheduling, interoperability, legal uncertainty and investment requirements. Balanced treatment is more defensible than talking about benefits of BIM. Some of the cost associated with rework is preventable through clash detection, but the value of the cost prevention depends on the timing of the clash detection, if the model has the relevant disciplines, and if the project team resolves the findings before procurement or installation. This was also the case for early case evidence, which came from relatively more developed adopters. Reported benefits should thus be regarded as possible mechanisms and not as universal percentages.

Bryde, Broquetas and Volm (2013) investigate the reported benefits of BIM in a project-management context and conclude that positive benefits exist in multiple project-management dimensions, such as cost-related benefits. They are frequently referenced as proof of the benefits of BIM on projects. A closer reading requires restraint: the source base is reported cases, and successful or noteworthy implementations are more likely to be documented. Cost savings can also be achieved through avoidance, productivity, avoidance of rework, and better coordination, all of which don't have a common denominator. The study does, however, offer valuable empirical evidence of what cost outcomes are in some projects, and not just in theory.

Sacks et al. (2010) investigate the relationship between lean construction and BIM, and find that there are complementarities between visualization and information flow, and between production control and waste reduction. The idea is that there is a dependence between BIM benefits and related management routines. A coordinated model can reveal a constraint but a dependable planning process is required to eliminate a constraint. Similarly, an update on quantity will show exposure to costs, but a control meeting and a response that has been authorised is required to alter the outcome. This interaction perspective is a departure from simple regressions where the use of "BIM" is treated as uncoupled from process discipline.

The literature therefore places BIM as an information infrastructure which can impact on cost in several ways: more consistent quantities, earlier option evaluation, fewer manual transfers, better design coordination, traceable change, connected progress measurement and shared visibility. These mechanisms can overlap and should not be used indiscriminately. For instance, coordination can minimize unnecessary change, and cost integration can speed up pricing of a required change. Both have a positive impact on cost management, but in different stages and results. The survey should be based on practices including linked quantities, timely updates and traceability, not on whether or not “BIM reduces costs” is being experienced, which can be a matter of belief.

2.5 5D BIM, quantity take off and estimating

Typically, the term 5D BIM is used to describe the ability to connect model objects and quantities to cost data. Smith (2014) states that this evolution will alter the project cost manager's role by allowing for quicker testing of options, automation of measurement and more integrated decision support. The article is useful for a professional role analysis, but the article is a conference proceedings contribution and makes significant use of industry practice. It demonstrates what 5D can enable, not how many organizations can get it done reliably. Furthermore, a rapid measure is useful only if the object classification and scope coverage and rate logic are valid.

More directly, Stanley and Thurnell (2014) provide empirical evidence from quantity-surveying practice in New Zealand. Reported benefits included faster measurement and better visualization, while barriers included training, implementation cost and model quality. The occupational focus is relevant because quantity surveyors work close to cost workflows, although the national and sample context limits transfer to Saudi companies. Time saving alone does not mean that final forecasts are more accurate. The source therefore informed separate survey items on speed, accessibility, update capability, reliability and decision usefulness.

Choi, Kim and Kim (2015) present an open-BIM quantity take-off system for the schematic estimation of building frames. Their work shows that standardized exchange can be used to make early estimates when design information is not complete. Technical feasibility is the key contribution, as quantities can be derived by structured rules instead of re-measurement. The system, however, addresses a limited building component and design phase. Other costs, such as temporary works, preliminaries, risk, market escalation, subcontract strategy and items not represented as model objects, must also be managed as part of the whole project estimate. The article should then be focused around a narrower claim regarding the acquisition of quantities, rather than a claim that BIM will completely automate cost estimating.

Ma and Liu (2014) also introduce an intelligent approach to acquisition of construction information for cost estimation. They have built a prototype that demonstrates how semantic relationships can be used to transform model data into estimating inputs. It tackles a real cost management issue: often, staff have to spend a lot of time locating, interpreting and re-formatting design information before they can do the calculation. Automation can minimize repetitive tasks and facilitate faster updates. However, a technical mapping is not sufficient to determine if the design is complete, if the procurement conditions have changed or if a historical rate applies. Human commercial judgment is still required, and the proposed research should not be seen as a substitute for human commercial judgment.

According to Monteiro and Poças Martins (2013) the reliability of quantity take-off is a function of modeling guidelines. Objects need to be constructed and broken down in ways that are consistent with measure rules. This finding is important since it establishes model quality as a boundary condition. A model that is correct in the eyes of the beholder may not be able to be used for cost extraction, and an automated output can seem precise even if there are omissions or double counting. Paper thus warrants the inclusion of questions about

standardized data structures and trust in linked information, not just questions about automation. It also provides a reason why interoperability and process readiness should be two distinct aspects of digital transformation.

Fung, Salleh and Mohd Rahim (2014) and Ismail et al. (2016) correlate BIM capabilities with quantity-surveying tasks. Both sources agree that measurement, cost planning, documentation and collaboration can be digitally supported. They are useful because they are task-specific, which can make the survey items understandable to employees. The primary drawback of capability catalogues and practitioner expectations is that they do not show actual performance. When a questionnaire restates the expected benefits, answers might be given based on a general sense of enthusiasm. Instead, items should describe current practice, such as whether approved changes to the model are made to quantities without duplication or whether the cost report can be used to trace quantities to current design information.

Moses, Heesom and Oloke (2020) explore the views of the contractors regarding the adoption of 5D BIM in the United Kingdom. Their findings highlight the need for people, processes and standards and demonstrate that more than just choosing software is involved when it comes to the adoption by contractors. The UK procurement and institutional environment is different to Saudi Arabia, but the implementation mechanisms are applicable: cost integration needs models to use, roles to define, collaboration and staff capability. This source also points to a transferability issue. The results of well-established BIM markets can overestimate what may be achievable in less advanced markets with less established contractual requirements, client demand or classifications.

In these studies, the clearest theoretical impact of 5D BIM on process efficiency and information consistency is observed, not necessarily on the final cost variance. While faster quantities can help estimate cycles and influence response, scope decisions, risk, price volatility, productivity and commercial behaviour also help influence final cost performance. For a study with a direct relationship between digital transformation and cost management, the dependent variable should be process-effectiveness. It can determine if digital practices lead to improved estimating updates, visibility, forecasts and decisions without stating that technology is the sole reason for a project being delivered on budget.

2.6 Whole-life Cost, Alternatives and Change Control

Digital cost management isn't limited to the initial estimating process. Zanni et al. (2019) present a methodology for incorporating whole-life costs in the BIM design process. The method can help to make the capital, maintenance, replacement and operating implications apparent when comparing alternatives. This is a great strategic advantage as it can generate a higher life cycle cost when the initial cost is low. However, life-cycle cost outputs are still dependent on the service-life assumptions, discount rates, usage patterns, and future prices. Digital integration enhances the capacity to simulate and compare scenarios, but not the uncertainty in the underlying assumptions.

Le, Likhitrungsilp and Yabuki (2020) combine BIM and relational database for life-cycle cost evaluation. Their system illustrates how components of a model can relate to cost records over time. Relational structure can help minimize the number of files that are spread out and provide traceability, a key element of effective cost information. The evidence is still a system development and validation exercise. It does not demonstrate that normal businesses keep the database, update deterioration and replacement assumptions and utilize outputs in approvals. Available information and used information should then be clearly differentiated in the conceptual framework of the chapter.

Jang et al. (2021) suggest an infrastructure BIM platform for lifecycle management, which goes beyond the project delivery phase to asset utilization. The handover loss in infrastructure projects is often observed where design and construction data is delivered in forms that are not easily reused by the operators. The lifecycle platform can retain cost-relevant asset data, but it needs long-term governance, consistent identifiers and institutional ownership. A cross-

sectional survey of employees is safer to determine if project data are accessible and reusable than to ask respondents to assess overall lifecycle savings.

Change control is a more direct cost management process. Handayani, Likhitrungsilp and Yabuki (2019) propose an integrated system for change-order impacts analysis using BIM. Teams can use structured design and schedule relationships to more quickly identify affected quantities and activities. A quicker analysis can help make better authorization and contingency decisions, particularly when changes are made under schedule pressure. But many change costs come from disruption, learning effects, and cumulative interactions that a model may not adequately capture, as well as commercial negotiation. The system is designed to support impact analysis, but it does not replace records and judgment.

In this context, Sigalov et al. (2021) combine BIM with smart contracts based on blockchain for automated payments and contract management. The mechanism is appealing: if something is proven to be progressing, then it can be valued or paid, which could minimize the time for delays and increase the auditable. However, legal enforceability, data-oracle reliability, and the complexity and acceptance of contracts are not trivial. An automated rule may also be applied incorrectly. The study should instead be used as evidence of a new architecture that enables traceable payments, rather than as evidence that smart contracts can solve disputes or lower costs in Saudi projects.

The life-cycle and change-control studies show a pattern. The quality of data continuity, traceability and calculation speed throughout decisions can be enhanced by digital transformation, but effectiveness relies on the quality of the assumptions and the authority of the process of which they are part. This pattern allows for a mediated interpretation: Digital capability enhances information processing, which enhances cost-management routines, which enhances project outcomes. The middle relationship is the subject of the proposed thesis, since the final costs for the public survey can not be verified by the auditing. This is a more focused result that is methodologically better and more understandable to respondents of varying levels.

2.7 Cloud platforms, common data environments and interoperability

Cloud platforms and common data environments are not just important because of the fact that storage is a transformative process, but because project cost management relies on access to up-to-date, shared information. A cloud environment can make models, records and dashboards available across locations and organizations, minimizing the time lag of exchanging files via email. It can also consolidate permission and revision records. But centralization does not ensure a shared semantic structure. Inconsistent files will make the cloud a more effective document repository than a unified cost control environment.

Platform perspective is tacit in the BIM and digital-transformation literature. Jang et al. (2021) illustrate how to integrate lifecycle platforms and Sigalov et al. (2021) how to connect payment rules with a shared information model. At a strategic level, Bharadwaj et al. (2013) provide an explanation for the increase in speed and scope of digital operations when resources are connected. These sources make up the mechanism that a common environment can reduce the information latency. They are not an excuse to believe that any cloud subscription will be more cost effective. Accessibility, classification, version control and user compliance must be gauged.

Interoperability is technically and organizationally. In the technical sense, there are exchange formats, identifiers and mappings that need to be established. Parties shall agree organizationally on coding, status definitions and responsibility. Choi et al. (2015) present an open-BIM path for quantity exchange, and Monteiro and Poças Martins (2013) illustrate the importance of the modeling conventions used. A company can pass a file without understanding its contents and still pass the file successfully. The proposed construct should therefore contain the extent of the sharing or exchange of relevant cost information between

project systems with minimal duplicate entry and the ability of employees to trace the origin and status of the data.

There is a countervailing concern for security and trust. According to Fuller et al. (2020), the key issues in connected digital-twin environments are cybersecurity and privacy and interoperability. Project cost information may be commercially sensitive, particularly from the client, contractor and supplier perspective. Organizations can also choose to limit access, potentially safeguarding legitimate interests but bringing back information silos. Digital transformation isn't the same as 'transparency for all'. Good governance ensures appropriate visibility, with a traceable source of truth, based on a role.

Client needs, data-residency policies, contractual norms and the size and capabilities of small suppliers can also influence cloud and common-data-environment practices for Saudi companies. A large company might have an integrated system with subcontractors reporting spreadsheets or paper records, leaving a paper handoff at the end of the process. Survey questions should focus on the entire employee journey—not just the corporate platform. A good item is one that asks if the information that is relevant to design, schedule, procurement and cost is linked for the respondent's projects; a weak item is one that asks whether the company “uses cloud technology.”

2.8 Digital Twins and Real-time Cost Visibility

The integration argument is extended in the digital-twin literature with a dynamic link between the physical asset or process and its representation. Jones et al. (2020) show through a systematic review that the term is used inconsistently and propose characteristics that distinguish twins from static models. This is a discipline that is definitional. A coordinated BIM model is not necessarily a digital twin; a twin typically involves ongoing data sharing and the ability to represent the changing state. The term “twinning” would be an overstatement of digital maturity in literature and survey responses.

In the semantic construction digital twin, Boje et al. (2020) suggest that the heterogeneous information is linked in richer meaning. Semantic links might be used to relate an observed installation, a model object, a schedule activity, a procurement package and a cost account for cost management. This linkage may shorten the time required to determine the cause of a variance. However, the paper is clearly forward-looking. It points to avenues of research, not to overall savings by the organization. It should encompass the conceptual mechanism of traceability and feedback, rather than an empirical claim of improved cost performance.

Sacks et al. (2020) outline the construction process using digital-twin information systems and highlight the feedback between the physical production and digital representation. This feedback is applicable to progress measurement, one of the weakest aspects of many cost control systems. Earned value and forecast updates can be made earlier, if the quantities and status are recorded consistently. However, the recognition of an installed component does not create an earned value, quality acceptance or commercial entitlement. The data must be interpreted under measurement and contract rules. The digital twin can enhance evidence availability – project controls establish its cost meaning.

Opoku et al. (2021) summarize the use of digital-twins in construction and report significant interest and early adoption of digital-twins. Their review is particularly useful as a corrective to technological optimism. The literature is largely conceptual, pilot-based or is more concerned with operations and maintenance than project cost control. It is not appropriate to assume that all Saudi companies currently practice twins; a thesis should rather describe the emergence of twins as a component of digital transformation. The general survey questions about real data and connectedness are likely to be more valid than when asking all respondents about “digital twins” which may be interpreted in a variety of ways.

Fuller et al. (2020) mention enabling technologies, including sensors, IoT, data analytics and communication infrastructure, as well as challenges in security, data quality and interoperability. These are all conditions that illustrate the potential power and danger of real-

time data. Too many and too frequent unreliable observations will cause either false alarms or false confidence. It is not the amount of data that is important for cost management, but the quality of the information that is required at the appropriate decision level and frequency. The concept of the survey is not real time, but rather timely and trustworthy visibility.

Digital-twin evidence is used to support a feedback-control interpretation. Digital capture enhances observation; Models are used to structure expected state; Analytics are used to compare expected and actual state; Managers make decisions and take action; Next data show the outcome. All links are vulnerable. Sensors can be missing, models might be outdated, mappings can be wrong, thresholds can be poorly defined, actions can be delayed. The proposed research would be able to assess employees' perceptions of the integrated chain, but not the effect of any particular technical component. When interpreting any regression coefficient for the overall construct of digital-transformation, this limitation should be noted.

2.9 Big data, artificial intelligence and predictive cost management

Bilal et al. (2016) provide an overview on Big Data in construction and discuss the opportunities for the volume, variety and velocity of project information. The ability to store historical estimates, procurement information, progress, productivity, risk and change data in an analyzable format can be beneficial to cost management. However, the information on construction is not always comparable and does not always convey the same meaning. Different scope, location, specification, market and risk may be included in a unit rate from one project. With additional data, a similar reference class does not necessarily exist. Predictive value is thus dependent on data governance and contextual features.

Darko, et al. (2020) use scientometric analysis to trace AI research in architecture, engineering and construction. Their study shows that they grow fast and are broad in their fields, but bibliometric prominence does not necessarily mean field effectiveness. It indicates what researchers study and cite. This restriction is useful for a thesis: corporate stories can portray AI as an existing reality even if the applications are still in experimental phases. Avoid using the term “AI-driven” in survey questions. It should consider whether analytical tools can be used to detect patterns, make forecasts or offer early warnings in normal project operations.

The authors of Abioye et al. (2021) provide a review of current AI applications, opportunities and challenges in construction, including planning, risk, safety, estimating and monitoring. The review highlights the potential to support decisions in addition to data scarcity, skills, interpretability and implementation challenges. AI can predict relationships that are too intricate for straightforward rules, or detect unusual variance patterns for cost management. But, a statistically valid model may be impractical if its drivers are not transparent, the training data are biased, or managers do not believe the model. Predictive accuracy and organizational use are distinct results.

Pan and Zhang (2021) conduct a critical review of the AI applications in construction engineering and management. They can be used to find AI in the cost process, such as prediction for early estimates and forecasts, recognition for capturing progress, optimization for resource decisions, and language or knowledge methods for document analysis. The width also poses a measurement problem. A single “AI use” item encompasses various technologies and mechanisms. The transformation construct should therefore be measured on analytics-enabled decisions, and the literature provides an explanation for the possible tools that can support this.

Taboada et al. (2023) conduct a review of AI in project management, highlighting the applications in planning, scheduling, resource management, risk and prediction. They have a project management orientation that makes their reviews more relevant than cross-industry AI reviews. However, the evidence base is not uniform, with several potential and technically tested applications and fewer organizational field evaluations. The correct answer is that under some circumstances, AI can aid in project decisions, but it does not mean that using AI

leads to cost control. Human oversight and data quality and process integration are key moderators.

García de Soto and Adey (2016) offer a concrete estimating application by combining AI and traditional techniques for preliminary resource-based estimates. The hybrid design is significant because it eliminates any sense of opposing algorithms and professional judgment. Traditional relationships are used to encode domain knowledge, and early project estimates contain limited information. AI can detect patterns in past cases, and experts can determine if the comparison is valid. The study is preliminary and case-bounded, therefore, it does not make a claim of superiority but instead supports a hybrid decision logic.

AI creates additional governance risks. Training data might have historical underestimation, practice or selection bias. A mean-error-oriented model can discount tail risk, and a model based upon finished projects might not include cancelled or unusually troubled projects. Staff can also follow an algorithm due to the fact it looks like it is precise. Therefore, a digital transformation must also enable the review, challenge and action of analytical outputs. A company that has an AI tool but lacks a validation system, ownership or escalation process could have more technological sophistication and less reliability on control.

This balance can be captured in statements such as 'Analytical tools provide useful early warnings', 'Forecasts are informed by current and historical data', and 'The basis of digital outputs is understood and verifiable by employees'. Respondents should not be asked to recognize machine-learning techniques. This kind of jargon would give the edge to the experts and make it less valid at lower levels. Measuring the experienced decision-support function is supported in the literature, and secondary evidence is used to interpret the technology categories behind the experienced function.

2.10 Monitoring and forecasting that is enabled by digital technology

There is a need for a baseline and a periodic comparison of authorized plan, commitments, actual cost, progress and expected completion in cost management. Digital tools can automate calculations and visualisation but they are not a valid baseline. Combining scope, schedule and cost measures is presented by Anbari (2003) in the form of earned value management (EVM) extensions. These measures are more easily made available and updated in a digital system. The methodological prudence is crucial: if the work breakdown, budget allocation or progress measurement is weak, an automated cost-performance index conveys bad information quicker.

Kim, Wells and Duffey (2003) suggest a process for successful implementation of EVM and stress factors other than formulas. Their study is predating modern cloud platforms, but their overarching message is still relevant today. EVM must be accepted by management, have the right level of detail, be clearly defined and aligned with project processes. These requirements can be met and manual effort can be reduced with a modern dashboard. This source therefore suggests that the treatment of people/process readiness as a part of digital transformation rather than as a control variable.

Vandevoorde and Vanhoucke (2006) compare some methods for forecasting the duration of projects using earned value metrics. While they have a dependent outcome (duration), the study illustrates a general principle for digital cost control: the quality of the forecast is dependent on the model and the stage of the project. A single deterministic forecast may not be as helpful as a process of comparing methods and uncertainty. The paper should be written as a cost of evidence for methods, not for direct costs.

Batselier and Vanhoucke (2015) empirically test the validity of the time and cost prediction through real project data. They are better at comparing forecasts than using perception surveys, as forecasts can be compared to actual results. It also exposes some boundaries: historical data completeness, project mix, and reporting practices impact results. The paper presents the notion that digitally stored project histories enable organizations to

experiment with different approaches for better performance. Without such institutional data, firms could be prone to continuing to use the same forecasts without empirical calibration.

