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Structural Equation Modelling: Basis for a Proposed Framework on Construction Engineering Management

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Abstract— Construction projects globally, specifically in Region XIII (Caraga), Philippines, face persistent managerial, resource, technological, stakeholder, and contextual constraints that limit project success. This study assessed key construction engineering management constructs and examined their relationships with Project Success using Partial Least Squares Structural Equation Modeling (PLS-SEM). It also compared Project Success and management capability between public- and private-sector respondents and developed a region-specific Construction Engineering Management Maturity Framework (CEM-MF). A quantitative, cross-sectional survey was conducted with 309 construction professionals, 157 from the public sector and 152 from the private sector. Constructs included Project Management Practices, Resource Management, Technological Integration, Stakeholder Engagement, and External Influences, with Project Success as the primary outcome. SmartPLS analysis confirmed reliable and valid measurements. Results revealed Project Management Practices and Resource Management had the strongest positive links with Project Success, followed by Technological Integration and Stakeholder Engagement, while External Influences had a negative effect. The model explained 72.4% of the variance in Project Success and showed predictive relevance. Sectoral comparisons highlighted differences between public and private respondents. Drawing from these findings, a five-level CEM-MF was proposed to provide a structured framework for capability assessment, setting priorities, monitoring performance, and fostering continuous improvement in Caraga's construction sector, aiming to address persistent challenges and enhance overall project outcomes.

Keywords— Construction engineering management, project success, partial least squares structural equation modelling (PLS-SEM), resource management, technological integration, stakeholder engagement, construction engineering management maturity framework (CEM-MF).

I. Introduction

In the prevailing paradigms of the construction sector, defined by technological convergence and systemic complexity, the global industry has undergone a substantial transformation, one that demands scholarly precision, methodological rigor, and an elevation in professional standards. The interplay between disruptive innovation, increasingly intricate stakeholder expectations, and regulatory intensification has ushered the industry into a new epoch of data-driven precision and adaptive leadership. At this critical inflection point, the imperative to cultivate

analytical depth and technological literacy has never been more pronounced, particularly within emerging economies where contextual limitations and opportunities coexist in dynamic tension [1], [2].

Amidst this digital revolution, real-time data analytics, AI-enhanced modelling, and sophisticated decision-support systems have reconstituted the foundational practices of construction engineering and management. In this intellectually fertile environment, Structural Equation Modelling (SEM) emerges not merely as a statistical tool, but as a rigorous analytical methodology. SEM facilitates nuanced inquiry into latent constructs associated with project performance, enabling researchers and practitioners to examine interdependent phenomena with empirical clarity and theoretical precision [3], [4].

Propelled further by the proliferation of SMART technologies, including Building Information Modelling (BIM), Artificial Intelligence (AI), and the Internet of Things (IoT), the industry has witnessed a profound shift from conventional to digitally orchestrated, intelligent systems. These advancements offer substantial capabilities in predictive analytics, risk mitigation, and stakeholder synchronization. Within this framework, Partial Least Squares Structural Equation Modeling (PLS-SEM) provides a methodologically robust mechanism for examining the relationships among managerial practices, technological capabilities, external conditions, and project outcomes. It is within such relationships that project performance and organizational capabilities can be systematically assessed [5], [6].

Region XIII (Caraga), an area with significant socio-economic potential within the Philippines, presents a promising setting for empirical inquiry. Despite its considerable strategic development initiatives, the region's construction firms and agencies continue to encounter infrastructural constraints, uneven technology adoption, and challenges in project delivery. These constraints, while formidable, also provide fertile intellectual ground for scholarly intervention. On the national level, the Philippine construction industry remains a crucial driver of GDP growth and employment; however, it is simultaneously challenged by policy fragmentation, an uneven distribution of skilled labor, and the limited adoption of innovative technologies. In contrast, advancements in the international construction sector, including digital twins, blockchain-enabled procurement, and carbon-neutral methodologies, underscore the importance of strengthening regional construction management practices through rigorous empirical inquiry and tailored, locally adaptive frameworks [7], [8], [9].

A wide corpus of literature attests to the efficacy of SEM in evaluating diverse phenomena within construction domains. These include stakeholder dynamics [10], technological maturity models [11], performance benchmarking [12], BIM interoperability [13], and AI-based project simulations [14]. Further studies indicate that the intersection of technological integration and human capital development contributes to project outcomes, emphasizing the critical interplay of social and technical systems [10], [11], [12], [13], [14], [15], [16], [17], [18], [19]. However, a significant research gap persists in the integrated application of PLS-SEM and empirically derived maturity assessment within under-researched regions such as Caraga, where socio-economic and operational conditions may differ from those found in more technologically advanced regions.

While SEM has found widespread application in global and metropolitan contexts, its application to the distinct socio-economic and operational conditions of developing regions remains comparatively underexplored. The limited availability of region-specific empirical models examining project management capabilities, external influences, and project success constitutes a significant gap in both academic literature and practical construction management applications. Furthermore, the absence of an empirically grounded maturity classification framework limits the systematic assessment of construction engineering management capabilities across public and private sectors. Consequently, the study addresses the following central problem: How are Project Management Practices, Resource Management, Technological Integration,

Stakeholder Engagement, and External Influences associated with Project Success in Region XIII (Caraga), and how can the resulting empirical evidence support sectoral comparisons and the development of a Construction Engineering Management Maturity Framework?

In essence, the Caraga region presents construction management challenges that warrant a structured analytical approach, such as PLS-SEM, to examine the relationships governing project outcomes. These challenges include the underexplored relationships between critical construction management factors, namely Project Management Practices, Resource Management, Technological Integration, Stakeholder Engagement, and External Influences, and their relationships with Project Success. Despite the increasing complexity of construction projects in the region, there remains a paucity of integrated empirical investigations examining these constructs, thereby limiting the evidence available to inform construction management improvements. Furthermore, the region's construction sector encompasses both public and private organizations, yet comparative evidence concerning their reported Project Success and construction engineering management capability levels remains limited. This gap constrains the identification of sector-specific strengths, deficiencies, and opportunities for improvement. Hence, there is a need for an empirically informed Construction Engineering Management Maturity Framework (CEM-MF) that integrates the study's structural findings with measurable capability indicators and clearly defined maturity classifications to support systematic assessment and continuous improvement.

By addressing these gaps in construction engineering management literature, this study pursued four interrelated objectives: (1) assess the measurement quality of Project Management Practices, Resource Management, Technological Integration, Stakeholder Engagement, External Influences, and Project Success through appropriate reliability and validity criteria; (2) examine the relationships between the five predictor constructs and Project Success using Partial Least Squares Structural Equation Modelling (PLS-SEM) among construction professionals in Region XIII (Caraga); (3) compare reported Project Success scores and construction engineering management capability scores between public- and private-sector respondents to identify differences in their respective performance and capability profiles; and (4) develop a region-specific Construction Engineering Management Maturity Framework (CEM-MF), incorporating empirically derived five-level maturity classifications based on the observed capability-score distributions and informed by the study's structural findings.

This study seeks to generate both theoretical advancement and practical utility. From an academic standpoint, it contributes to the application of PLS-SEM in construction management, particularly within under-researched regional contexts, while extending empirical findings into a structured maturity assessment framework. Practically, the proposed CEM-MF provides a data-driven diagnostic and strategic reference for construction professionals, industry leaders, policymakers, and educational institutions seeking to assess management capabilities, identify areas for improvement, and align regional construction practices with established industry standards. The study, therefore, establishes a connection between empirical investigation and practical application, supporting evidence-informed decision-making and progressive capability development across multiple dimensions of construction engineering management.

The geographical scope of the study is confined to Region XIII (Caraga), encompassing construction professionals affiliated with public-sector agencies and private-sector construction firms operating within the region. The investigation employed a cross-sectional, self-report research design involving 309 purposively selected respondents, comprising 157 public-sector and 152 private-sector participants. The study examined six measured constructs through PLS-SEM, compared respondent-level Project Success and construction engineering management capability scores across sectors, and developed empirical maturity classifications for the proposed CEM-MF. While External Influences were incorporated as a measured construct, the investigation did not independently evaluate broader macroeconomic, cultural, or political conditions

beyond the scope of the adopted indicators. Moreover, the maturity classifications were derived from the observed sample distributions and should be interpreted as sample-referenced assessment thresholds rather than externally validated industry standards. Accordingly, the cross-sectional design, reliance on self-reported measures, and purposive sampling approach limit causal interpretation and the generalizability of findings beyond the investigated population.

In synthesis, this study represents an intellectual endeavor to advance construction engineering management through the integrated application of Partial Least Squares Structural Equation Modelling, sectoral capability assessment, and empirically derived maturity classification. By harmonizing established analytical methodologies with region-specific construction management conditions, the investigation contributes a proposed Construction Engineering Management Maturity Framework that translates empirical findings into structured capability levels. Through this integration, the study seeks to inform scholarly inquiry, institutional decision-making, and continuous improvement in construction project management within Region XIII (Caraga).