Batselier and Vanhoucke (2017) combine the EVM with exponential smoothing and reference-class forecasting. The two methods can be used together to enhance accuracy, leveraging within-project trends and outcomes from similar projects. It's a very clear example of how digital transformation is improving the traditional control method, not replacing it. The outcome is achieved by selecting an appropriate reference class and keeping comparable histories. A Saudi company that has a variety of projects with different coding might not get the same gain without significant data preparation.

Kim and Kwak (2018) suggest an adaptive combination approach to enhance the accuracy of project cost forecasts and the predictability of project operations. The key idea is that there is no one best model, weights can change with the evidence. This is important to digital analytics, as software can update and compare forecasts more often than a manual process. However, adaptive complexity also raises governance requirements. Users require transparent performance measures and controls against overfitting. Advanced forecasts should be presented as decision support, rather than as unquestionable forecasts.

The issue of project control under uncertainty is explicitly discussed by Acebes et al. (2014). They have a stochastic approach to the interpretation of baselines and variance which is a challenge to deterministic interpretations. Digital systems can mimic ranges and probabilities, and make uncertainty more apparent, but organizations may still require a single number for approval. A cultural shift from false precision to risk-informed decision making is, therefore, an essential element of effective transformation. Staff are able to see if forecasts are refreshed and risks are captured even if they are not familiar with simulation techniques.

The literature on forecasting suggests three different cost management outcomes: timeliness, accuracy and actionability. A report can be timely but inaccurate; accurate but delivered after a decision; or accurate and timely but ignored. Timeliness and analytical capacity are the most directly impacted by digital systems. The level of accuracy is dependent on baseline, data and method, and the level of actionability is dependent on responsibilities and governance. The proposed dependent construct should consist of three separate claims, and not merge them into a single claim that dashboards “improve cost control.”

2.11 Mechanisms Linking Digital Transformation to Cost-management Effectiveness

The first mechanism is that of reduced information latency. A design, procurement or progress event can appear in the cost view in a shorter time in the integrated systems. To illustrate this, Choi et al. (2015), Ma and Liu (2014), and Handayani et al. (2019) offer task-specific examples in the areas of quantity extraction and change assessment. If thresholds and escalation paths are present, reduced latency provides the manager more time to intervene. The mechanism suggests that the more digital integration, the more positive the relationship with timely cost decisions, not necessarily lower final cost.

The second is a decrease in duplicate entry and reconciliation. If model objects, schedule activities and cost accounts have the same identifiers, an approved change can be transferred from one view to another with fewer manual transfers. This benefit is dependent on the modelling rules, as demonstrated by Monteiro and Poças Martins (2013), and digital cost tools are synthesised across tasks by Sepasgozar et al. (2022). While duplicate entry reduction can save professional time for analysis, automation can also spread a wrong mapping. The net effect is based on controls of master data and exceptions.

The third mechanism is enhanced traceability. Platforms can maintain the association between the source information, versions, decisions and transactions. Some examples of structured lifecycle, platform and payment traceability are provided by Le et al. (2020), Jang et al. (2021) and Sigalov et al. (2021). Improved traceability can enhance the auditability and alter the negotiation, but more records does not necessarily mean more accountability. If

access rights and ownership are not known, the organization might have a lot of data but there is no authoritative record.

The fourth is predictive capacity. Historical and current data can be used for EVM, statistical combinations, reference classes and AI-supported estimates (Batselier & Vanhoucke, 2015, 2017; García de Soto & Adey, 2016; Kim & Kwak, 2018). Prediction can provide exposure prior to the more typical threshold reports, but this benefits requires calibration and similar data. A predictive signal is only useful if the cost team is able to adequately communicate it to decision makers and if managers are able to take action on it.

Shared situational awareness is the fifth mechanism. Technical and commercial participants can share a common view of scope, progress and change (Bryde et al., 2013; Sacks et al., 2010; Sacks et al., 2020) by using BIM visualization, dashboards and connected models. Shared visibility can help to minimize coordination delay and conflicting interpretations. It can also cause over confidence if the model shown excludes off model scope, unapproved changes or commercial risks. Attractive graphics are not enough to create awareness, it should be visible and uncertain.

Organizational learning is the sixth mechanism. Systematic estimate error, recurring change causes and the relative performance of forecast methods can be identified by retained, structured project histories. This mechanism links dynamic capabilities (Warner & Wäger, 2019) with empirical forecasting (Batselier & Vanhoucke, 2015). Projects that are closed without data reconciliation are unlikely to be successful in learning, and managers who punish negative forecasts will encourage positive forecasting. Digital storage is required but not enough, organizations need to compare predictions with outcomes and change practice.

All these mechanisms together have a positive hypothesis, but they also explain why the relationship should not be deterministic. Digital transformation increases information-processing capacity. Whether that capacity is converted via standardized data, competent users, governance and action routines, will depend on the cost-management effectiveness. From a statistical perspective, a positive direct association can represent multiple mechanisms and missing moderators. The thesis should be seen as evidence consistent with the mechanism set, rather than proof that each mechanism was active in each respondent's company.

2.12 Risks, Failure Modes and Implementation Conditions

Digital transformation can either raise the cost of the project, or control the risk of the project during implementation. Investment is needed for software, integration, training, model development and process redesign. Cost and capability barriers are identified by Stanley and Thurnell (2014), Azhar (2011) and Moses et al. (2020). Projects are overhead while benefits can be realized after a learning period. If there is a positive long-term potential, the weak effect can be detected by a cross-sectional survey. It is more informative to measure maturity and/or routine usage rather than recent adoption.

Data quality is the most important technical failure mode. Integrated reports can be tainted by incomplete models, inconsistent coding, late actuals, wrong progress measures or unapproved changes. The significance of cost-oriented modeling is illustrated by Monteiro and Poças Martins (2013), and the wider data challenges by Bilal et al. (2016) and Fuller et al. (2020). The more integrated, the wider the spread of both right and wrong information. The items in the questionnaire should therefore measure trustworthiness and standardization in addition to connectivity.

Failure to interoperability creates “digital manual work” – employees export, clean, map and re-enter data from one system to another. The organization might be quite “digital” at the application level, but cost staff rely on spreadsheets for output reconciliation. This unnoticed work can cause delays in reporting and key-person risk. While Choi et al. (2015) offer some solutions for the technical challenge, organizational classification is still a challenge. This gap is well suited to be revealed by the perceptions of employees, as they experience duplicate work first-hand.

A second significant condition is skills and role redesign. Smith (2014) predicts that the role of the cost manager will evolve, and the AI reviews highlight data and analytical skills (Abioye et al., 2021; Pan & Zhang, 2021). Passive learning via button clicking is not enough. Staff should be aware of data sources, model status, cost rules and the limitations of automated forecasts. It is also important to determine who will be responsible for the validation of outputs and who will have ownership of exceptions. If there is no clarity about their roles, users may not trust the system or take it for granted.

Fragmentation of data can be limited by contractual agreements. Parties may be concerned that clear documentation would compromise negotiating positions or make them more liable. Whyte and Hartmann (2017) demonstrate how digitized information impacts delivery arrangements, and Sigalov et al. (2021) highlight the legal and procedural issues of automated contracts. Technological integration is not purely internal and project cost management is part of the commercial relationship. The proposed survey is limited to company employees, and it is important to recognise that the observed capability might be limited by client and supply-chain behaviour.

Confidentiality, continuity and cyber security also play a role. Connected cost, procurement and progress systems are valuable targets and a platform outage can have a negative impact on control. Fuller et al. (2020) have named security as a digital-twin challenge. Strong controls can diminish ease of access, which can result in a design tradeoff, not just a maximum. The concept is appropriate access: employees should have access to the information they need to do their job, and sensitive data should be subject to the control of the concept. A general item on “easy access” should be worded in a way that doesn't suggest that access is easy.

Last but not least, digital tools can perpetuate a behavioral bias. Managers can incentivize teams to maintain an approved baseline, to postpone the recognition of changes or to choose favorable forecasts. Automated dashboard can't eliminate incentive to misclassify or delay data. The dynamic capabilities view of Warner and Wäger (2019) suggests that leadership and culture shape the ability to capture negative signals. The thesis should therefore not be technologically deterministic, and should not contain readiness items on management support, training and actual use of digital evidence in decision making.

2.13 Saudi Arabia and GCC evidence

Saudi Arabia provides a strategically relevant but empirically underdeveloped context. Large and complex programs have a high demand for integrated cost information, but companies vary significantly in size, industry, place in the supply chain and level of digital maturity. The majority of the Saudi BIM studies focus on the adoption, barriers or enabling initiatives, not project cost-management outcomes. This is the gap that is at the heart of the thesis. Local evidence can be used to determine whether capabilities and constraints are salient but it cannot be used to test the proposed dependent variable as if it had already been tested.

Al-Hammadi and Tian (2020) conducted a survey of 228 participants in the Saudi AEC industry and identified lack of demand, experts and awareness as key BIM adoption barriers. The study was small in size and focused locally, so it is valuable for construct selection. It includes readiness items related to skills, awareness and organizational use. The relative importance rankings are perceptions from a cross sectional design and do not indicate by how much better cost forecasts would be if the barrier was removed. The findings should be used to explain heterogeneity, not to provide effect sizes.

Al-Yami and Sanni-Anibire (2019) evaluate the current status, advantages and challenges of BIM in the construction sector in Saudi Arabia. They say that BIM is not fully established yet and pinpoint coordination-related benefits and transition requirements. The study contributes to the establishment of local relevance for model-based information and re-engineered processes. But the perceived benefits may be a reflection of expectations,

particularly among BIM participants. It should not be interpreted as a definitive maturity indicator for 2026, but rather compared to implementation cases and subsequent studies.

Almuntaser, Sanni-Anibire and Hassanain (2018) explore the use and application of BIM in a Saudi Arabian AEC company. The case provides detail of the process that broad surveys do not: Adoption demands leadership, staged change and organizational accommodation. It is single firm, so it is not generalizable, but this is analytically helpful. Saudi companies should not be taken for granted as being the same. A survey with respondents from across the firms, ranks and sectors can expand coverage, but convenience distribution via public channels will still prevent probability-based population claims.

Alaboud and Alshahrani (2023) use interpretive structural modelling to examine BIM adoption in the Saudi construction industry. They focus on interdependence of factors, not a flat barrier list. This is in line with the socio-technical argument of the chapter: the interaction of policy, competence and standards, as well as management support. The method is based on the expert judgement view of structuring relationships and does not observe the cost change at the project level. It thus does not validate the proposed coefficient of digital-transformation, but rather a systems interpretation of the adoption conditions.

The study by Algahtany et al. (2023) assesses the government efforts in improving BIM application in Saudi Arabia through a survey and factor analysis approach. They identify competency development, awareness, curricula, contractual frameworks and financial support among important initiatives. These findings directly support the people/process readiness dimension and demonstrate that adoption is influenced beyond the confines of the firm. They also indicate the limits of the company-level model being proposed: government and client initiatives can impact both digital capability and cost-management practice. When discussing results, the thesis should refer to these omitted variables in the context.

Iqbal et al. (2025) conducted a recent Saudi study on the factors that motivate the adoption of BIM, incorporating fuzzy Delphi, interpretive structural modelling and MICMAC. Among important drivers are reduced design-cycle time and efficient planning and management. It is a recent study which is openly available, but does not look at cost effects which have been audited. Its expert methods set up perceived priorities and interrelationships. It emphasizes the importance of the timeliness and planning integration in the questionnaire, and strengthens the requirement of direct evidence of cost-management effectiveness.

Gerges et al. (2017) study BIM implementation in the Middle East region to establish a baseline level of awareness and usage in the region. The research across countries is useful to determine common challenges like limited maturity, fragmented implementation, capability gaps etc. Its downfall is aggregation, as the requirements of institutions and structures differ in the Saudi Arabia market, the UAE market and other markets. The data from 2017 are earlier than more recent policy and platform development. It should be used as historical regional context, NOT as a current Saudi prevalence estimate.

The study by Elrefaey et al. (2022) examines the application of digital technologies in construction projects in the UAE in the context of COVID-19. The disruption sped up remote communication and digital practices, proving that external shocks can change adoption. The UAE is a helpful GCC comparison but there are differences between the countries and pandemic conditions that restrict transferability. The study demonstrates that technology adoption can increase with a need for it, but it does not necessarily mean that the data integration or cost-control maturity of the underlying improved. This separation between frequency of use and transformative ability is applicable to the Saudi survey.

According to the Saudi/GCC synthesis, there are three contextual expectations. First, digital maturity is probably not uniform, and the survey should reflect the extent of digital integration not a yes/no adoption classification. Second, the relationship between technology and cost is likely to be influenced by competence and awareness, and contracts and management support. Thirdly, newer evidence may differ from earlier studies due to recent national and client initiatives. The proposed sample of about 100 public respondents can

provide exploratory evidence at the company level but cannot be statistically representative of the Saudi companies as a whole without a known sampling frame.

2.14 Theoretical framework

The main theoretical approach is information-processing theory. Projects are uncertain due to changing scope, interfaces, market prices, productivity and stakeholder decisions. Capacity to acquire, interpret, and communicate information at the right rate and richness for that uncertainty is essential to effective cost management. Digital integration, automation, analytics and real-time visibility increase potential processing capacity. If capacity is adequate to meet information needs, estimates and forecasts can be made earlier and decisions made based on a more coherent evidence base. If capacity is too high and the data quality is too low, the organization has noise instead of control.

This lens is used to describe the proposed direct relationship without making the assumption that any given tool is always effective. BIM enhances capacity through scope and quantities; platforms enhance availability and exchange; sensors and twins enhance observation; analytics enhance pattern detection; and digital reporting enhances communication. There are examples in the literature at each of these points (Choi et al., 2015; Fuller et al., 2020; Taboada et al., 2023). The theory also states the boundary conditions: interoperability, data standards and competencies determine the usability of nominal capacity.

Dynamic-capabilities theory complements information processing theory by providing explanations for action and renewal. Sensing, seizing and transforming capabilities are the ones that transform digital opportunity into organizational change, as demonstrated by Warner and Wäger (2019). Cost dashboards and forecasts contribute to sensing. Seizing is authorization, intervention and reallocation of resources. Transforming is the process of standardizing data, revising roles and learning from forecast errors. A company may have information-processing technology, but fail to have the dynamic capability to utilize it. That is why readiness should be part of—or at least next to—the digital-transformation construct.

The process-level explanation of the dependent variable is offered by feedback-control theory. To complete a control cycle, a standard or baseline is needed, then the actual state is observed, followed by a comparison to the standard, a diagnosis, corrective action, and then feedback. Some aspects of this cycle are operationalized in EVM and forecasting research (Anbari 2003; Batselier & Vanhoucke 2015). Digital transformation can cut time for observation and comparison, add depth to diagnosis and track action. It will not cover a bad baseline or a lack of authority. Cost management-effectiveness scale should therefore include the entire practical cycle and not just report speed.

The three lenses are compatible but not redundant. Under uncertainty, information-processing theory provides an explanation for the importance of connected data. Dynamic capabilities are the means by which organizations organize information and alter routines. Feedback control provides an understanding of the order in which cost performance is managed. They complement a socio-technical model in which digital transformation is expected to lead to cost-management effectiveness based on the ability to increase information capacity and to respond to it more effectively, provided that it is prepared and governed. The proposed cross sectional design can test the relationship between the two latent constructs but cannot distinguish between mediation or temporal capability development.

2.15 Conceptual Model and Hypothesis Development

The five related dimensions are proposed as the components of the higher-order independent construct of digital transformation capability. Digital data integration is the issue of whether design, schedule, procurement, progress and cost information can be linked. Automation and analytics relate to the extent to which routine processing and pattern detection aid work. Real-time visibility relates to the timeliness and access to current status. Interoperability issues are related to exchange without duplicate entry and traceable meaning.

People/process readiness relates to training, standardized processes, support and actual use in decisions. This structure is based on the basic difference between technology and transformation (Vial, 2019; Verhoef et al., 2021) and the evidence of implementation in BIM and Saudi studies.

The dependent construct project cost-management effectiveness has five dimensions. Estimate and update quality discusses if cost data is accurate for the current scope and assumptions. Monitoring visibility includes timely recognition of commitments, actuals and variance. Forecasting and early warning deal with anticipated final cost and new exposure. Change-control responsiveness is about the speed and traceability of impact assessment and authorization. Cost decision quality refers to the provision of understandable evidence to managers in a timely fashion. These dimensions are consistent with the BIM, change and AI and EVM literatures, but do not involve financial disclosures.

There is converging, albeit indirect, evidence for a positive correlation. Technical studies have demonstrated the ability of models and databases to automate quantities, link cost data and evaluate change (Choi et al., 2015; Handayani et al., 2019; Le et al., 2020). Reviews and cases have documented BIM benefits related to cost, with a focus on variability and barriers (Bryde et al., 2013; Sepasgozar et al., 2022). Retained data and combined methods can enhance the prediction under studied conditions as indicated by forecasting studies (Batselier & Vanhoucke, 2017; Kim & Kwak, 2018). Saudi research indicates that the technologies and barriers are available locally, but do not always test the effectiveness of cost management directly.

Based on this, the following alternative hypothesis is proposed: H1: Digital transformation capability has a positive relationship with perceived project cost-management effectiveness in Saudi companies. The null hypothesis is: H01: There is no significant relationship between Digital transformation capability and perceived project cost-management effectiveness in Saudi companies. For regression reporting, the term “impact” in the thesis title should be taken as predictive association, unless temporal or quasi-experimental evidence is subsequently gathered.

When sample size and reliability allow, dimension-level hypotheses can be used for diagnostic purposes. H1a: There is a positive relationship between digital data integration and cost-management effectiveness. H1b: automation and analytics are positively related to cost-management effectiveness. H1c: The effective management of costs is linked to digital visibility in a timely manner. H1d: The more interoperable the system is, the more effective cost-management is. H1e: The relationship between people/process readiness and cost-management effectiveness is positive. Five correlated predictors may cause overfitting if there are about 100 responses. The primary analysis should be based on an overall score or a parsimonious factor score; dimension models should be secondary and presented with variance-inflation diagnostics.

Controls or group variables such as job level, project experience, sector and organization size may be used instead of central causal predictors. Lower-level staff can make good observations on the work flow, but cannot be seen as much as senior managers. The analysis should aim to determine if there are any differences in perceptions between the broad job-level groups (excluding operational staff). Small cells must be aggregated prior to ANOVA or dummy-variable regression. Controls must not be added mechanically, as each will take away degrees of freedom and can mask a stable primary relationship in a sample close to 100.

2.16 Extended critical synthesis throughout the project cost-management cycle

Front-end definition and conceptual estimating

Digital transformation starts to impact cost management early, even before there is a detailed design or formal budget. A front-end estimate is a preliminary estimate made with limited information to determine feasibility, to compare concepts and to set funding

expectations. Digital models can then make these assumptions explicit and enable the calculation of alternatives consistently, and historical databases and AI can help find similar patterns. What matters is not that a system knows the future, but that assumptions, quantities, rates and uncertainty can be changed without having to reconstruct an estimate from disjointed documents. However, in cases of limited initial data, García de Soto and Adey (2016) show that a hybrid solution, which includes resource-based domain logic and AI, is more feasible than an unqualified “AI estimate.”

There is a representation problem for early digital estimation. Design models include geometry but exclude procurement strategy, temporary works, contractor overheads, escalation, location factors and risk. Choi et al. (2015) intentionally restrict their open-BIM take-off to the building frame at schematic stage to show the power and the limits of automation. In a similar vein, Ma and Liu (2014) demonstrate intelligent information acquisition, although the acquired attributes remain to be interpreted in terms of cost. These prototypes would be treated as complete automated estimates in a literature review, missing out on non-modelled scope. Digital capability enhances the structured evidence provided to estimators, and scope completeness and contextual adjustment are determined by professional judgment.

Historical analytics present a problem of comparability. Bilal et al. (2016) highlight the opportunity and challenge of using diverse construction data. Once the database is filtered by asset type, size, location, procurement, specification, market date and risk, there are only a handful of projects that are truly comparable. The too general classes will yield inaccurate averages and the too specific classes may be statistically weak. Systematic comparison is possible with digital transformation, but there is a need for metadata that is not always found in standard cost files. The responses to the question "use of historical data" should therefore be understood as a practice of the organization, rather than as a statement of statistical representativeness of the reference data.

Another front-end mechanism is alternative evaluation. Model and database integration, as demonstrated by Zanni et al. (2019) and Le et al. (2020), can be used to bring analysis beyond initial construction cost to the implications throughout the lifecycle. Capital and maintenance/replacement profiles can be compared repeatedly as designs change, using digital scenarios. This will enhance consistency and transparency, but is subject to uncertain service lives, usage, discount rates and future prices. The technology does not address value judgments in the planning horizon or tolerable uncertainty. Therefore, cost-management effectiveness should be measured by clarity of assumptions and usefulness of decisions, rather than speed of calculations.

Later control is also influenced by front-end estimates, via anchoring. An early figure can be a political or commercial commitment before information is ripe. Quick computation in the digital realm can give the false impression of accuracy. The dynamic capabilities lens suggests that good firms need to be able to adjust their expectations as circumstances shift (Warner & Wäger, 2019). The digitally mature cost process should capture estimate classes, uncertainty ranges and change history to provide decision makers insight into what became more certain and why. A weak process can employ complex software to protect an outdated anchor.

The literature thus suggests that the traceability, repeatability and update speed of estimating is more strongly enhanced by front-end digital capability than absolute accuracy. The accuracy is a function of scope maturity, market conditions, risk quality and reference quality. Respondents should not be asked whether digital technology “makes estimates accurate” because most employees would not be able to make this determination. More defensible questions include whether an estimate can be adjusted if the scope changes, whether relevant historical information is available, and whether the basis for the estimate can be traced.

Detailed Estimating, Budgeting and Baseline Formation

During detailed design, 5D BIM can link the quantity of objects to cost items. Stanley and Thurnell (2014) and Smith (2014) discuss benefits of measurement and option testing, and Monteiro and Poças Martins (2013) explain the need for cost-oriented modeling rules. The cost baseline is not just the total of quantities in the model multiplied by rates. It also distributes budgets throughout control accounts, includes risk and contingency and captures the approved scope and execution strategy. Model linked estimates can enhance inputs but not supplant baseline governance.

The quality of the mapping between design breakdown and cost breakdown is particularly important. Designers use models based on systems and objects, contractors might use work packages, resources or responsibility based, finance systems use accounts and legal entities. There is very rarely a one to one relationship. Interoperability thus needs to be mapped using tables, rules and ownership. Choi et al. (2015) show a standardized exchange at a specific level of scope, but it is necessary to keep the mappings as designs and packages updated when the scope changes, as in a company. Even if technical file exchange is successful, duplicate entry can reappear at the semantic boundary.

The status dimension comes in with budget authorization. Cost systems should show proposed, approved, committed, forecast and actual amounts. A dashboard that merges them without a status indicator can appear up-to-date but lead to incorrect decisions. While Sigalov et al. (2021) demonstrate the potential of formal rules to link information and transactions, their smart-contract architecture also emphasizes the need for clear conditions. In a normal project controls, a change should not be placed in the approved baseline just because the model quantity changed. The key to digital transformation is to maintain the authorization logic while updating the exposure rapidly.

There is a trade-off with baseline detail. Having fine-grained control accounts offers a detailed level of visibility, but requires significant data maintenance and progress tracking. Coarse accounts make it easier to work with the data, but less informative about the causes. Digital tools reduce some processing cost, allowing more detail to be possible, but too much detail can create noise and non-compliance by users. Effective implementation of EVM relies on organizational fit, as noted by Kim, Wells and Duffey (2003). The correct baseline structure is thus a management design decision and not the highest level of detail that a platform can hold.

Another integration benefit is budget uniformity throughout documents. If the estimate, schedule and scope model have common identifiers, teams can verify that the entire scope of work has been allocated a time and a budget. Sacks et al. (2010) show complementarities between information modelling and production-control practices. This is not automated completeness. The management effort and risk allowances and off-model activities still need to be reviewed. Digital checks are most useful when they are used to identify exceptions that require professional attention and not when they are used as a substitute for reconciliation.

The literature reviewed in this chapter is consistent with the non-deterministic model. Digital capability provides structure, repeatability and cross checks. The effectiveness of the baseline is dependent on the scope of the authorization, realistic assumptions, coding design and user ownership. If the proposed study identifies a high correlation between digital transformation and cost management in the perception of the reader, it is coherent with the improvement of the baseline practices but it is not possible to determine which coding or authorization mechanism is responsible for this. For this diagnosis there would have to be qualitative follow-up.

The procurement, commitments and commercial visibility.

Procurement transforms budget intention to commitments and exposure. Project cost management should differentiate purchase orders and subcontracts placed, work received but not invoiced, variations pending, and forecast procurement and actual payments. These states can be linked with an enterprise or cloud platform, provided package and cost codes are compatible. Bharadwaj et al. (2013) outline the strategic need for a cross-functional

integration of digital resources: procurement and project controls are digital islands that lose cost value when separated.

Model-linked quantities can be used as tools in package preparation and bid comparison. The benefit is greatest if the bidders understand the scope is consistent and if design changes are clearly visible. However, there are qualifications, risk allocation, alternative methods and market capacity that cannot be automatically normalized by a model quantity. The cost manager needs to consider the numerical and contractual differences. Digital transformation can structure the evidence and highlight inconsistencies, but it can't simply be a mechanical comparison of lowest price.

Commitment data is considered reliable, since it is based on contracts, but may be delayed. A likely variation or provisional quantity or currency exposure may be excluded from a subcontract value. Digital systems that show the original order, pending exposure, can underestimate forecast cost. Handayani et al., 2019, demonstrate the assessment of change impacts using connected information, which can be used as a way to include changes before formal approval. Governance needs to differentiate between exposure and approved commitment, otherwise, early warning can taint accounting status.

As discussed by Sigalov et al. (2021), automated payment and contract logic may be used to correlate verified progress with commercial transactions. This automation can reduce processing time and provide uniformity in audit trails. It is contingent on the evidence source, measurement rules and dispute provisions. The construction process often takes place over a period of time, is subject to quality hold points and negotiated valuation. Smart rules are therefore more fully appreciated as the automation of agreed, well-defined cases, with exceptions being sent to humans. There is no literature that supports complete elimination of commercial judgment.

Limits of participation in supply chain restrict end-to-end transformation. A main contractor can then use BIM and an integrated enterprise platform, and smaller suppliers can submit unstructured documents. Employees then serve as translators between environments, and the desired efficiency is only within one organisation. Oesterreich and Teuteberg (2016) list industry fragmentation as a general problem of digitalization. This imbalance could be pronounced in Saudi and GCC markets, where companies vary widely in size and technological sophistication. Company-level survey scores should be read as the company's experience of the workflow integration, not as a reflection of whether all partners are using the same platform.

There are also power and confidentiality issues with procurement visibility. Not all positions in price and contingencies and negotiation can be shared by the project team. Digital maturity is appropriate: role-based access and controlled aggregation. The research instrument must not suggest that all information is to be made available to all staff. A valid statement would be, "Do respondents get the cost information they need for their project responsibilities in time?"

Progress measurement, actual cost and variance diagnosis

Reliable observations of physical progress and incurred cost are needed for monitoring. Progress can be captured faster with digital models, mobile apps, sensors and imagery, and actuals can be added to the control view with accounting integrations. Sacks et al. (2020) explain how digital-twin systems in construction can provide feedback. The crucial qualification is that physical observation, earned progress and commercial entitlement are different concepts. An installed component can be physically installed but incomplete, rejected or not payable. Cost systems should not allow sensor detection to be counted as earned value.

Actual cost is also not instantaneous. Invoices are received after work is done, accruals involve judgement, payroll and equipment records are done at different times, and shared overheads may be done at a later time. Real-time cost is thus a part of a dream. Digital transformation can minimise latency and estimate accruals, but show data date and status.

According to Fuller et al. (2020), data quality and interoperability are important for connected systems. A current-looking dashboard with no clear date cut-off can engender more confidence than the evidence itself.

Integrated dimensions are useful for variance diagnosis. The causes of cost overrun can be quantity growth, rate change, loss of productivity, delay, rework, procurement strategy or coding error. Analysts can get from symptom to probable drivers faster when scope, schedule, procurement and cost data are connected. Boje et al. (2020) see the possibility of semantic relationships that would facilitate such queries. This capability is considered emerging and should be treated as such in their research direction. Many companies still rely on local knowledge of analysts to build causal chains.

Visualization can be used to enhance the communication of variance, especially between professions. Views in BIM can identify impacted work, and dashboards can present trend and status. Bryde et al. (2013) report on coordination and cost benefits of BIM. Scale, thresholds and aggregation choices can impact attention and visualization is not neutral. A red indicator might be a minor coding timing problem, a green summary might mask a major package exposure. Digital cost-management effectiveness is not just about dashboards, it's about being able to go into the details and understand the status.

Frequency of monitoring should align with decision frequency. For design packages that develop slowly, daily data may be unnecessary, but for high volume production, it may be helpful. Too many refreshes can take up mental space and lead to reacting to noise. According to information-processing theory, fit is predicted, not maximum speed. Survey items should avoid the use of the word “real-time” as much as possible, and should instead use words like “when needed” or “timely”. Respondents are able to assess the reports, make decisions without taking on a technical ideal that is not suitable to their project.

Respondents for this stage are especially valuable operational employees. They understand if progress is recorded once or transcribed, if system records are similar to the field reality, and if corrections are easily traceable. Reconciliation work may not be seen by senior managers, but is seen as summarized outputs. Thus, adding rank diversity can enhance mechanism coverage. Even though access and responsibility are shown to affect perceptions, analysis should still test their effect on job level shifts.

Predicting final expenses and warnings.

Forecasting is the process of taking past performance and future exposure and converting it to an estimate at completion. A digital system can gather commitments, actuals, progress, trends, risks and changes, but the forecast is a model of what may happen in the future. Standard EVM extensions are explained by Anbari (2003), and Batselier and Vanhoucke (2015) show how to do empirical evaluations of cost and time forecasts. All these sources indicate that validity and automated calculation are two distinct issues. The organisation has to test predictions against results and change the method of choice.

When forecasting early, there is instability since a little of actual performance is extrapolated over a large amount of work left. Later forecasts are more evidence but less time for intervention. This timing trade-off cannot be avoided with digital transformation; it can only be improved by frequent updates and the introduction of new predictors. A range or risk signal may be the most useful early warning, rather than a point estimate. Acebes et al. (2014) argue for probabilistic control in the face of uncertainty, which questions single-number reporting conventions.

Forecasts made using a combination of methods can be more robust. Batselier and Vanhoucke (2017) combine EVM with exponential smoothing and reference-class forecasting, and Kim and Kwak (2018) propose an adaptive combination approach. The studies offer method-specific evidence that digital analytics can enhance prediction. They are only applicable if there are adequate historical and current data. A company can't just purchase analytical software and create a credible reference class.

Accurate forecasts are not the only measure of performance. A method can perform well with respect to the average error but not alert to extreme overruns. Managers might want to be conservative in their forecast to make their decisions for contingencies, or they might need to be explained before they take action. Interpretability and trust are cited as challenges to AI adoption (Abioye et al., 2021; Pan & Zhang, 2021). To make a cost decision, it is not enough to have a forecast with less statistical error in the test, but also one that conveys the assumptions and uncertainty of the forecast.

Digital forecasts can be undermined by behaviour. Teams are allowed to overrule any negative output, to delay any changes in the input, and to use a method that will maintain the approved figure. On the other hand, managers can take a machine generated result for granted. A mature process documents versions of the forecast, the rationale for overrides and eventual errors. This audit trail makes each project learning evidence. In the transformation capability, as described by Warner and Wäger (2019), there is also a component of renewal of routines, which is provided by the forecasting literature.

Items for early-warning and forecast should be based on practice for the proposed survey: Can emerging cost exposure be detected before it is irreversible; can estimates at completion be adjusted when evidence changes; can digital outputs aid in understanding the decisions made. “Accuracy” can be self-reported and respondents are not expected to compute forecast error. Future research should compare survey maturity scores with the actual forecast-error history for companies with access to the history.

Change, risk, contingency and claims.

Project changes are a significant link between digital information and cost outcomes. Quantities, procurement, sequence, productivity, temporary works and contractual entitlement may all be impacted by a design change. Handayani et al (2019) show an approach to change-order impact assessment integrated with BIM. The benefit is to follow up affected elements and dependencies earlier. The method is not able to provide a complete prediction of cumulative disruption or negotiation outcomes, as they would be influenced by the contract and site conditions. Therefore, digital change control should be a combination of automated identification and documented professional assessment.

Version control is the key. Cost teams need to be aware of which design is authorized, which is being considered, and which has been replaced. Cloud platforms can keep revision histories, and users can still use downloaded/duplicated versions. Whyte and Hartmann (2017) stress the fact that digital information alters the way information is delivered and assumed responsibility for, and the authoritative nature of information must be a component of that delivery. A shared model without status discipline can speed up conflicting decisions.

There needs to be a link between uncertainty identified and cost allowances in risk and contingency management. Often digital risk registers are not linked to the cost forecast, and result in a narrative list of risks without quantified exposure. Integrated systems can connect risks to packages and plan events and contingency drawdown. Acebes et al. (2014) offer a probabilistic control perspective and Zanni et al. (2019) demonstrate scenario-based cost evaluation. Integration enhances consistency, but is sensitive to probability and impact judgments.

Contingency visibility involves a governance trade-off. Excessive transparency can reduce the power of negotiation, but too little disclosure can reduce accountability. Access and approval rules are required based on roles. This again shows why “more transparency” is an incomplete transformation objective. Good cost management ensures that appropriate information is delivered to authorized decision makers and maintains an auditable justification for its use.

Conflict between records and delayed notice is a frequent cause of claims and disputes. Digital platforms can keep correspondence, evidence of progress, model versions and dates of decisions, which may minimize reconstruction work. There is a developing trend toward automated contractual evidence, as illustrated by Sigalov et al. (2021). The interpretation of

the laws, the concept of causation and entitlement remains human and jurisdiction-specific. The thesis should include that traceability can help in claims management, but not that digitalization can do away with disputes.

Saudi BIM studies show that contractual frameworks are among the BIM adoption environments. Algahtany et al. (2023) highlight BIM-related contractual development as one of the critical government initiatives. This local evidence further strengthens the importance of having a perspective on change-control technology in the context of contract governance. A company can be very capable internally but not be recognised as a model company or have digital approvals recognised in contracts. The relationship with cost effectiveness observed may thus differ from client to client and from procurement route to procurement route.

Decision quality, action and organizational learning

Cost information is useful only when it affects a decision or when it substantiates the fact that no change in the decision is required. Variance detection, if timely, can result in redesign, procurement adjustments, resource changes, contingency use or scope decision. This shift from sensing to seizing is known as dynamic capabilities theory (Warner & Wäger, 2019). A digital dashboard is a sensing instrument, and governance, authority and resources will decide whether the organization will take the information. The questionnaire should ask whether digital cost information is used in decisions on projects.

Quality of decisions is hard to measure directly due to uncertainty of outcomes. A good decision can be followed by a bad market event and a bad decision can be followed by a lucky one. Employees can, however, evaluate the quality of a process: Alternatives are compared, Assumptions are made visible, Relevant functions contribute, Decisions are made before options close. The concept of transformation impacts on value-creation and organizational arrangements, rather than on information speed, is supported by Vial (2019) and Matt et al. (2015).

A cross-functional team can help to minimize the blind spots and can help to slow down decisions. Distributed digital innovation is described by Nambisan et al. (2017) and project platforms extend participation. Effective governance specifies who recommends, challenges and approves. Without decision rights, it's repeated review. Digital transformation should, therefore, be linked to better workflow and status, rather than more people on the platform.

Organizational learning completes the cycle. Companies can compare original estimate, approved changes, actual cost/successive forecasts; classify error sources; and update rates or models at completion. The empirical study on which Batselier and Vanhoucke (2015) rely shows the potential of using a real-project database for analysis. Many organizations hold onto final accounts but not the assumptions and forecast versions that are needed to understand error. A learning capable digital environment keeps outcomes and decisions.

Psychological and managerial conditions are required for learning to take place. Forecast error may be used exclusively as a vehicle for assigning blame, and staff may be tempted to hide uncertainty or manipulate classifications. If closeout is performed in a hurry, data is not reconciled. Cultural preparedness is, therefore, a component of people/process readiness that involves the use of negative evidence to enhance practice. This cultural component is hard to measure in a brief questionnaire but can be captured in terms of management support, training and use of lessons.

The literature on cost management tends to focus on the generation of information and the literature on transformation focuses on structural change. If you put them together, you'll see that decision and learning routines are the missing conversion layer. This is why the thesis question cannot be answered by technical studies and adoption surveys. The proposed empirical model explores whether employees experience digital capability improvements, as well as cost-management routines, and offers a foundation for more focused longitudinal research.

The comparative evidence quality and implications for measurement.

The evidence reviewed is of variable quality. Choi et al. (2015), Ma and Liu (2014), Handayani et al. (2019), Le et al. (2020) and Sigalov et al. (2021) show feasibility and illustrate mechanisms under designed conditions. They have high task specificity and low external validity. They can operate in a chosen building, dataset or workflow but company-wide adoption faces varying inputs and incentives. These studies should produce a questionnaire, not prevalence or causal statements.

Reviews by Oesterreich and Teuteberg (2016), Bilal et al. (2016), Abioye et al. (2021), Pan and Zhang (2021), Opoku et al. (2021) and Taboada et al. (2023) offer broad coverage. They find common opportunities and gaps and take over the quality and publication of included research. The number of publications may seem more advanced than practical application in fast-growing technologies, as there are often many conceptual and prototype papers. Reviews provide a comprehensive framework and need to be used with caution regarding realized benefit.

Case studies like Almuntaser et al. (2018) show process and context of implementation. They are good at elucidating the interaction between leadership, skills, workflows, but a firm cannot be a national market. Reported-benefit studies (e.g. Bryde et al. 2013) expand the project base, but may overrepresent documented or successful projects. The thesis should clearly triangulate: technical feasibility, reported benefit, organizational process and local adoption all indicate plausibility, but no single stream makes the proposed relationship certain.

The review has the most explicit quantitative evidence of performance in archival forecasting studies. Instead of asking users if tools are useful, both Batselier and Vanhoucke (2015, 2017) and Kim and Kwak (2018) compare predictions with outcomes. They are strong in objective error measurement, but weak in relying on historical data sets and algorithms. They show that data-driven approaches can enhance forecasting in a studied context, and not necessarily all digital transformation can enhance all cost-management efforts.

Saudi surveys and expert models have high contextual relevance, but primarily capture adoption factors. Competence, demand, standards, policy and management conditions are found important by Al-Hammadi and Tian (2020), Alaboud and Alshahrani (2023) and Algahtany et al. (2023) and Iqbal et al. (2025). The cross-sectional or judgment-based designs they used do not provide a temporal sequence. They provide local assessment of readiness and capability and maintain a central cost-management relationship.

The proposed survey should therefore include several reflective items for each construct, not include any brand names of technologies, and include statements that can be answered using project experience. A five-point agreement scale can be used for reliability analysis and regression, however, acquiescence can be a problem in agreement. Confusing negatives should be avoided, and neutral wording and a limited number of carefully checked reverse statements may help. Specialized practices should have an option of “not applicable” but should not be considered a middle point.