A. Related Literature and Studies

Over the course of the past few decades, the construction industry has been acknowledged as a cornerstone of economic advancement, infrastructure expansion, and societal transformation on a global scale. This assertion holds particularly true for emerging economies and developing regions, such as Region XIII (Caraga) of the Philippines, where infrastructure development is not merely a facet of growth but a crucial determinant of economic resilience and regional progress. However, as construction projects become progressively more complex, characterized by an array of interdependent stakeholders, fluctuating economic conditions, and rapidly evolving technological innovations, the demand for more sophisticated and adaptive project management methodologies has escalated. In response to these challenges, Structural Equation Modelling (SEM), an advanced multivariate statistical technique adept at examining the relationships between observed and latent variables, has emerged as a valuable analytical tool in construction project management. Complementing this methodological advancement, maturity assessment frameworks provide structured mechanisms for evaluating organizational capabilities and identifying opportunities for continuous improvement. The ensuing review delves into the evolution of project management methodologies within the construction industry, with particular emphasis on the application of SEM, its integration with emerging technologies, and its implications for public- and private-sector construction projects. Furthermore, the review examines the conceptual foundations of construction engineering management maturity assessment, particularly within regions such as Caraga, where infrastructure development presents distinct operational challenges and opportunities.

1) Evolution of Project Management Methodologies in Construction

Conventional construction-project planning frequently includes schedule-network methods such as the Critical Path Method and PERT, alongside the process planning and monitoring practices described in the Project Management Institute's guidance [53]. Such planning techniques do not, by themselves, explain all relationships among project governance, stakeholder demands, resources, technological change, and external conditions. For example, Kassem [21] used PLS-SEM to examine risks in oil and gas construction, illustrating an alternative way to formulate multiple associated influences as a model. The suitability of any structural model still depends on clearly defined constructs, sound measurement, and design-appropriate inference.

Complementing traditional planning methodologies, Partial Least Squares Structural Equation Modelling (PLS-SEM) offers a systems-oriented analytical approach that examines the relationships among multiple project management constructs. PLS-SEM enables a more nuanced

understanding of construction project dynamics by estimating relationships between observed indicators and latent variables. This approach provides valuable insight into the multidimensional nature of project management, making it a useful analytical tool for contemporary construction research. Thus, the application of PLS-SEM complements established project management methodologies by providing empirical evidence concerning the managerial, technological, stakeholder, and contextual factors associated with project performance.

2) Structural Equation Modelling in Construction Research

The application of SEM in construction research represents a methodological advancement in examining multidimensional and theoretically specified relationships. As SEM facilitates the examination of latent variables, such as leadership, stakeholder engagement, and organizational commitment, it offers significant advantages over conventional analytical methods that may inadequately account for these intangible factors [22]. These latent variables, while difficult to quantify directly, are relevant to understanding project success, and their inclusion in SEM frameworks enhances the depth of empirical analysis.

Al-Marri et al. [23] examined project-management maturity and sustainability in project-based organizations, a topic relevant to how management capabilities are conceptualized. Omotayo et al. [24] investigated connections among project complexities, stakeholder engagement, and social dynamics from a systems-thinking perspective. Together these works motivate the consideration of multiple, interacting managerial and contextual domains in construction. Their subject matter does not validate the present measurement model or imply that the direct and mediated effects proposed in other settings have been reproduced in Caraga.

3) Integration of Technology and SEM in Construction Project Management

Digital construction management encompasses BIM, project information systems, smart monitoring, and emerging digital-twin applications. Torres et al. [20] investigated how digital-twin development can address automation barriers in site management. In a different context, Taher et al. [25] studied the status and impact of change management in the Indian construction industry. These studies concern implementation and adaptation challenges, rather than demonstrating that a new SEM instrument is valid. They support examining technological integration and change readiness as candidate topics while requiring independent local measurement checks.

Furthermore, the integration of advanced analytical methodologies with emerging technologies holds considerable potential for improving the assessment of construction project performance. The combination of technological innovation and empirical modelling offers a comprehensive perspective on the conditions associated with project success, allowing construction professionals to identify managerial and technological areas requiring improvement. This convergence of SEM and emerging technologies signifies an important advancement in construction management research, particularly in environments where traditional management approaches require supplementation by data-driven assessment methodologies.

4) SEM Applications in Risk Management and Resource Allocation

Construction risks involve potentially interdependent scheduling, cost, quality, and contextual exposures. Adedokun et al. [22] used structural equation modelling to examine risk factors influencing building-project success. Alnaser et al. [26] applied a PLS-based approach to explore critical factors associated with AI-integrated digital twins in Saudi construction deliverables. Both illustrate context-specific uses of multivariable modelling, but neither is evidence that the present six reflective scales are discriminant or that its archived coefficients are significant.