Separation between predictor and outcome wording is required for construct validity. Digital transformation products should be about integrated data, automated processing, interoperability, visibility and readiness. Cost-management items should: describe estimates, monitoring, forecasts, changes and decisions. For example, an item like “digital systems improve our cost forecasts” pollutes both constructs and mechanically adds to the correlation. The relationship is supported by the literature but the hypothesis should not be stated in the questionnaire as an item.

Reliability is not enough. Redundant wording may lead to a high Cronbach alpha. If sample size is adequate, exploratory factor analysis should be used to determine if items group together as they should. The number of indicators should be kept to about 100 and factor results should be interpreted with caution. Correlation and regression can then be used to test composite scores, with diagnostics for residuals, influential observations and

multicollinearity. Comparing visibility between jobs can be done at the job level without excluding lower-ranked respondents.

CMV is another limitation as the same respondent rates digital capability and cost effectiveness at the same time. There are more effective procedural remedies than a single post-hoc statistic: assure anonymity, separate sections, vary anchors where appropriate, avoid evaluative labels, and state that there are no correct answers. Single factor dominance can be checked statistically, but it cannot be proved that there is no bias. The final thesis should address the possibility that positive organizational sentiment raises the relationship.

The result should be interpreted at the respondent-perception level. When regression is significant, the defensible conclusion is that there is a relationship between digital-transformation practices and project cost-management practices, after controlling for selected background variables. Any statement of a percentage reduction in cost overrun or national prevalence or causal impact on audited performance is unconvincing. This precision helps maintain the utility of the study and helps pinpoint the next research step: matched surveys and project records over time and across companies.

2.17 Competing explanations, boundary conditions and propositions

Alternate explanations and reverse causality

The relationship between digital transformation and cost-management effectiveness, if positive, can be interpreted in a number of ways. The proposed mechanism is the connected data, automation, visibility and readiness enhance information and feedback for cost processes. The other is reverse causality: companies with more established project controls might be better equipped to choose and use digital tools. They already have work breakdown structures, coding discipline, historical data and trained staff, making it easier to integrate digital. With one wave, you can't tell which one came first. The final discussion must therefore take into account the reciprocal reinforcement and not state the unidirectional causal sequence as a fact.

As a competing explanation, there is the quality of general management. The increased leadership capability may allow well managed companies to invest in technology, train employees, standardise procedures and control costs effectively. According to Warner and Wäger (2019), transformation is strategic renewal, and leadership and organizational learning are not external elements. If management quality is not included, the digital-transformation coefficient will partially represent it. Readiness and support may be part of the construct of the questionnaire but should not be used as a way of separating out the independent contribution of technology from all management quality.

These can be affected by firm size. Enterprise platforms and specialized BIM teams and data infrastructure might be available to large companies, and they might have formalized project controls. Small companies can communicate informally and rapidly, with no integration overhead, but may not have historical databases or dedicated analysts. Such nonlinear differences may not be captured by a simple size control. There should be broad categories of organization size; about 100 responses should be obtained and findings are exploratory. The relationship does not need to be expected to be stronger in larger companies with less interaction power.

The complexity of the project is also unclear. For complex projects, there is more information required and it may be worth implementing more sophisticated systems; however, there are also more interfaces, uncertainty and change. The company uses high digital capability in the most challenging projects, so high digital capability doesn't necessarily equal poor cost outcomes. According to information processing theory, capacity should be assessed in relation to the information needs. The proposed measure of cost-management effectiveness is not completely free of the problem of raw outcome confounding, but project type and complexity are relevant context for interpretation.

Adoption can be influenced by client requirements and requirements of the supply chain, without the internal readiness to adopt. A contractor can leverage BIM when a client demands model deliverables, but still controls costs via spreadsheets. On the other hand, an experienced cost team might be able to make internal integration without describing the program as transformation. The findings of the Saudi studies on government initiatives and drivers of adoption indicate that external institutions play a role (Algahtany et al., 2023; Iqbal et al., 2025). The survey should assess enacted practice (more akin to capability than formal mandate) and the thesis should include discussion of client requirements as a confounder.

Industry sector can influence available data and cost routines. The representation of assets, procurement, project length and project measurement are different in construction, energy, manufacturing, information technology and services. The evidence in the context of BIM is more applicable to the built environment, and the thesis title is more general in terms of Saudi companies. Whereas the theoretical core (integrated data and feedback) can travel with the final sample, specific tools and terminology cannot. Record the sector and make claims about BIM appear as a prominent project-cost pathway, not the only type of digital transformation.

Boundary conditions and moderators

One of the most obvious moderators is likely data quality. To enable automation and analytics, data must be complete, timely and uniformly coded. Data limitations are repeatedly identified by Bilal et al. (2016) and the AI reviews, and the impact of modeling rules on quantities is demonstrated by Monteiro and Poças Martins (2013). High quality integration can decrease manual reconciliation and enhance forecasting. If the quality is poor, integration can propagate errors and introduce false precision. The present survey incorporates the standardization and trust in the ability construct, and a larger study might examine data quality as a distinct variable.

People capability is a second moderator. Smith (2014) predicts that cost professionals will assume more of an analytical role, while Pan and Zhang (2021) and Taboada et al. (2023) demonstrate that AI-driven decisions will demand new knowledge. Sources, assumptions and exceptions must be understood by the user. Training influences the likelihood of using systems as designed and the ability to challenge outputs. Competency development and limited expertise are identified as locally salient competencies (Al-Hammadi & Tian, 2020; Algahtany et al., 2023). These findings support the importance of readiness on par with technical dimensions.

Support of top management is essential but not enough. Leaders may be able to pay for platforms and demand reporting, but too much focus on positive indicators can create a lack of data integrity. Dynamic capabilities involve leaders recognizing and embracing negative information, rather than just promoting technology. Support involves resources, clarity of roles, tolerance of early learning and willingness to change decisions. An open-ended question asking management simply if it supports digital transformation can get the nod of the ceremonial variety. More specific language should be used to ask if managers are using digital evidence and offering training or process resources.

Interoperability moderates the return from individual applications. A disconnected, high-quality model can still be used for visual coordination, but needs manual transfer for financial control. Choi et al. (2015) show the standardized quantity exchange, while Jang et al. (2021) present the platform-level continuity. The overall evidence points towards complementarity: the usefulness of one technology increases if there is also connectivity of data and processes. This is why counting applications is not a good maturity indicator.

Another moderator is contract and procurement arrangements. Integrated delivery can help to create incentives to share information, while adversarial or fragmented delivery can limit information. Sacks et al. (2010) provide evidence of management complementarities associated with BIM, while Whyte and Hartmann (2017) articulate the transformation of delivery relationships through digital information. While the Saudi government and industry efforts will continue to adjust the expectation of the contracts, companies have diverse client

contracts. The proposed study should not attempt to test detailed contractual interactions with a small sample; they should be set as a boundary.

The maturity of the technology and time since implementation are important. Early adoption may lead to a short period of parallel running of old and new processes and a corresponding increase in workload. Benefits may only be realized after coding, templates and historical data are stabilized. Comparisons across sections can then underestimate mature effects or mask steady-state capability. The instructions for the survey should include questions on the usual practices in the project, and the analysis could include years of digital-project experience as a descriptive variable, if available.

Trust and explainability moderate analytical use. Interpretability is recognized as an AI challenge by Abioye et al. (2021), and forecast combinations can be methodologically sophisticated as demonstrated by Kim and Kwak (2018). Users must be given sufficient information to determine if a forecast is related to the scope and risk at the time. Failure modes include blind trust and blanket rejection. The desired capability is calibrated reliance: routine automation for stable cases, visible assumptions and human review for exceptions.

The transferability of Saudi companies.

International BIM and forecasting research provides mechanisms, not automatic national predictions. Professional roles, standard forms, classification systems, client maturity and supply-chain structures are diverse. The findings of Stanley and Thurnell (2014) in New Zealand and the findings of Moses et al (2020) in the UK should not be extrapolated to the Saudi context, but the content of their questionnaires could be applied. The thesis should clearly identify the evidence used for concept definition, and the evidence used for local context.

Saudi evidence shows that adoption is not even and competence, awareness, contractual support, and government initiatives are required (Al-Hammadi & Tian, 2020; Al-Yami & Sanni-Anibire, 2019; Algahtany et al., 2023). The reason this is analytically useful is that a relationship can only be estimated by the variance of digital capability. It also poses sampling risk; that is, respondents who are interested in digital practice may overrepresent more mature firms. Recruitment should be done through a wide professional network and not just by advertising the survey to BIM specialists.

The public survey design is not a probability sample, but a practical solution to access problems. Lower level employees may see data entry, report prep and reconciliation with field that higher level employees don't. Senior staff members may be knowledgeable with budgets, strategy and authorization, but don't experience as much operational friction. There is no right or wrong. The questionnaire should be observable practices and the analysis should be done at the level of broad job groups to see if there are systematic differences in visibility.

If the instrument is reliable and the number of predictors is small, then about 100 responses will support a parsimonious regression. It is not enough for a complex structural equation model with many dimensions, interactions and controls. The literature indicates a rich causal system but the empirical model should be proportionate to the data. The main test is an overall digital-capability composite that predicts an overall cost-management composite. Exploratory correlations and individual regressions with caution may be reported at the dimension level.

Transferability is also influenced by language. The digital and cost terms are sector and rank dependent. If an Arabic version is used, translation and back-translation should maintain the concepts of commitments, estimate at completion, approved change and interoperability. Research in Saudi Arabia, such as that of Algahtany et al. (2023), has employed bilingual survey procedures, highlighting the importance of language accessibility. Definitions should be brief and functional to assess practice, not technical in English.

Where digital transformation is linked to modernization and national development, social-desirability bias may be high. Respondents might overstate skills or hesitate to criticize an employer. Anonymous collection, the absence of an employer-name question and neutral

wording reduced this pressure. The consent statement explained that answers concerned general experience and would be summarized. Positive-response bias nevertheless remains a study limitation.

Dimension-level proposition development

Direct relations between digital data integration and cost-management information are the most obvious. According to model based quantity studies and relational database systems, it is possible to reduce manual acquisition and support updates by connected scope and cost data (Ma & Liu, 2014; Le et al., 2020). That value is extended throughout the control cycle with integration with schedule, procurement and progress. The reverse side of that is that those who feel more integrated will give more accurate and timely costs information, when data quality is considered.

Repetitive effort can be minimized and prediction improved with automation and analytics. AI reviews document applications ranging from estimating to monitoring and project management (Abioye et al., 2021; Taboada et al., 2023), and forecasting studies reveal certain accuracy improvements under tested conditions (Batselier & Vanhoucke, 2017; Kim & Kwak, 2018). The proposition is positive but conditional: analytics are useful if data are comparable and outputs are reviewed. The questionnaire should assess the usefulness of the routine support, not the mere adoption of AI.

Early warning could be enhanced by timely visibility. There is literature on digital-twin and feedback to explain the comparison between current observation and expected state (Sacks et al., 2020; Fuller et al., 2020). Cost management benefits are realized when emerging exposure is seen and corrective options are still available. The proposition is about timing of decisions, not about accounting in real time. So items should not promise “real-time actual cost”, but use “timely”.

Interoperability should minimize reconciliation delay and inconsistency. The possibility and dependence on standards are shown in both the Open-BIM quantity research and modeling-guideline studies (Choi et al., 2015; Monteiro & Poças Martins, 2013). The idea is that if fewer employees report duplicate transfers and there is more transparency about the transfer process, they also report more effective cost updates. A high digital score can mask poor interoperability items.

People/process readiness is expected to turn technical capability into action. Skills, management, awareness and organizational change are common themes in the intersection of dynamic-capabilities theory and adoption studies in Saudi Arabia (Warner & Wäger, 2019; Al-Hammadi & Tian, 2020; Algahtany et al., 2023). Readiness can function as a component, a moderator or an antecedent. The small sample size may suggest a focus on capability dimensioning, and future studies might involve mediation or interaction with larger, longitudinal data.

The dependent dimensions are also reinforcing each other. Disciplined change control maintains the meaning of the baseline; better monitoring improves the inputs into the forecast; better forecasts identify changes or risks that need decisions; decision feedback improves future estimates; and better estimates improve the monitoring baseline. The cycle is based on feedback-control logic and evidence of EVM implementation (Anbari, 2003; Kim et al., 2003). Although each practice may be diagnostically different, factor analysis may reveal a common cost-management factor.

Limits of integrated proposition and interpretation.

The integrated proposition is not that all digital technologies can enhance all cost tasks. That companies who have more connected, automated, timely, interoperable and organizationally embedded project information would be expected to demonstrate more effective estimating, monitoring, forecasting, change control and cost decisions. This formulation is in line with the evidence but does not claim to be universal for a specific tool. It is also held accountable by workers in all industries and levels.

Internal consistency and item-total behavior and construct separation should be established before testing the main hypothesis. If some of the digital dimensions do not load together, do not force a composite in order to get a regression. The measurement result is substantive evidence: it can indicate that Saudi respondents differentiate between technical integration and readiness. Then the model may be simplified or reported separately depending on the number of samples.

A statistically significant relationship would provide support for the literature-based mechanism set, but would not establish causation. However, reverse causality, management quality, and selection into digital projects and common-method bias are still possible. The size of the effect and confidence intervals are more important than the threshold p value. A small significant coefficient is likely to be a true modest coefficient, whereas a large uncertain coefficient is likely to be an unstable sample coefficient. The final thesis should include unstandardized and standardized coefficients, model fit, residual diagnostics and assumptions.

It would also be informative if there were a non-significant result. It may be because digital competence is not consistent, because tools are not embedded in cost processes, because measurement is weak, or because the organizational and contractual conditions prevail. It should not be seen as a sign that digital transformation is worthless. Correlations of dimensions and patterns of description can help determine where integration, analytics, visibility, interoperability or readiness is the weak link.

Finally, the literature provides an empirical and disciplined contribution: the available and current evidence of the perception of the relationship between the enacted digital practice and the cost-management routines of project employees in Saudi companies. The contribution is less in the sense of an audit of cost savings but more than an adoption-opinion survey. It directly tackles how future firm-level and longitudinal studies can link transformation to proven project outcomes.

Evidence required following the survey, measurement logic.

The proposed instrument should differentiate between exposure and capability and outcome. Exposure refers to whether the respondents have been involved in projects that involve the relevant digital systems; it is a useful screening tool but not a predictor. Capability relates to what the connected environment routinely enables and is the independent variable. Outcome is what is measured and depends on the effectiveness of cost-management practices, and is the dependent variable. Separating these levels prevents the respondent who has simply seen BIM being regarded as proof of a company's transformation capability. It also does not require respondents to make a cost effectiveness statement prior to the statistical test.

Each scale item should express one idea. Statements that mix integration, accuracy and speed are hard to understand because a respondent may agree to one part of the statement but not the other. For instance, "Our integrated systems deliver accurate cost reports in a timely fashion" combines architecture, quality and timeliness. Three shorter items can determine if information is related, if the source is reliable, and if it is received in time. This makes the questionnaires longer, but the final design of 20 questions may include matrix questions with multiple Likert statements without increasing the number of questions shown. Each statement should be considered a separate variable in SPSS.

The answer choices must be the same for each matrix. Respondents of all ranks have access to a five-point agreement scale ranging from strongly disagree to strongly agree. There is a separate "not applicable / cannot judge" option to avoid uninformed midpoint answers for specialized practices. This option should be specified as system-missing, not as the numeric midpoint. Too many missing data points can then show that an item needs knowledge that is not known by many of the public samples. An item should not be kept because of its technical sophistication.

Content validity needs to be determined prior to public release. A minimum of one project-controls or cost-management practitioner, one digital/BIM practitioner and one research-methods reviewer should evaluate if the items include the constructs and are easily understood

beyond senior management. Ambiguity, completion time and unexpected interpretation can be identified by a small pilot. This is the chapter's main theme: even a sophisticated concept is of little value in practice if the common project employee cannot apply it consistently.

Data collection was followed by descriptive analysis, reliability assessment, bivariate correlation, multiple regression and a role-group comparison. Frequencies were used to assess sample composition, and item distributions were examined for response concentration. Cronbach's alpha assessed internal consistency for the multi-item constructs. The regression tested the three prespecified digital-capability predictors together, while the Welch comparison accommodated unequal group sizes and variances. Because the sample was modest and the thesis was designed around prespecified business-management constructs, an exploratory factor model was not used to manufacture a more complex statistical structure.

There are substantive meaning assumptions of regression as well. If there is a high correlation between the digital dimensions, it may be that respondents perceive integration, visibility and interoperability as a single capability. Heteroscedasticity could be due to the fact that the cost practices of firms vary more at higher maturity. Influential cases can be legitimate respondents from highly developed or highly decentralized organizations, not necessarily errors. Diagnostic decisions should be recorded and results from influential observations compared with results from no influential observations, if appropriate.

Uncertainty should be included in the analysis. The confidence intervals for correlations and regression coefficients tell about the precision that can be achieved with about 100 responses. Practical interpretation should not be replaced by statistical significance. A standardized coefficient can be discussed in terms of the five-point scale, but cannot be converted to a percentage of project cost saved. Perceived effectiveness of practice, not variance in currency, is measured by the dependent variable. This boundary should be included in the abstract, results and conclusion, and it should not be limited to a limitations paragraph.

The survey can help to create ideas for more effective designs in future. A multi-company study may correlate the capability score of employees with forecast error, change-cycle time, cost-report latency or final cost variance. A longitudinal study could be conducted that would track the same projects before and after the implementation of an integrated platform, capturing the maturity of implementation and market conditions. A mixed-method case study might document the path of a digital signal from its initial emergence to its adoption (or not) as a management action. The present cross-sectional survey would not provide evidence for temporal order and mechanism in these designs.

Finally, the open-access evidence base makes the auditability easier. The readers can examine the technical systems, reviews, forecasting tests and Saudi adoption studies used to support each construct. Even if an article is open access, it does not mean that it does not require critical appraisal, as paywalled articles do. The source ledger thus documents the support and the lack of support that each study offers. The final Word document should contain links to the full text of the article or DOI in the reference list to enable supervisors to check context, not decorative citations.

2.18 Research gap

The first gap is an outcome gap. Saudi studies mainly focus on BIM awareness (Al-Hammadi & Tian, 2020), BIM adoption (Alaboud & Alshahrani, 2023) barriers (Algahtany et al., 2023), drivers or government initiatives (Iqbal et al., 2025). They set up that digital construction is locally relevant and institutionally conditioned, but they do not directly measure the perceived effectiveness of estimating, monitoring, forecasting, change control and cost decisions. The proposed study moves from intention to adopt to a project-control construct.

The second gap is a construct gap. Much research identifies digitalization with the use of BIM or a named technology. The basic literature provides a broader definition of

transformation and construction evidence indicates BIM value is dependent on platforms, data standards, analytics, and human routines. The proposed research, therefore, adopts a multidimensional capability construct. This prevents having to imagine that a company with isolated software is the same as a company with connected and governed workflows.

The third gap is a respondent gap. In published BIM and cost studies, the attention is usually directed towards quantity surveyors, managers, experts or firms that are known to have adopted a technology. These samples offer the expert point of view but can lack operational experience and may overrepresent enthusiasts. The proposed public survey contains employees of all ranks with project exposure. It does not rely on budget numbers, executive knowledge, or an observation of practices. The drawback is that public recruitment leads to non-probability sampling and company coverage is uncertain.

The fourth gap is an evidence conversion gap. Technical prototypes show what systems can do and organizational studies show barriers. There are fewer studies that relate everyday integration, automation, visibility and readiness with cost-management routines in one empirical model. This is the perception level regression test of the proposed link. Its findings can indicate if firms that are more digitally capable also achieve better scores for cost work. They cannot establish audited savings, rule out reverse causality or determine which specific application caused the association.

The fifth gap is the contextual and the temporal gap. The Middle Eastern baseline studies are older than the recent Saudi policy and market and project developments, and newer Saudi studies are on adoption structures. International data from the United Kingdom, New Zealand, Europe or East Asia have different contractual and professional structures. A recent survey conducted by a Saudi company offers some exploratory evidence, but conclusions are limited to the sample and the time period. It should be used in conjunction with, not as a substitute for, firm records or longitudinal case research.

2.19 Integrated concluding chapter summary

There is support in the literature for a nuanced expectation that digital transformation is positively linked to the effectiveness of project cost-management. The most robust mechanisms are reduced information latency, duplicate entry, enhanced traceability, shared visibility, predictive capacity and organizational learning. BIM and 5D studies present detailed evidence of quantities, estimating and cost integration; platform and digital-twin studies continue the logic of connected, dynamic information; AI and forecasting studies demonstrate the power of data to enable earlier and potentially more accurate forecasts. None sets an automatic or universal cost benefit.

The critical synthesis also highlights factors that can dampen or reverse the relationship: poor model and master-data quality, incompatible coding, lack of skill, fragmentation of contracts, security constraints, weak baselines, and unclear decision rights and behavioral bias. It is noted that Saudi studies validate expertise, awareness, demand of clients, contracts, organizational support and government initiatives as salient. They also indicate that local research has focused on adoption, not on cost-management effectiveness.

The thesis therefore treated digital transformation as a socially enacted technological capability and project cost management as a set of observable control practices. The central hypothesis concerned a positive association between these constructs in the achieved Saudi-company sample. Neutral practice statements, reliability assessment, correlation and multiple regression were used to test the model in a form accessible to employees at different ranks. Because the design was cross-sectional and non-probability based, the results are reported as associations with uncertainty and do not claim that technology caused project-cost outcomes.

This chapter established a model that employees at different ranks could answer without disclosing confidential project accounts. It specified five objectives, five matching research questions and five paired hypotheses. Three digital capabilities were tested as predictors of a

six-item perceived cost-management outcome, and job level was used for the planned role comparison. Chapter Three describes the procedures applied to the retained survey data.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter explains the research philosophy, design, population, sampling approach, instrument, ethical safeguards, variable coding and statistical analysis actually used. The final analysis drew on 100 complete eligible responses contained in the retained Excel survey file. The methods are reported as implemented, while procedures for which no retained documentation was available are not presented as completed activities.

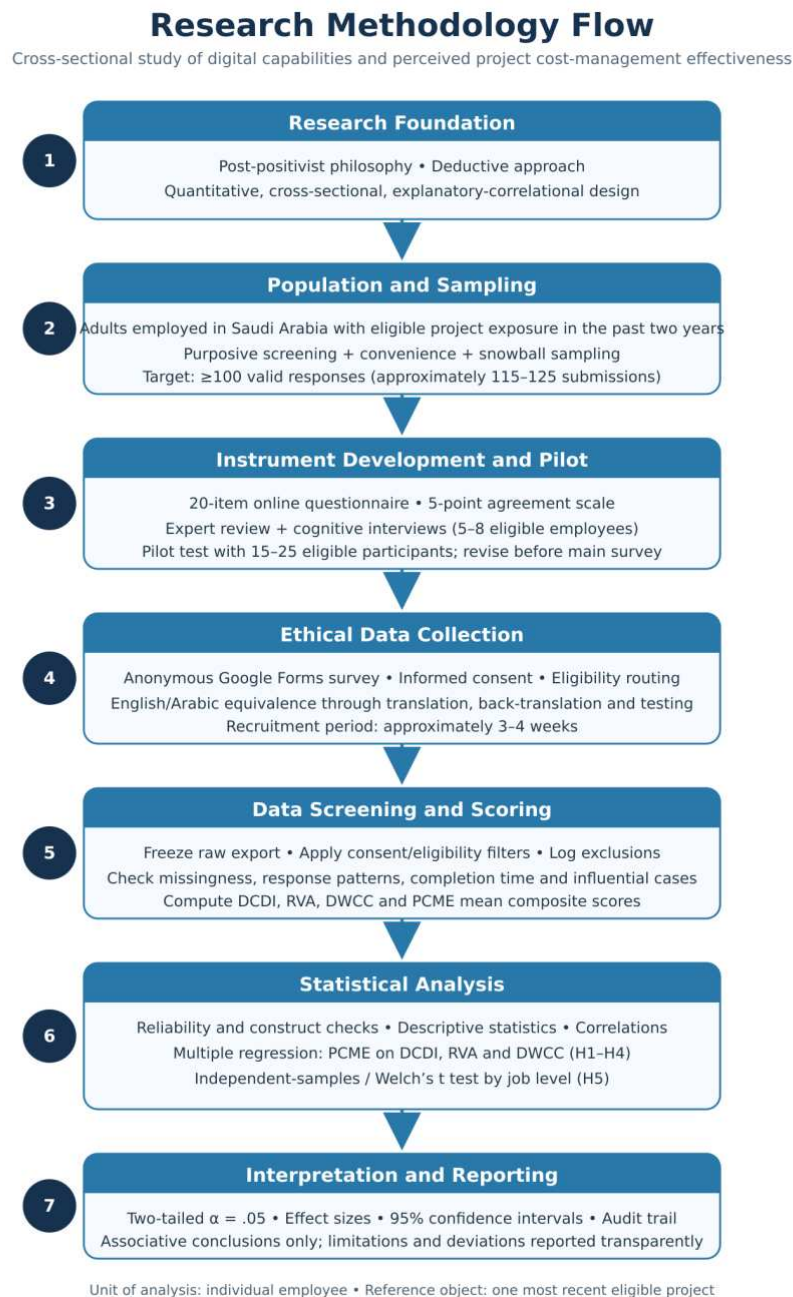


Figure 3.1. Research methodology flow.

3.2 Research Philosophy and Approach

The study is based on a post-positivist quantitative approach. It is based on the premise that fallible but meaningful indicators of digital control practices and perceived cost-management effectiveness can be provided by project employees. Multiple items are used because a latent organizational capability cannot be measured perfectly by one question. Reliability, validity, uncertainty and alternative explanations are explored rather than scores being treated as fact (Creswell and Creswell, 2018; Saunders, Lewis and Thornhill, 2019).

The approach was deductive. Digital-transformation, information-processing and management-control literature informed a model linking integration, visibility/analytics and workflow support to perceived cost-management effectiveness. The hypotheses and three-predictor structure were specified before interpreting the observed coefficients, and the non-significant workflow result was retained.

3.3 Research Design and Unit of Analysis

The study used a quantitative, cross-sectional, explanatory-correlational design. Each participant completed one online questionnaire about one recent eligible project. Pearson correlations described bivariate relationships, simultaneous multiple regression estimated conditional associations, and a Welch independent-samples comparison examined broad job-level differences. Because exposure and outcome were recorded at one point in time, the design did not establish causal impact.

The unit of analysis was the individual employee and the outcome was perceived PCME. A project served as the reference object, but not the statistical unit, because anonymous distribution did not establish whether multiple respondents came from the same identified project. The data were therefore neither aggregated to project or company level nor reported as audited project scores.

3.4 Target Population and Eligibility

The target population consists of adults who are currently employed in Saudi Arabia and who have personally participated in the last two years in a project in which the use of digital tools has been directly involved in the cost or closely related cost control information. Respondents are eligible if they developed, viewed, accepted, shared or frequently accessed digitally-supported cost, schedule, progress, procurement, contract or change information. The eligibility wording includes lower ranking employees who have had real process exposure and excludes general public opinion.

Participants were instructed to use one recent eligible project as the reference for Questions 6–20. The retained dataset contained 100 respondents who consented, confirmed current employment in Saudi Arabia and confirmed direct involvement in a digitally supported project during the previous two years. All 100 substantive records were complete.

3.5 Sampling Strategy and Recruitment

A probability sampling frame for eligible project employees across Saudi sectors was not available. The achieved sample was therefore treated as a screened convenience sample drawn through accessible professional and personal networks. Eligibility questions limited participation to respondents with direct recent exposure, but the resulting sample cannot be treated as statistically representative of all project employees in Saudi Arabia.

The final sample included 42 non-managerial respondents, 30 supervisors or team leaders, 21 project or functional managers, four project directors or senior executives, and three respondents who preferred not to state their role level. Sector representation was broad but uneven, with the largest group from construction, engineering, infrastructure or real estate. These distributions were reported descriptively rather than used to claim national representativeness.

3.6 Sample Size and Power

The primary model contained three predictors. A conventional medium-effect planning benchmark of $f^2 = .15$, $\alpha = .05$ and .80 power indicates a requirement of approximately 77 complete cases for a three-predictor regression (Cohen, 1988; Faul et al., 2009). The achieved sample of 100 exceeded that benchmark and was adequate for the planned simple model, although it remained too small for detailed interaction, sector-specific or structural-equation models.

All 100 retained cases were complete and eligible, so no statistical imputation was required. The analysis remained deliberately limited to the prespecified constructs and one broad role-level comparison. The sample supports interpretation of medium overall relationships but does not guarantee adequate power for small unique coefficients; the non-significant DWCC estimate is therefore treated as statistically inconclusive rather than proof that workflow and change control are unimportant.

3.7 Instrument Design

There are a total of 20 numbered questions in the survey. Q1–Q3 establish consent and eligibility, Q4–Q5 describe job level and sector, Q6–Q14 measure three predictors and Q15–Q20 measure PCME. Substantive items: 5-point agreement scale. All items relate to a single project and are intended to be answerable without specific cost data.

There are 3 items on each of the 3 predictor scales. DCDI captures connection, consistency and reduced reconciliation; RVA captures timely visibility, warning and forecast updating; DWCC captures approval traceability, change linkage and corrective action. The outcome has six items to cover distinct cost-management functions. There are no reverse-worded items as this can cause method effects and confusion in a short multilingual workforce survey.

The instrument was theory-driven and contextualized for this study rather than presented as an established standardized scale. Item wording was designed around practices visible to employees without requesting confidential cost values. Because no retained formal expert-review or cognitive-interview record accompanied the final dataset, the thesis does not claim that a documented validation panel or formal cognitive-interview programme was completed. Construct interpretation is therefore supported mainly by theory, item content and observed internal consistency.

3.8 Pilot Study

No separate pilot dataset or pilot revision log was retained with the final research files. Accordingly, the final thesis does not claim pilot-based reliability or pilot-driven item changes. Reliability estimates reported in Chapter Four are based on the 100-case final dataset.

This limitation does not invalidate the survey, but it narrows the validity claim. The items have clear theoretical alignment and acceptable internal consistency, while future work should undertake documented expert review, cognitive interviewing and independent scale validation before treating the measures as established instruments.

3.9 Data Collection Procedure

The questionnaire was implemented in Google Forms and the final response file was exported to Excel. The opening section explained the study, stated that participation was voluntary and anonymous, and screened consent, current employment in Saudi Arabia and recent direct project exposure. The retained workbook contained no names, employer names, project identifiers or financial values.

The analysis used the retained 100-row Excel export as the source dataset. Each row contained responses to the same 20 questions, and all substantive Likert items were complete.

No duplicate full response and no duplicate 15-item Likert response pattern was identified. Exact invitation counts, reminder counts and collection dates were not stored in the analytical workbook and are therefore not claimed in this thesis.

The analytical workbook did not contain a form-language variable, so no language comparison was performed and the thesis does not claim a documented bilingual back-translation procedure. The wording reproduced in Appendix A is the English questionnaire used for interpretation of the retained variables. A future multilingual replication should use independent translation, back-translation and cognitive testing (Brislin, 1970).

3.10 Ethical Considerations

The form required voluntary consent and did not request project names, company names, contract amounts, actual costs, contingency values, vendor/client identities, system-security details or individual performance information. All 100 retained respondents selected consent and met both eligibility conditions. No claim is made here about an ethics approval identifier because no such identifier was present in the retained analytical materials.

The Excel dataset was handled as an anonymous research file and used only in aggregate analysis. Results were reported for sufficiently broad groups, and the three “prefer not to say” role responses were retained in the overall analyses but excluded from the two-group role comparison because they could not be assigned legitimately to either category.

3.11 Variable Coding and Composite Scores

Agreement items were coded from 1 = strongly disagree to 5 = strongly agree. DCDI was the mean of Q6–Q8, RVA the mean of Q9–Q11, DWCC the mean of Q12–Q14 and PCME the mean of Q15–Q20. All retained substantive responses were complete; consequently, every composite used all of its assigned items and no missing-item rule or imputation was needed in the final dataset.

Role categories were reported descriptively. For H5, the 42 non-managerial employees formed one group and the 55 supervisors, managers, directors and executives formed the managerial group. Three “prefer not to say” responses were excluded only from that comparison. Sector was used descriptively and was not entered as a control because several categories were too small for stable sector-specific inference.

3.12 Data Screening

Data screening began with the retained Excel file. Consent and eligibility frequencies were checked, Likert values were mapped to the 1–5 coding scheme, item completeness was confirmed and full-row and substantive-pattern duplicates were examined. The workbook contained 100 eligible complete cases, no impossible Likert values and no exact duplicate response records.

Because all 1,500 substantive item cells were complete, no cases were removed for missingness and no values were imputed. The analytical denominator for reliability, correlations and regression was therefore 100. The role-level comparison used 97 cases because three respondents selected “prefer not to say.”

Item responses were bounded from 1 to 5. Unusual but valid response combinations were retained because disagreement or mixed ratings can represent genuine project experience. Regression influence was assessed using residual and Cook-distance diagnostics rather than deleting cases simply because their views differed from the majority.

3.13 Reliability and Construct Validity

Cronbach’s alpha was calculated for DCDI, RVA, DWCC and PCME. The values ranged from .741 to .903, exceeding the commonly used .70 reference point while being interpreted in light of the short three-item predictor scales (Nunnally & Bernstein, 1994). The results

support internal consistency in this sample but do not by themselves establish construct validity.

Content interpretation was based on the theoretical mapping of each item to the proposed capability. A four-construct measurement structure was retained, but no confirmatory factor analysis was claimed because a sample of 100 is limited for stable measurement-model validation. Future research should test the structure on a larger independent sample.

Common-method risk was reduced procedurally through anonymity, one-project anchoring and neutral practice-focused wording, but it was not eliminated because the same respondent rated predictors and outcome (Podsakoff et al., 2003). The observed relationships may therefore partly reflect shared perception or response style, and the results are not presented as audited project-level effects.

Discriminant interpretation was supported by moderate inter-scale correlations and low regression collinearity. Predictor correlations ranged from .343 to .395, and the maximum VIF was 1.28. These values did not suggest that respondents treated the three capabilities as identical, although theoretical overlap is expected because integration, visibility and workflow often operate together.

3.14 Descriptive and Bivariate Analysis

Role and sector were summarized with frequencies and percentages. Items and composites were summarized with *n*, mean and standard deviation, and agreement/disagreement percentages were used for the item discussion. The construct table reports the principal descriptive statistics required for the management interpretation.

Pearson correlations described the bivariate associations among DCDI, RVA, DWCC and PCME. Simultaneous regression then estimated the unique association of each predictor while holding the other two constant. This distinction was central to H3: DWCC correlated positively with PCME, but its unique coefficient was not statistically significant after integration and visibility were included.

3.15 Multiple Regression

PCME was regressed simultaneously on DCDI, RVA and DWCC. The final report includes unstandardized *B*, standard error, standardized beta, *t*, two-tailed *p* and 95% confidence interval for each predictor. For the overall model it reports *F*, degrees of freedom, *R*² and adjusted *R*². H4 was evaluated from the joint model rather than from any single coefficient.

A directional expectation was considered supported when the relevant coefficient was positive and its two-tailed *p* value was below .05. Confidence intervals were used to show precision. A non-significant coefficient in the simultaneous model was interpreted as insufficient evidence of a unique adjusted association, not as proof that the underlying management practice lacks value.

3.16 Assumption Checks and Sensitivity Analysis

Linearity and residual behavior were examined through fitted-model diagnostics. The reported Shapiro–Wilk, Breusch–Pagan, Cook-distance and VIF values did not indicate material residual-normality, heteroscedasticity, influence or collinearity problems. Independence remains an assumption because anonymous distribution could not rule out more than one respondent from the same organization or project.

Tolerance/VIF and Cook's distance were used to assess collinearity and influence. No valid case was deleted on the basis of an unusual opinion. This retained the full 100-case sample for the main model and avoided selective improvement of the results.

The final model used conventional ordinary least squares estimates because the diagnostics did not indicate a material need for a corrective estimator. Robust procedures would not have

corrected the more important design limitations of convenience sampling, self-report measurement and cross-sectional timing.

3.17 Job-Level Comparison

H5 compared mean PCME scores for 42 non-managerial and 55 managerial respondents using Welch's independent-samples t-test. The three respondents who preferred not to state a role level were excluded from this comparison only. Group n, mean, standard deviation, p value and Hedges' g were reported.

The comparison was non-directional. A significant difference would have indicated different average perceptions between the two broad groups, not superiority or dishonesty. The achieved categories were too small for reliable separate conclusions about supervisors, project managers and senior executives.

3.18 Hypothesis Decisions and Reporting Standards

Two-tailed $\alpha = .05$ was used for the five prespecified decisions. Estimates, effect sizes and uncertainty were considered alongside p values. Failure to reject a null hypothesis was not interpreted as proof of zero effect.

Interpretive language remained associative: digital capabilities were "associated with" or "statistically predicted" perceived effectiveness in the fitted model. The thesis does not claim that digital transformation caused an audited change in project cost performance.

The analytical source was the retained Excel export. A coded working dataset and reproducible Python calculations were used to verify frequencies, composite scores, reliability, correlations, regression and figures. Percentages and coefficients in Chapter Four were reconciled against the 100-row source file.

The retained workbook did not include invitation counts, reminder counts, form-language metadata or collection timestamps. These details are therefore treated as limitations rather than reconstructed retrospectively. The measurement and analysis model is shown in Figure 3.2.

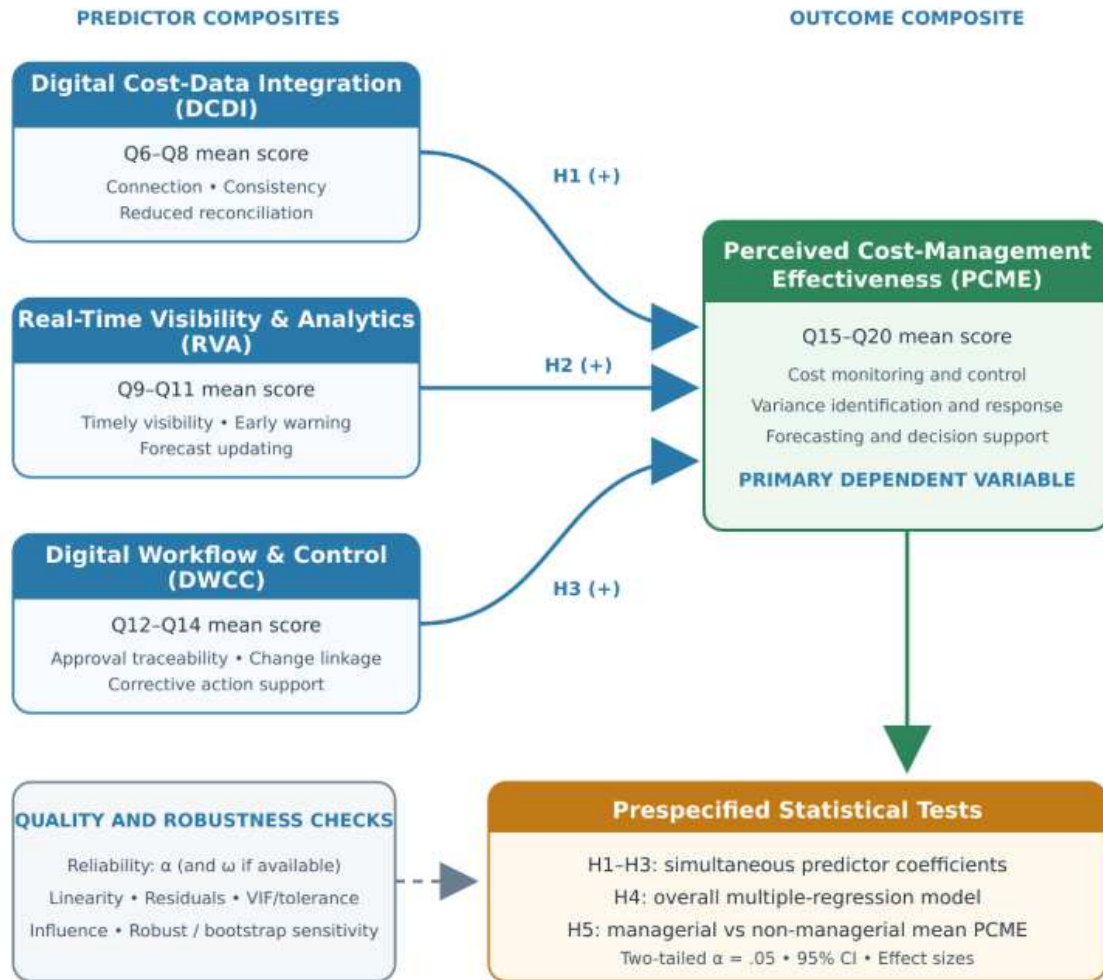


Figure 3.2. Measurement and analysis model.

3.19 Chapter Summary

This chapter described the completed 100-case cross-sectional survey and the analysis used in the thesis. It defined the one-project reference, 20-question instrument, three predictor scales, six-item outcome, screening rules, role comparison and associative interpretation. The design supports a focused business-management assessment while preserving confidentiality and acknowledging the limits of convenience sampling and employee perception.

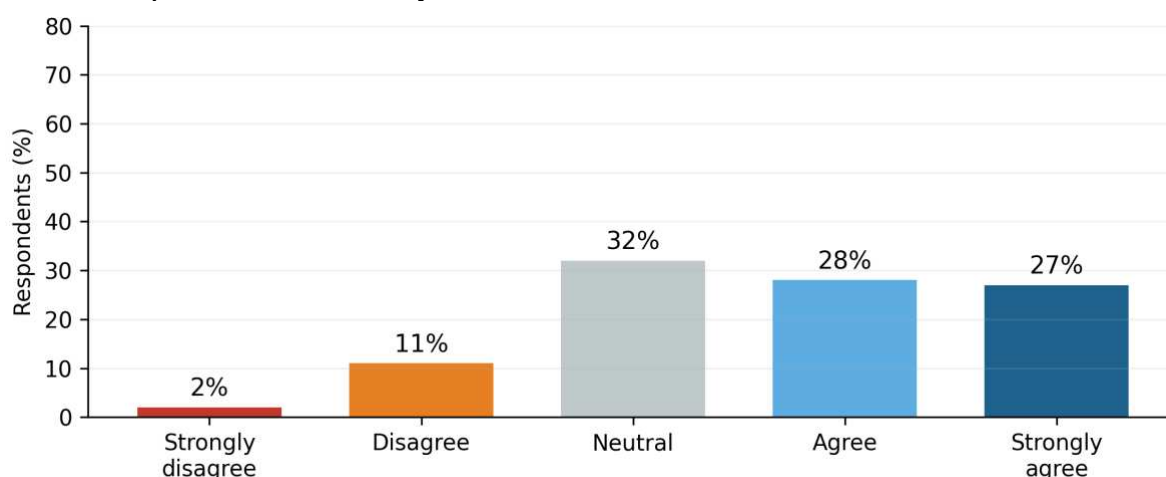
CHAPTER FOUR: FINDINGS, ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter presents the empirical findings on project cost-management effectiveness from 100 complete eligible employee responses in Saudi Arabia. It follows the quantitative design stated in Chapter Three and interprets the results as cross-sectional associations rather than causal proof. Results are linked throughout to the digital-transformation and capability literature reviewed in Chapter Two.

4.2 Survey Participation and Key Response Patterns

The Google Forms export contained 100 complete eligible records and all substantive Likert questions were completed. The raw export was preserved, no full duplicate response record was found, and the coded data were analysed without removing genuine unusual opinions. The following visuals provide an accessible overview of three key survey questions before the composite statistical analysis.



4.2.1 Respondent Profile

All 100 retained respondents consented, worked in Saudi Arabia and confirmed direct recent involvement in a digitally supported project. The sample covered several organizational levels: 42 non-managerial employees, 30 supervisors or team leaders, 21 project or functional managers, four project directors or senior executives, and three respondents who preferred not to identify their role level. This distribution provided both operational and managerial perspectives without implying that the sample proportionally represents the Saudi project workforce.

Sector coverage was broad. Construction, engineering, infrastructure or real estate accounted for 25 responses; energy, utilities, oil, gas or mining for 18; manufacturing, logistics or transportation for 13; banking, finance, insurance or professional services for 12; government or public services for 12; healthcare or education for 10; information technology, telecommunications or digital services for seven; other sectors for two; and one respondent preferred not to say. The spread supports cross-sector management interpretation, but small category sizes do not support reliable sector comparisons.

Table 4.1. Respondent profile by role level and sector.

Dimension	Category	n	%
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Dimension	Category	n	%
Role level	Non-managerial employee	42	42%
Role level	Supervisor or team leader	30	30%
Role level	Project/functional/department manager	21	21%
Role level	Project director/senior manager/executive	4	4%
Role level	Prefer not to say	3	3%
Sector	Construction/engineering/infrastructure/real estate	25	25%
Sector	Energy/utilities/oil/gas/mining	18	18%
Sector	Manufacturing/logistics/transportation	13	13%
Sector	Banking/finance/insurance/professional services	12	12%
Sector	Government/public services	12	12%
Sector	Healthcare/education	10	10%
Sector	IT/telecommunications/digital services	7	7%
Sector	Other	2	2%
Sector	Prefer not to say	1	1%

Figure 4.1. Response distribution for Q6: digital cost information was connected with relevant schedule, progress, procurement or change information.

The distribution for Q6 shows the balance of agreement, neutrality and disagreement among the 100 respondents. This visual evidence is descriptive and should be read with the later composite results. It demonstrates that digital practice is not experienced uniformly: the research question concerns whether higher perceived digital capability is associated with stronger project cost-management effectiveness, not whether every organization has reached the same maturity.

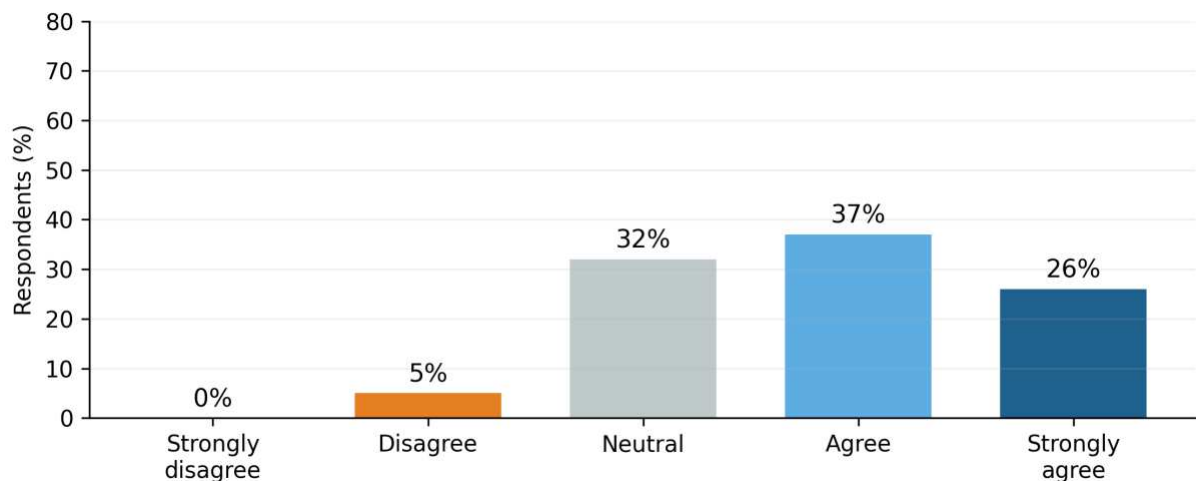


Figure 4.2. Response distribution for Q11: digital information supported timely updates to expected final project cost.

The distribution for Q11 shows the balance of agreement, neutrality and disagreement among the 100 respondents. This visual evidence is descriptive and should be read with the later composite results. It demonstrates that digital practice is not experienced uniformly: the research question concerns whether higher perceived digital capability is associated with stronger project cost-management effectiveness, not whether every organization has reached the same maturity.

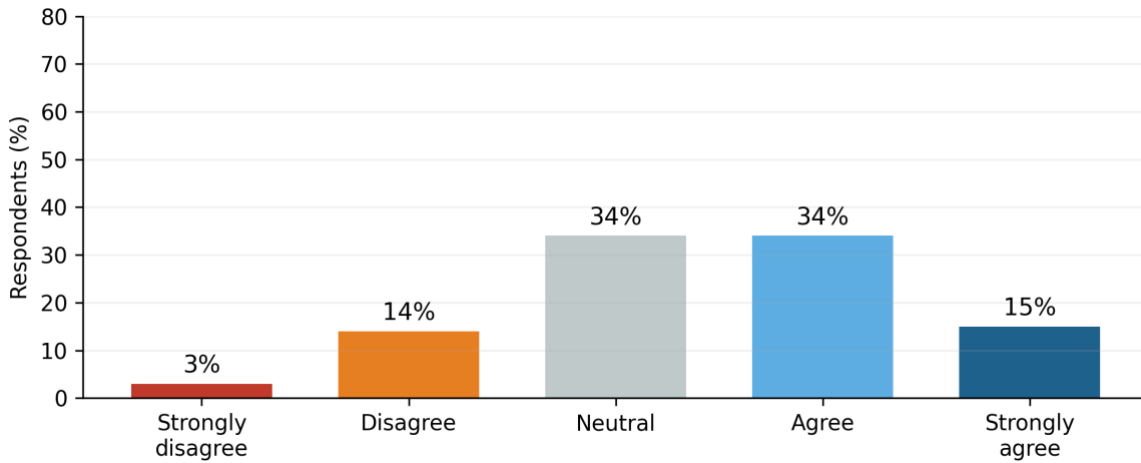


Figure 4.3. Response distribution for Q12: digital workflows created a clear record of cost-related reviews and approvals.

The distribution for Q12 shows the balance of agreement, neutrality and disagreement among the 100 respondents. This visual evidence is descriptive and should be read with the later composite results. It demonstrates that digital practice is not experienced uniformly: the research question concerns whether higher perceived digital capability is associated with stronger project cost-management effectiveness, not whether every organization has reached the same maturity.

4.3 Reliability and Overall Cost-Management Patterns

Cronbach alpha was calculated for each multi-item construct. All values met acceptable internal-consistency expectations, supporting the construction of the planned composite scores. Mean values were above the scale midpoint, indicating moderately positive rather than extreme assessments.

Construct	Items	Alpha	Mean	SD
DCDI	3	0.857	3.62	0.93
RVA	3	0.741	3.74	0.74
DWCC	3	0.748	3.47	0.85
PCME	6	0.903	3.50	0.88

Table 4.2. Reliability and descriptive statistics for the study constructs.

4.4 Employee Views of Digital Project-Cost Practices

4.4.1 Connection of cost information with schedule, progress, procurement and change records

Q6 recorded a mean of 3.67. 55% of respondents agreed or strongly agreed, while 13% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to DCDI, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns shared coding structures and interfaces. Whyte (2019) and Whyte and Hartmann (2017) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a

particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is a cost report that is technically correct but disconnected from progress or commitments. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for finance, planning, procurement and project controls. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to map common project identifiers across cost accounts, activities, packages and change records. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.2 Consistency of project-cost updates across digital records

Q7 recorded a mean of 3.62. 52% of respondents agreed or strongly agreed, while 12% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to DCDI, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns data ownership, update calendars and source-of-truth rules. Bilal et al. (2016) and Sepasgozar et al. (2022) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is different functions updating valid records at different times and producing avoidable reconciliation. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for system owners, cost engineers and functional data stewards. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may

originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to assign named owners, update cut-offs and exception checks for every critical cost field. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.3 Reduction of duplicate entry and manual reconciliation

Q8 recorded a mean of 3.56. 53% of respondents agreed or strongly agreed, while 17% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to DCDI, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns interoperability and disciplined automation. Monteiro and Poças Martins (2013) and Ma and Liu (2014) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is automation transferring a coding error more quickly or creating a new spreadsheet outside the controlled process. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for estimating, design, procurement and accounting. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to measure re-entry points and remove only those transfers for which data definitions are stable. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.4 Timeliness of digital cost and status information

Q9 recorded a mean of 3.75. 62% of respondents agreed or strongly agreed, while 10% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to RVA, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns reporting cadence and decision lead time. Vial (2019) and Verhoef et al. (2021) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is frequent dashboards built from late commitments or unapproved progress values. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for site teams, planners, commercial staff and decision makers. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to set update deadlines according to the decision window rather than dashboard refresh capability. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.5 Use of reports and analytics to identify emerging cost variance

Q10 recorded a mean of 3.63. 56% of respondents agreed or strongly agreed, while 10% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the

item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to RVA, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns threshold design, variance explanation and escalation. Acebes et al. (2014) and Anbari (2003) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is alert volume that directs attention to immaterial movements while structural exposure remains hidden. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for cost controllers, risk owners and package managers. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to pair every material threshold with an accountable reviewer, cause category and escalation route. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.6 Support for timely updates to expected final project cost

Q11 recorded a mean of 3.84. 63% of respondents agreed or strongly agreed, while 5% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to RVA, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns forecast governance and remaining-work assumptions. Batselier and Vanhoucke (2015, 2017) and Kim and Kwak (2018) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated

platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is a current actual-cost report being mistaken for a reliable estimate at completion. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for planning, procurement, commercial and delivery leadership. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to require forecast movements to show commitments, progress, remaining work, risks and approved changes. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.7 Traceable digital records of cost-related reviews and approvals

Q12 recorded a mean of 3.44. 49% of respondents agreed or strongly agreed, while 17% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to DWCC, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns decision rights, audit trails and approval evidence. Sigalov et al. (2021) and Handayani et al. (2019) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is an electronic approval recording who clicked accept without showing the cost basis considered. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for commercial managers, approvers and document-control staff. Cost management is produced through their combined inputs rather

than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to define the evidence required at each approval gate and connect it to the controlled cost record. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.8 Linkage of approved changes to cost records and forecasts

Q13 recorded a mean of 3.53. 49% of respondents agreed or strongly agreed, while 15% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to DWCC, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns change valuation, baseline control and forecast alignment. Handayani et al. (2019) and Le et al. (2020) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is approval occurring before a complete cost impact is known and the forecast remaining unchanged. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for design, contracts, cost control and sponsors. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to use one change identifier from initiation through valuation, approval, budget treatment and forecast revision. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.9 Assignment and tracking of corrective actions for cost issues

Q14 recorded a mean of 3.43. 48% of respondents agreed or strongly agreed, while 20% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to DWCC, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns accountability, due dates and closure evidence. Bryde et al. (2018) and Kim et al. (2003) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is actions remaining open in a workflow while operational priorities move elsewhere. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for action owners, line managers and project-control governance. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to make closure dependent on evidence of implementation and revised cost exposure, not status selection alone. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.10 Reliability of cost information for routine control decisions

Q15 recorded a mean of 3.60. 53% of respondents agreed or strongly agreed, while 15% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the

item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to PCME, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns data definitions, reconciliation and confidence in use. Whyte (2019) and Bilal et al. (2016) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is teams creating shadow calculations because the official number is not sufficiently explained. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for finance, project controls and operational users. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to track recurring reconciliation differences and resolve their process causes rather than only correcting totals. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.11 Early identification of emerging cost variance

Q16 recorded a mean of 3.25. 41% of respondents agreed or strongly agreed, while 25% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to PCME, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns leading indicators and speed of response. Acebes et al. (2014) and Batselier and Vanhoucke (2015) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is variance becoming visible only after commitments, progress or design decisions are difficult to reverse. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for package managers, planners, risk teams and cost engineers. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to identify precursor measures for high-exposure packages and review them before the monthly cost close. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.12 Usefulness of expected-final-cost forecasts for decisions

Q17 recorded a mean of 3.69. 60% of respondents agreed or strongly agreed, while 18% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to PCME, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns forecast credibility, scenario assumptions and managerial use. Batselier and Vanhoucke (2017) and Kim and Kwak (2018) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is a forecast being numerically updated but not trusted because the remaining-work logic is opaque. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for forecast preparers, delivery managers and sponsors. Cost management is produced through their combined inputs rather than by the

cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to document major assumptions, ranges and decision consequences alongside each forecast revision. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.13 Traceability of approved change effects in control records

Q18 recorded a mean of 3.48. 50% of respondents agreed or strongly agreed, while 19% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to PCME, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns baseline integrity and whole-life visibility. Handayani et al. (2019) and Zanni et al. (2019) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is approved scope being visible in a change log but absent from budgets, contracts or forecast-at-completion values. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for change managers, contracts, finance and asset stakeholders. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to reconcile approved changes across scope, budget, forecast, contingency and contract registers at each reporting cycle. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such

evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.14 Timeliness of the project team's response to material cost issues

Q19 recorded a mean of 3.41. 43% of respondents agreed or strongly agreed, while 18% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to PCME, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns authority, escalation and organizational responsiveness. Bryde et al. (2018) and Warner and Wäger (2019) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is good information reaching a team that lacks authority, resources or incentives to act. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for project leadership, functional managers and accountable action owners. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to specify decision rights and escalation time limits for different levels of cost exposure. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.4.15 Overall perceived effectiveness of project cost management

Q20 recorded a mean of 3.55. 51% of respondents agreed or strongly agreed, while 14% disagreed or strongly disagreed. The remaining responses were neutral. This pattern places the item above the scale midpoint but also shows that the practice was not experienced consistently across the sample. It contributes to PCME, and its variation is useful because the study examines differences in enacted capability rather than simply asking whether organizations own digital tools.

The management meaning of this item concerns the combined quality of information, forecasting, governance and response. Vial (2019) and Verhoef et al. (2021) show why digital information creates value only when it changes how project information is organized and used. The survey result is therefore better interpreted as evidence about a management routine than as a score for a particular software product. A project may have a sophisticated platform and still receive a low rating if the process around the platform is fragmented, late or unclear.

A central implementation risk is technology investment being treated as the outcome rather than evidence that the control cycle works. This risk cannot be solved by adding another dashboard or approval screen alone. Managers need to examine the origin of the data, the person accountable for updating it, the rule used to classify it and the decision that depends on it. When these elements are unclear, digital speed can amplify inconsistency. When they are explicit, the same technology can reduce delay and make responsibility easier to trace.

The item also has a cross-functional implication for executives, PMOs, project teams and system owners. Cost management is produced through their combined inputs rather than by the cost-control function in isolation. A weakness observed by one group may originate upstream in another group's coding, timing or authorization. Management review should therefore follow the information path across functions and identify where meaning, ownership or decision authority is lost.

A practical response is to assess digital maturity through decision quality, traceability and learning rather than the number of applications deployed. The purpose is not to prescribe one platform, but to establish a testable control routine. Evidence could include system timestamps, reconciliations, change histories, forecast explanations, approval records or action-closure documents, depending on the item. Comparing the employee rating with such evidence would help management distinguish a perception problem from a process, data or governance problem.

The result should remain bounded by the research design. It represents an informed employee perception of one recent project, not an audit of technical architecture or financial outcome. Sector, project phase, contract type and organizational maturity can all affect what the respondent sees. The value of the item is diagnostic: it identifies a management question that deserves verification, while the overall model shows whether higher ratings tend to coexist with stronger perceived cost-management effectiveness.

4.5 How Digital Capabilities Relate to Cost-Management Effectiveness

Pearson correlations and simultaneous regression were used to examine how the three digital-practice dimensions related to PCME. All three predictors had positive bivariate correlations with the outcome. RVA had the strongest bivariate relationship ($r = .616$), followed by DCDI ($r = .495$) and DWCC ($r = .394$). Predictor intercorrelations ranged from .343 to .395, indicating complementarity without severe overlap. The regression model was significant, $F(3, 96) = 28.55$, $p < .001$, and explained 47.2% of the variation in PCME (adjusted $R^2 = .455$).

Table 4.3. Pearson correlations among the study constructs.

Construct	1	2	3	4
1. DCDI	—			
2. RVA	.372	—		
3. DWCC	.343	.395	—	
4. PCME	.495	.616	.394	—

Note. N = 100. All displayed correlations between different constructs are positive; the table is descriptive of the achieved convenience sample.

Table 4.4. Simultaneous regression coefficients predicting perceived project cost-management effectiveness.

Predictor	B	SE	β	t	p	95% CI for B
DCDI	.267	.077	.283	3.44	< .001	[.113, .420]
RVA	.549	.099	.466	5.55	< .001	[.353, .745]
DWCC	.116	.085	.113	1.36	.178	[-.054, .285]

Digital cost-data integration had a positive, statistically significant adjusted coefficient (B = .267, SE = .077, β = .283, p < .001, 95% CI [.113, .420]). H01 was rejected in favor of H11. The finding indicates that respondents who reported more connected, consistently maintained cost information also tended to report stronger cost-management effectiveness after RVA and DWCC were held constant.

Real-time visibility and analytics produced the largest unique coefficient (B = .549, SE = .099, β = .466, p < .001, 95% CI [.353, .745]). H02 was rejected in favor of H12. Timely visibility, early warning and support for expected-final-cost updates were therefore the strongest independent correlates of the perceived outcome in this model.

Digital workflow and change control had a positive but statistically inconclusive adjusted coefficient (B = .116, SE = .085, β = .113, p = .178, 95% CI [-.054, .285]). H03 was not rejected. DWCC nevertheless had a positive bivariate correlation with PCME (r = .394), suggesting that workflow may share explanatory variance with integration and visibility or may depend more strongly on implementation quality. The result does not justify treating change governance as unimportant.

Diagnostics supported the use of the model: Shapiro-Wilk p = 0.339, Breusch-Pagan p = 0.919, maximum Cook's distance = 0.092, and maximum VIF = 1.28. These values did not indicate material residual, influence or multicollinearity concerns. The findings should nevertheless be read alongside the study limitations: self-report data, cross-sectional timing and a non-probability sample.

4.6 Findings Across Employee and Managerial Levels

The Welch comparison found no statistically significant difference in PCME between 42 non-managerial respondents (M = 3.44, SD = 0.95) and 55 managerial respondents (M = 3.53, SD = 0.82), p = .624, Hedges' g = .10. The three respondents who selected “prefer not to say” for role level remained in the overall analysis but were excluded from this two-group comparison because they could not be assigned to either group. H05 was not rejected.

4.7 What the Findings Mean for Project Cost Management

Strategic alignment and investment discipline

Digital cost capability should be governed as a business-control capability rather than an isolated technology project. The model indicates that connected information and decision-ready visibility matter more than the mere presence of electronic records. Investment cases should therefore specify the management problem being addressed, the affected decision cycle, the accountable owner and the evidence that would show improvement. A platform implementation that does not change coding discipline, forecast review or decision authority may digitize activity without improving control.

For Saudi organizations managing diverse portfolios, strategic alignment also requires selective standardization. Common identifiers, minimum forecast rules and approval evidence can be standardized across projects, while sector-specific workflows remain flexible. This balance prevents each project from inventing incompatible data structures but avoids forcing a construction, energy, technology or healthcare project into the same operational detail. Portfolio leadership should govern the minimum control architecture and allow project teams to tailor execution within it.

Information quality and ownership

Information quality is a management responsibility distributed across the project network. Cost controllers depend on quantities, progress, commitments, contract terms, schedule status and change decisions generated elsewhere. A visible dashboard cannot compensate for unclear ownership of those inputs. Each critical field should have a business definition, source, owner, update timing and reconciliation rule. Persistent exceptions should be treated as process failures to be resolved, not as routine spreadsheet work that employees absorb indefinitely.

The results suggest that organizations should examine latency as well as accuracy. Information can be correct when entered but arrive too late for a reversible decision. Management should identify the decision window for major commitments, package forecasts and change approvals, then design update cycles around that window. This connects digital reporting to operational value and prevents “real time” from becoming a technical label with no relationship to how quickly the organization can respond.

Employee capability and adoption

User capability involves more than navigation training. Employees need to understand cost definitions, coding logic, forecast assumptions, materiality thresholds and the consequences of late or incomplete updates. Training should therefore combine system use with control reasoning. Role-based examples are particularly important: a site engineer, buyer, planner and finance analyst interact with different fields, but each affects the reliability of the final cost picture.

Adoption should also be monitored through behavior and exception patterns rather than login counts alone. Repeated offline reconciliations, delayed approvals, unexplained forecast changes and shadow spreadsheets may signal that the official process does not fit operational needs. User feedback should be reviewed as evidence about process design. The objective is not to eliminate all local analysis, but to ensure that authoritative decisions and values return to a controlled, traceable environment.

Governance, accountability and response

The non-significant unique DWCC coefficient is a useful management caution. Recording an approval electronically does not guarantee that the decision considered complete scope, cost, schedule and risk information. Governance should specify what evidence is required, who has authority at each exposure level, how approved changes affect budgets and forecasts, and what happens when a response is overdue. The quality of the decision path matters more than the existence of a workflow screen.

Accountability also requires closure evidence. Corrective actions should not be considered complete simply because their status was changed. Closure should show what was implemented, how the expected cost exposure changed and whether follow-up is required. Escalation rules should be proportional to materiality so that managers are not overwhelmed by routine alerts while significant exposures remain unresolved.

Organizational learning and continuous improvement

Digital records create an opportunity for structured learning when organizations retain forecast histories, change causes, contingency movements and final outcomes. Post-project review should compare what was expected at successive decision points with what occurred, identify why assumptions changed and feed the lessons into estimating databases, risk

allowances and future control configurations. This converts traceability from a compliance feature into a learning asset.

Learning should also operate during delivery. Recurring reconciliation problems, late commitments and repeated forecast explanations can be reviewed across projects to identify systemic causes. A portfolio-level governance group can distinguish a local execution issue from a common data-definition, supplier-interface or approval-design problem. The survey constructs provide a practical diagnostic vocabulary for that review without claiming that one maturity score is sufficient to judge every project.

4.8 Chapter Summary and Hypothesis Outcomes

The findings are generally supportive of a positive relationship between enacted digital practices and the effectiveness of project cost management. The reliability was satisfactory to good, the overall regression model was statistically significant, and the diagnostics were satisfactory. Detailed item analysis provides information on areas of good practice and those where implementation is not consistent. Conclusions and recommendations, along with limitations and future research directions are presented in Chapter Five.

The conclusions, recommendations and future research are presented in Chapter Five.

CHAPTER FIVE: CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH

5.1 Chapter Overview

The results of the study are presented in this chapter, which also links the results to the research objectives and explains the implications of the results for project cost management in the Saudi organizations. It then offers recommendations based on the evidence, the contribution of the study, the limitations of the study, and directions for future research. The conclusions are explicitly constrained. The survey did not measure the actual cost-management effectiveness of the named projects, nor did it experimentally test for causation, but rather measured digital practices as observed by employees and their perceived cost-management effectiveness at one point in time.

5.2 Conclusions by Research Objective

The first goal explored was digital cost-data integration. This outcome confirms the finding that connected project information is related to better cost management. Digital cost-data integration was a positive and significant contribution to the full regression model ($B = .267$, standardized beta = $.283$, $p < .001$). Cost information that was linked to schedule, progress, procurement and change information and was kept up to date, and not so reliant on duplicate entry, was more likely to be reported as reliable, timely, and useful. Integration is not only about finding a cost application, it is about the practical coherence of the project-control environment.

The second goal was real-time visibility and analytics. This was the strongest unique predictor ($B = .549$, standardized beta = $.466$, $p < .001$). Perceived cost-management effectiveness was closely related to timely cost and status information, and early identification of variance and support for updates to expected final cost. The outcome is consistent with the control objective of predicting the outcome: No historical expenditure can provide the final outcome. Digital tools add managerial value when current commitments, progress, remaining-work assumptions, and approved changes are translated into an updated estimate at completion in a timely fashion for action.

The third goal was to explore the digital workflow for change and cost control. When the other digital capabilities were added, its regression coefficient was positive, but not statistically significant ($B = .116$, standardized beta = $.113$, $p = .178$). This is not to say that change governance is not important. The construct was also positively correlated with the outcome, but it was not as consistently experienced by respondents as either integration or visibility and had overlapping explanatory power with them. While a digital approval record can help with traceability, the workflow can still not be effective at improving outcomes if the change values are late, not connected to forecasts, or not connected to decision authority. The correct answer is not that H3 is not supported in the simultaneous model, but that the organizations should not give up on digital change control.

The fourth objective evaluated the joint model. It was statistically significant, $F(3, 96) = 28.55$, $p < .001$, with $R^2 = .472$ and adjusted $R^2 = .455$. The three capabilities jointly accounted for 47.2% of the variance in perceived project cost-management effectiveness. The remaining variance leaves substantial room for unmeasured conditions such as contract structure, scope maturity, estimating quality, market volatility, governance, team capability and project complexity; it does not establish that any one of these omitted factors was statistically significant. For Objective 5, the managerial–non-managerial mean difference was small and non-significant ($p = .624$; Hedges' $g = .10$).

5.3 Implications for Project Cost Management

The results align with an information-to-action perspective of digital cost management. First, the relevant data need to be linked throughout the project control cycle. Second, the data that is connected should be timely and analytically useful. Third, governance needs to transform the information into recorded decisions and corrective action. The relative strength of real-time visibility suggests that organizations should consider whether digital reports add value to their forecast, and whether they give them the right time of response – rather than whether they simply replicate the approved budget. The non-significant unique workflow coefficient also serves as a caution to not assume that an electronic approval is a good control. Workflow quality relies on the extent to which the cost impact is complete, its relationship to the existing forecast and the authority of the individuals receiving the alert.

There was no significant difference in job level, indicating that cost-management effectiveness is evident outside the PMO. The information provided by engineers, planners, quantity surveyors, procurement, accountants, coordinators and supervisors affects the quality of the cost picture. A governance system that only looks at a senior dashboard to drive digital improvement can miss the sources of commitments, quantities, progress and change in the business. Saudi organizations should thus develop digital controls that are designed by the employees who develop and verify the underlying data.

5.4 Practical Recommendations

1. Link cost information to schedule, progress, procurement, contract and change records. Organizations should define common project codes, data owners and reconciliation rules so that the forecast rests on one traceable control structure rather than disconnected files.

2. Establish a regular forecast-at-completion procedure. Each reporting cycle should consider actual expenditure, commitments, measured progress, remaining-work assumptions, risks and approved changes. Material movements should have a stated cause, owner and decision requirement.

3. Use digital early-warning thresholds that lead to action. Each material alert should identify the reviewer, response deadline, available corrective options and escalation path. Alert volume should be controlled so that critical signals are not hidden among routine notifications.

4. Strengthen change-cost governance. Proposed changes should include documented scope, cost, schedule and risk implications before approval. Approved decisions should be reflected consistently in the budget, forecast, contingency and relevant contract record.

5. Improve user capability and data accountability. Training should cover cost-field definitions, coding discipline, progress measurement, forecast assumptions and the consequences of late updates. Recurring data-quality problems should be assigned to a named process owner.

6. Create a post-project cost-learning cycle. Final accounts, forecast histories, approved changes, contingency use and variance causes should be compared with earlier assumptions, and lessons should update estimating databases, risk allowances, coding rules and future control configurations.

5.5 Contribution to Knowledge

The study introduces a model for studying digital transformation that is observable by employees and connects digital transformation to project cost-management routines instead of to technology adoption overall. It separates connected cost data, real-time visibility and analytics, and digital workflow of change and control. The pattern of results provides nuances: integration and visibility had strong unique effects, whereas workflow did not after accounting for shared variance. This discovery invites theory and practice to investigate not only complementarity but also the quality of implementation, which is not assumed to be the

case if all digital capabilities are implemented independently. The study also provides evidence from Saudi project contexts and involves workers from all levels of the organization in addition to executive and technology-provider views.

5.6 Study Limitations

First, the design was cross-sectional, which does not allow for the temporal direction of the association to be confirmed. Projects that have well-developed cost management practices could be more inclined to use effective digital tools, and effective digital tools could also help to develop the cost management practices. Secondly, all variables were reported by the same respondent. Eligibility controls and neutral item wording increased relevance but do not remove the common-method association. Third, the dependent variable measured perceived effectiveness rather than audited cost variance, forecast accuracy, change value or final outturn.

Fourth, the convenience sample of 100 cannot represent every Saudi sector, organization and project type. It supported the planned three-predictor regression but not detailed models by industry, contract strategy, project phase or platform. Fifth, broad role grouping may conceal meaningful differences among planners, engineers, cost professionals, procurement personnel and sponsors. Sixth, project complexity, scope maturity, market escalation, contract incentives and organizational control maturity were not measured directly. These limitations restrict generalization and leave alternative explanations for the observed associations.

5.7 Directions for Future Research

Future studies should integrate the survey constructs with project records such as baseline estimates, commitment data, forecast histories, change logs, contingency use and final cost. Longitudinal designs might assess digital capability early in the project, and assess the accuracy of forecasts and the response to control later. Multi-informant studies can compare the perspectives of project managers, cost engineers, quantity surveyors, finance, procurement and operational staff on the same project. Stratified samples would allow comparisons to be made for construction, energy, manufacturing, public infrastructure and public service projects.

Further research should examine why digital workflow and change control did not have a significant unique coefficient. Possible explanations include overlap with integration, inconsistent workflow adoption, incomplete cost-impact analysis, approval delay or weak linkage between approval and forecast revision. Larger studies could test mediation and moderation involving project complexity, governance maturity, user capability and contract type. Qualitative case studies could follow a cost issue from field observation through digital recording, forecast impact, approval and corrective decision to identify where information loses value in the control chain.

5.8 Final Conclusion

The central conclusion is that connected, timely and decision-ready digital information was associated with stronger perceived project cost-management effectiveness in this sample. Cost-data integration and real-time visibility were the clearest independent predictors. Digital workflow remains managerially important, but the adjusted evidence was statistically inconclusive; electronic records alone are unlikely to add value without reliable cost impact, current forecasts and accountable response. Digital maturity should therefore be judged by whether emerging variance is identified, understood and acted upon in time—not by the number of systems deployed.

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APPENDIX A: FORMAL QUANTITATIVE QUESTIONNAIRE

Participant Information

This academic study examines how digital capabilities relate to project cost-management effectiveness in Saudi Arabia. Participation is voluntary and anonymous. Do not provide your name, employer, project name, budget, contract value, actual cost or confidential details. Answer Questions 6–20 about one most recent project during the last two years in which you directly used, created, reviewed or relied on digitally supported cost or related control information. Estimated completion time is five to seven minutes.

Section A: Consent and Eligibility

Question 1. Do you voluntarily consent to participate in this academic survey?

- Yes, I consent and wish to continue.
- No, I do not consent.

Question 2. Are you currently employed in Saudi Arabia?

- Yes.
- No.

Question 3. During the last two years, were you directly involved in a project that used digital tools or systems for cost, schedule, progress, procurement, contracts, reporting or change control?

- Yes.
- No.
- Unsure.

Section B: Respondent Profile

Question 4. Which option best describes your role level on the selected project or in the relevant work area?

- Non-managerial employee, specialist, engineer, analyst, accountant, planner or coordinator.
- Supervisor or team leader.
- Project manager, functional manager or department manager.
- Project director, senior manager or executive.
- Prefer not to say.

Question 5. Which broad sector best describes the selected project?

- Government or public services.
- Energy, utilities, oil, gas or mining.
- Construction, engineering, infrastructure or real estate.
- Manufacturing, logistics or transportation.
- Information technology, telecommunications or digital services.
- Banking, finance, insurance or professional services.
- Healthcare or education.
- Other sector.
- Prefer not to say.

Section C: Digital Capabilities for Project Cost Management

For Questions 6–14, select one response for each statement:

- Strongly disagree.
- Disagree.
- Neither agree nor disagree.
- Agree.
- Strongly agree.

Question 6. Digital cost information for the selected project was connected with relevant schedule, progress, procurement or change information.

Question 7. Relevant project-cost data were updated consistently across the digital systems or records used by the team.

Question 8. Digital tools reduced unnecessary duplicate entry or manual reconciliation of project-cost information.

Question 9. Digital tools provided cost and status information early enough to support project decisions.

Question 10. Digital reports or analytics helped the team identify emerging cost variance.

Question 11. Digital information supported timely updates to the expected final project cost.

Question 12. Digital workflows created a clear record of cost-related reviews and approvals.

Question 13. Approved project changes were linked clearly to the relevant cost records or forecasts.

Question 14. Digital workflows helped assign and track corrective actions when cost issues were identified.

Section D: Perceived Project Cost-Management Effectiveness

For Questions 15–20, use the same five response options from strongly disagree to strongly agree.

Question 15. The selected project's cost information was sufficiently reliable for routine control decisions.

Question 16. Emerging cost variance was identified early enough for the project team to consider action.

Question 17. Forecasts of the selected project's expected final cost were useful for decision making.

Question 18. The cost effects of approved project changes were traceable in the control records.

Question 19. The project team responded to material cost issues in a timely manner.

Question 20. Overall, cost management on the selected project was effective.

APPENDIX B: DATA CODING, ANALYTIC WORKFLOW AND REPRODUCIBILITY

B.1 Variable Coding

Eligibility, job-level, sector and experience responses were coded from the original Google Forms export. All substantive Likert items used 1 = strongly disagree through 5 = strongly agree. No substantive item required reverse coding.

B.2 Data Preparation and Composite Scores

The retained Excel export was used as the analytical source. All 100 rows met the three eligibility conditions and contained complete responses to Q6–Q20. Likert responses were mapped from strongly disagree = 1 through strongly agree = 5, and arithmetic-mean composite scores were calculated from their assigned items. No personal identifiers were present in the analytical workbook.

B.3 Analytical Tools and Reproducibility

The Excel workbook was imported into Python for reproducible checking and analysis. pandas supported structured data handling (McKinney, 2010), SciPy supported statistical functions (Virtanen et al., 2020), statsmodels methodology informed the regression workflow (Seabold & Perktold, 2010), and Matplotlib supported the figures (Hunter, 2007). The reported frequencies, reliability estimates, correlations and regression values were reconciled against the 100-row source file.

B.4 Statistical Analysis

The analysis included frequencies, means, standard deviations, agreement/disagreement percentages, Cronbach's alpha, Pearson correlations, simultaneous ordinary least squares regression and diagnostic checks. The role-level comparison used Welch's independent-samples t-test and Hedges' g. Three "prefer not to say" role responses were included in overall analyses but excluded from the two-group comparison.

B.5 Decision Rules and Output Files

The decision rules linked H1–H3 to the adjusted regression coefficients, H4 to the overall regression model and H5 to the role-level comparison. Supporting materials consisted of the retained Excel survey file, coded calculations, statistical summaries and figures. No claim is made that SPSS-format files were created or required.

DWCC: mean of Q12, Q13 and Q14; require at least two valid items.

PCME: mean of Q15–Q20; require at least five valid items.

B.3 Analysis-to-Hypothesis Map

H1 is evaluated from the DCDI coefficient in the simultaneous regression; H2 from the RVA coefficient; H3 from the DWCC coefficient; H4 from the overall regression F test, R^2 , adjusted R^2 and f^2 ; and H5 from the PCME job-level comparison. Reliability and diagnostics precede hypothesis decisions. Sector comparisons, mediation, moderation and interactions are outside the confirmatory model and must be labelled exploratory if attempted.

APPENDIX C: MANAGEMENT INTERPRETATION AND ACTION GUIDE

C.1 Purpose and Appropriate Use

This guide translates the study constructs into practical management questions. It is not a substitute for a cost-system audit and does not turn the survey into an objective project-performance score. Its purpose is to help managers use employee observations as an initial diagnostic, identify the evidence needed for verification and connect digital investment to the project-control cycle. A low score should trigger investigation rather than blame, while a high score should be tested against continued use, traceability and outcome evidence.

The guide can be applied at project, programme or portfolio level. At project level, teams can review the information path for one material cost issue. At programme level, leaders can compare recurring interface, forecast and change-control weaknesses. At portfolio level, governance teams can identify common data definitions and minimum controls that should be standardized. In every case, sector and contract context should be recorded before comparing results.

C.2 Digital Cost-Data Integration Review

Begin by tracing one cost item across the estimate, cost code, schedule activity, procurement package, progress record and change log. The objective is to determine whether the same business event can be followed without repeated interpretation or manual reclassification. Where identifiers differ, the review should record the mapping rule, its owner and how exceptions are resolved.

Assess source-of-truth rules. For each critical field, identify where the value originates, who may change it, when the update becomes authoritative and which downstream records depend on it. Duplicate values are not automatically a weakness when they serve controlled purposes, but unexplained duplication creates reconciliation work and uncertainty over which value should inform a decision.

Review interface failures as management events rather than purely technical defects. A failed transfer may originate in a missing definition, an unapproved coding change, a late upstream update or unclear responsibility. The corrective action should address the cause and specify how recurrence will be detected. Measures can include reconciliation exceptions, re-entry hours, unmatched commitments and time required to resolve coding differences.

C.3 Management Review Meeting Structure

A regular cost review should begin with changes in the expected final position rather than a lengthy restatement of the approved budget. The forecast bridge should identify the most material movements since the previous review, the evidence behind each movement and the decision or action required. This structure directs attention to new information and prevents stable or low-risk areas from consuming the meeting while emerging exposure receives insufficient time.

The review should then examine data-quality and integration exceptions that could affect confidence in the forecast. Examples include unreconciled commitments, missing progress approvals, unmatched cost codes, provisional quantities and changes without a complete valuation. Each exception should have an owner and expected resolution date. Managers should distinguish an exposure already reflected through a prudent assumption from an omission that makes the forecast misleading.

The early-warning section should focus on a limited number of material indicators. For each signal, the team should state what changed, why it matters, what uncertainty remains and when the next irreversible decision occurs. This encourages forward-looking discussion and makes the value of timely digital information visible. It also creates a record of management judgment that can be compared with subsequent outcomes for learning.

The change-control section should reconcile the status of major proposed and approved changes with the budget, contingency, contract and forecast. Urgent or provisional decisions should be identified explicitly. The meeting should not treat approval as the end of the process; it should confirm that the authorized decision reached every relevant control record and that implementation responsibility is clear.

The action section should review overdue and high-exposure corrective actions by exception. Owners should explain barriers and request decisions where authority or resources are insufficient. Actions should be closed only when implementation evidence is available and the effect on cost exposure has been assessed. This prevents the action log from becoming an administrative list disconnected from the forecast.

The meeting should close with a concise decision record. Each decision should identify the issue, information considered, responsible owner, required date and expected effect on the project-control position. Digital workflow can capture this record, but the meeting chair remains responsible for ensuring that the decision is unambiguous and reaches the people who must implement it.

Periodic governance review should assess whether the meeting itself remains useful. Measures can include the proportion of decisions supported by current evidence, the age of unresolved material exceptions, the time between warning and action, and recurring issues that appear across several cycles. The objective is a shorter and more decision-focused control process, not an increase in meeting documentation for its own sake.

This structure links the three digital capabilities directly to management practice. Integration determines whether the meeting has a coherent information base; visibility and analytics determine whether emerging exposure is understood; and workflow determines whether decisions and actions are traceable. The meeting is therefore one practical point at which digital transformation becomes organizational cost-control capability rather than a collection of separate technical features.

C.4 Visibility and Forecast Governance Review

Define timeliness from the decision backward. A weekly or daily refresh has little value if a commitment is recorded after the decision window or if measured progress is not approved until the reporting cycle has closed. Managers should identify the latest time at which information remains actionable for major packages and align update responsibilities with that deadline.

Separate reporting of actual cost from forecasting of expected final cost. A credible forecast should explain commitments, remaining work, productivity assumptions, risks, opportunities, approved changes and management actions. Material movements should be attributable to a cause and should show whether the change reflects new information, a revised assumption or a corrective decision.

Design early-warning rules around materiality and action. Each alert should have a responsible reviewer, an expected response time and a defined escalation route. The organization should monitor both missed critical alerts and excessive low-value alerts. A useful indicator is not the number of notifications generated, but the proportion of material warnings that received timely investigation and a documented decision.

C.5 Workflow and Change-Control Review

Select a sample of proposed and approved changes and trace each from initiation through technical review, cost and schedule assessment, approval, budget treatment, forecast revision, contract action and implementation. A single change identifier should connect these stages. Gaps indicate where an approval trail exists without full cost traceability.

Examine approval quality rather than approval speed alone. The reviewer should be able to see the scope basis, quantified cost exposure, schedule consequence, risk treatment and source of funding or contingency. Urgent decisions may use provisional values, but the workflow should show how provisional assumptions are replaced and reconciled when better information becomes available.

Corrective actions require ownership and closure evidence. An action record should state the exposure addressed, responsible person, due date, intended effect and evidence required for closure. Overdue actions should be escalated according to materiality. Closure should show what changed in the work or forecast, not merely that an electronic status was updated.

C.6 Role-Based Management Questions

Role	Management question	Illustrative evidence
Executive/sponsor	Are major forecast movements linked to decisions, risks and approved changes?	Forecast bridge, decision log, contingency movement
Project manager	Are emerging exposures visible early enough to change delivery choices?	Package forecasts, action logs, escalation history
Cost/project controls	Can every material value be traced to a source, code and update owner?	Reconciliations, coding maps, forecast assumptions
Planning/site team	Are progress and remaining-work assumptions aligned with the cost forecast?	Progress approval, quantities, productivity evidence
Procurement/contracts	Are commitments and changes reflected promptly and consistently?	Purchase orders, contract changes, commitment register
Finance	Do project-control values reconcile to financial records with explained timing differences?	Ledger reconciliation, accrual rules, cut-off evidence
System/data owner	Are interfaces, definitions and access rules governed as business controls?	Data dictionary, interface exceptions, access/change logs

C.7 Interpreting Improvement Over Time

Improvement should be assessed through repeated evidence rather than a one-off perception score. A practical review cycle can combine the survey items with process indicators such as reconciliation exceptions, forecast update timeliness, unresolved material

alerts, change-to-forecast lag and corrective-action closure. Trends should be interpreted with project stage and workload because an increase in identified exceptions may initially reflect better visibility rather than poorer performance.

Management should avoid turning the constructs into a simplistic league table. Differences may reflect sector regulation, contract structure, project maturity, system access or the respondent's role. The most useful comparison is often within the same organization over time, accompanied by documented changes to governance, process and capability. Where ratings and objective evidence disagree, the disagreement itself is a valuable diagnostic requiring discussion with the employees who create and use the information.

C.8 Sector-Sensitive Application

Construction and infrastructure projects often depend on the relationship between design quantities, work packages, schedule activities, procurement commitments and measured progress. Integration reviews in this environment should test whether model or drawing revisions can be traced to quantity changes and whether those changes reach the commercial forecast. The management risk is not limited to inaccurate measurement; it also includes a delay between technical change and recognition of its commercial effect. Evidence may include model versions, quantity reports, package codes, progress certificates, change notices and forecast bridges.

Energy, utilities, oil, gas and mining projects may involve long-lead equipment, complex contracting, shutdown windows and exposure to commodity, logistics or specialist-resource conditions. Visibility should therefore cover commitments, delivery status, escalation assumptions, contractor exposure and commissioning requirements. A forecast can appear stable while risk accumulates in a small number of critical packages. Management review should focus on the timing and consequence of those packages rather than relying only on aggregate percentage completion.

Manufacturing, logistics and transportation projects may combine capital expenditure with commissioning, production-interface and operational-readiness costs. Digital cost information should connect equipment procurement, installation progress, testing, inventory, facility changes and operational transition. Managers should be alert to cost shifting between project and operational budgets, because a project can appear controlled while unresolved implementation work is transferred to the receiving operation. Clear boundary definitions and handover criteria are therefore part of cost governance.

Technology, telecommunications and digital-service projects often use shorter delivery cycles and may not rely on traditional quantity measurement. Their relevant cost drivers include internal labor, vendor subscriptions, cloud consumption, integration effort, data migration and change requests. Forecast governance should connect backlog or release scope with resource assumptions and vendor commitments. The principle remains the same: timely information must show what remains to be delivered and the expected resources required, not only expenditure already incurred.

Government and public-service projects may face formal authorization, procurement and accountability requirements. Digital workflow can improve traceability, but additional approval stages can also lengthen the period between identifying an issue and acting on it. Management should distinguish statutory or policy controls from internal duplication and should ensure that decision records show the public-value and cost basis considered. Transparency is strengthened when approved changes, funding treatment and delivery consequences can be followed through one controlled record.

Healthcare and education projects may involve service-continuity constraints, specialized equipment, user consultation and regulatory or safety requirements. A narrowly financial

forecast may miss the cost effect of phased access, training, temporary facilities or operational disruption. Cross-functional review should therefore include clinical, academic or service users where their decisions affect scope and sequencing. Digital tools add value when they connect these operational requirements to cost and schedule implications early enough to preserve options.

Banking, finance, insurance and professional-service projects often include regulatory, cybersecurity, supplier and organizational-change components. Some major exposures arise from testing, remediation, data quality or delayed adoption rather than physical quantities. Cost-control routines should link risk acceptance, control requirements, vendor deliverables and internal-resource forecasts. Senior dashboards should distinguish approved scope from unresolved compliance or remediation work so that apparent budget stability is not achieved by leaving necessary work outside the current forecast.

Sector tailoring should not remove the common management logic of the study. Every context still requires an authoritative information base, timely interpretation, traceable decisions and accountable response. The practical difference lies in the evidence used and the pace of the decision cycle. Organizations should therefore standardize the questions asked—what changed, what does it cost, who owns the response and when is action required—while adapting the supporting records to sector and project type.

C.9 Phased Implementation Roadmap

Phase 1 should establish the management case and baseline. Leaders should identify the decisions currently affected by late, fragmented or weakly traceable cost information and select a limited number of high-value use cases. Baseline evidence may include reconciliation effort, forecast-update delay, unresolved changes, duplicated entry and the time between identifying a variance and assigning action. This prevents the programme from beginning with a broad technology specification that is disconnected from operational need.

The first phase should also define ownership. A senior sponsor is required for cross-functional decisions, but operational data owners must be named for the fields and processes that create the cost picture. A responsibility map should show who originates, validates, approves and consumes each important data element. Conflicts between finance, planning, procurement, engineering and project controls should be resolved before automation embeds competing definitions.

Phase 2 should stabilize definitions and minimum controls. The organization should agree project identifiers, cost categories, status definitions, update cut-offs, materiality rules and the evidence required for forecast and change decisions. Not every field needs enterprise-wide standardization. Priority should be given to information that crosses functional boundaries or supports portfolio comparison. Local detail can remain flexible when it does not disrupt authoritative reporting or traceability.

During Phase 2, teams should simplify the process before automating it. Duplicate approvals, unused fields and reconciliation steps may have accumulated for historical reasons. Removing them requires consultation with users and control owners because an apparently redundant step may address a legal, financial or operational risk. The goal is a documented future-state process in which each transfer and approval has a clear purpose, owner and output.

Phase 3 should configure interfaces, workflow and reporting around the agreed control design. Testing should use realistic project scenarios, including late commitments, partial progress, disputed changes and provisional values. Successful calculation alone is insufficient. Users should verify that the information reaches the correct decision maker, that

exceptions can be understood and that the controlled forecast or budget is updated consistently after approval.

Training in Phase 3 should be role based. Users who create records need guidance on definitions, timing and evidence; reviewers need guidance on materiality, assumptions and escalation; executives need guidance on interpreting forecast movement and uncertainty. Training should include the reason behind each control so that employees can identify when the configured process no longer fits the business situation rather than bypassing it silently.

Phase 4 should pilot the operating model on a manageable set of projects and monitor both intended outcomes and unintended work. The pilot should record interface exceptions, manual workarounds, delayed approvals, alert volumes and user questions. A rise in reported issues during early use may reflect improved visibility, so management should examine the nature and resolution of issues rather than treating the count alone as failure.

Phase 5 should scale only after the organization has evidence that definitions, responsibilities and decision routines work. Scaling should preserve a feedback route for local teams and should distinguish mandatory controls from configurable practices. Portfolio governance can monitor common indicators while project teams retain responsibility for explaining context. This approach treats transformation as an organizational learning process rather than a single deployment event.

Post-implementation review should compare the baseline with operational evidence. Relevant questions include whether reconciliation effort fell, forecast explanations improved, approved changes reached the forecast faster and material alerts received timely action. Perception items can be repeated, but they should be interpreted alongside system and project records. Where improvement is absent, managers should revisit process and ownership before assuming that more features are required.

C.10 Governance Maturity Levels

At an initial maturity level, cost information is mainly function specific. Teams maintain local files, interfaces depend on individual knowledge and reporting effort is concentrated near period close. Management can still exercise control, but the process is vulnerable to delay, staff turnover and inconsistent interpretation. The immediate priority is not sophisticated analytics; it is identifying authoritative records, critical handoffs and the most material sources of reconciliation.

At a defined maturity level, core codes, responsibilities and reporting routines are documented. Projects use agreed templates and approval paths, but compliance may vary and cross-system links may remain manual. Management should monitor exceptions and determine why teams bypass the standard process. The objective is to make the defined method usable in real delivery conditions and to ensure that local adaptation remains visible rather than creating an uncontrolled parallel system.

At an integrated maturity level, cost, schedule, progress, procurement and change information share controlled relationships. Updates flow with less re-entry, and managers can trace material movements to source records and decisions. Integration does not eliminate judgment. Governance should protect data definitions, access rights and change control for the interfaces themselves, because an automated mapping error can affect many reports simultaneously.

At an analytical maturity level, current data support early warning, forecast scenarios and targeted management attention. Models and thresholds should remain explainable to the decision makers who use them. Management should test false positives, missed exposures and sensitivity to assumptions. Analytical sophistication becomes a risk when employees cannot

challenge the signal or when model output is treated as authority without understanding the underlying data and business conditions.

At an adaptive maturity level, the organization learns across projects. Forecast histories, change causes, action effectiveness and final outcomes are compared, and lessons update estimating, risk and control practices. Governance at this level includes regular review of whether the digital process still fits strategy, contract models and delivery methods. Adaptation is controlled and evidence based rather than a series of unrecorded local workarounds.

Maturity should not be treated as a race toward maximum automation. Different project types may justify different control intensity, and a smaller project may be well governed with simpler tools. The relevant question is whether information quality, timeliness, traceability and response are proportionate to exposure. A mature organization can explain why a control is necessary, how it works and what evidence shows that it remains effective.

Movement between levels requires management capability as well as technology. Leadership must resolve ownership conflicts, protect time for forecast review, respond to escalated information and hold process owners accountable for recurring exceptions. Employees will reasonably disengage if they provide better data but observe no change in decisions. Visible management use of information is therefore part of the control environment and an important condition for sustained adoption.

C.11 Evidence and Review Checklist

For data integration, reviewers should obtain the current coding structure, interface map, data dictionary, ownership matrix and a sample reconciliation. They should select several material records and trace them across systems. Exceptions should be categorized by cause, age and exposure. The review should distinguish unavoidable timing differences from preventable re-entry or definition problems and should assign improvement actions to process owners.

For visibility and forecasting, reviewers should obtain successive forecast versions, movement explanations, commitment and progress cut-offs, risk assumptions and meeting decisions. A sample of large forecast changes should be traced to the information available at the prior review. This reveals whether the organization identified the exposure late, interpreted it slowly or decided not to act. Each outcome has a different management response.

For workflow and change control, reviewers should sample approved, rejected, pending and urgent changes. They should confirm that scope, cost, schedule, risk, authorization and forecast treatment are visible and connected. They should also inspect overdue actions and determine whether escalation occurred. A complete electronic trail is useful only when it represents the full decision and its effect on controlled values.

For employee capability, reviewers should compare training content with actual role responsibilities and recurring errors. Interviews should ask employees which fields or reports they do not trust, where they maintain offline calculations and what information arrives too late. These responses should be tested against records rather than accepted or dismissed automatically. Workarounds often reveal a genuine process gap even when they create an additional control risk.

For management use, reviewers should examine whether meetings and decisions refer to forecasts, risks, changes and actions in a consistent way. They should identify cases in which a significant warning was visible but no decision was recorded. This helps separate a data problem from an authority, incentive or governance problem. The aim is to close the information-to-action loop, not simply improve the appearance of the report.

The final review should record evidence, finding, exposure, owner, target action and follow-up date. Findings should be prioritized by decision risk and business consequence rather than by the number of system defects. Progress should be verified through changed behavior and records. Repeating the survey after improvement can provide a useful employee perspective, but it should be accompanied by the operational evidence described in this checklist.

C.12 Management Risk and Assurance Considerations

Digital integration can create concentration risk when many decisions depend on one interface, classification rule or authoritative dataset. Assurance should therefore test change control over mappings, access rights, backups and recovery procedures as well as the accuracy of current values. A controlled manual fallback may still be necessary for critical reporting periods, but its activation, reconciliation and retirement should be documented so that emergency practice does not become a permanent parallel process.

Automation can also obscure responsibility if employees assume that a transferred or calculated value has already been validated. Governance should make clear which controls are automated, which require human review and which assumptions remain judgmental. Exception reports should be assigned to business owners who understand the consequence of the value, not only to technical teams who can confirm that the system operated as configured.

Analytical forecasts carry model and assumption risk. Historical relationships may not hold when project scope, contract conditions, inflation, productivity or supply constraints change. Forecast owners should document major assumptions, compare scenarios and explain where management judgment overrides model output. Independent review should focus on sensitivity and decision consequence rather than expecting a single precise prediction from uncertain project information.

Access and confidentiality require proportionate controls. Employees need enough visibility to perform their roles, while commercial, personal and security-sensitive details should remain restricted. Excessive restriction can produce shadow records and delayed decisions; excessive access can expose confidential information. Role design should therefore follow the minimum information needed for accountable action and should be reviewed when responsibilities or project phases change.

Assurance should consider behavioral incentives. A system may be technically sound while users delay recording unfavorable information, avoid escalating uncertainty or protect local performance measures. Management messages and reward structures should support early disclosure and realistic forecasting. Review meetings should distinguish the identification of a problem from responsibility for causing it, because punishing early warning can undermine the very visibility that digital transformation is intended to improve.

Finally, assurance should remain proportionate. The purpose of additional evidence and control is to improve confidence and decision quality, not to slow every action. Materiality thresholds, risk-based sampling and clear approval limits can concentrate effort on consequential exposures. Periodic review should remove controls that no longer add value and strengthen those associated with recurring error, delayed action or significant financial consequence.