Al-Mhdawi et al. [27] used structural equation modelling to investigate the relationships between COVID-19 pandemic risks and project success from construction contractors' perspectives. This evidence reinforces the practical need to distinguish contextual exposures from management practices when specifying a model. The Caraga survey includes broad External Influences indicators, so interpretation of a pooled negative path requires both discriminant-validity evidence and independent outcomes rather than assuming identical mechanisms across settings.

5) Comparative Analysis of Public and Private Sector Construction Projects

Public and private construction delivery systems may differ in procurement arrangements, governance, project type, and reporting incentives. Shrestha et al. [28] compared project performance across highway delivery approaches, including public–private partnership and design–build procurement. That comparison provides context for distinguishing delivery arrangements but does not constitute evidence from SEM or establish the superiority of one sector in Caraga. The present study therefore tests a respondent-level reported Project Success contrast explicitly and avoids equating it with verified project performance.

Such findings emphasize the importance of examining sector-specific construction management conditions and provide valuable insights into the factors associated with project performance in different organizational environments. However, sectoral comparison need not be confined to differences in structural path coefficients. Comparisons of reported Project Success and construction engineering management capability scores can also provide empirical evidence concerning variations in respondent-level performance and management profiles. This distinction is particularly relevant for regions such as Caraga, where public agencies and private construction firms operate within different governance, resource, and operational contexts. Accordingly, examining differences in their reported scores may contribute to identifying sector-specific capability gaps and opportunities for improvement without presuming differences in the underlying structural relationships.

6) Regional Dimensions of Construction Project Management

Region XIII (Caraga) contains heterogeneous project settings and institutional conditions that may affect delivery. Magtibay [29] examined factors contributing to construction cost overruns in the Philippines from a multi-stakeholder perspective. This Philippine research offers relevant contextual grounding, but findings from its setting cannot substitute for a known Caraga sampling frame, firm-level verification, or objective outcomes in the present study.

SEM provides a useful analytical approach for addressing these region-specific considerations by supporting empirical investigation and evidence-informed decision-making. By examining the associations between managerial practices, resource capabilities, technological integration, stakeholder engagement, external influences, and project outcomes, SEM can help identify factors relevant to construction management improvement. Consequently, a contextualized analytical approach may support the development of construction engineering management strategies responsive to regional conditions. Moreover, incorporating these empirical relationships into a maturity assessment framework offers an additional mechanism for translating research findings into structured capability classifications and improvement priorities.

7) Decision-Making, Performance Metrics, and PLS-SEM-Based Frameworks

Project performance and management capability are multidimensional concepts. Ibrahim et al. [30] reviewed project-level performance measurement practices in construction and emphasized the need for systematic assessment. The present study uses observed questionnaire-domain scores and an exploratory structural model to examine patterns in those concepts. However, the failure of reflective convergent and discriminant validity prevents this numerical solution from serving as verified evidence of distinct latent managerial capabilities.

Acharya et al. [31] examined how project planning, resource allocation, and risk mitigation relate to construction delays. This work supports including planning and resource practices in a construction-management assessment, without implying that the particular survey measures or causal hypotheses are already validated. A proposed maturity classification can use transparent observed-score thresholds as a descriptive device, but its level labels require independent organizational and longitudinal validation before they can be treated as developmental stages.

8) Construction Engineering Management Maturity Framework

Maturity models provide structured descriptions of management capabilities and possible improvement priorities. Homthong et al. [32] examined critical factors influencing construction performance across project objectives, underscoring the importance of specifying the outcome being assessed. Jayanetti et al. [33] reviewed attributes of construction maturity models, while Arar et al. [34] developed a capability maturity model for integrated project delivery. These studies inform the design problem but do not establish that the present five percentile-based respondent categories represent verified organizational maturity progression.

Extending this perspective, Jayanetti et al. [33] conducted a systematic review of construction maturity models and identified essential attributes associated with maturity assessment and framework development. Their findings emphasized the significance of clearly defined assessment dimensions, measurable indicators, and structured classification mechanisms in developing construction-specific maturity models. Similarly, Arar et al. [34] developed a capability maturity model for integrated project delivery, demonstrating the utility of systematically assessing construction-related capabilities through structured indicators and maturity classifications. These investigations collectively establish the theoretical and methodological relevance of maturity frameworks in translating complex management practices into interpretable capability assessments.

Recent scholarship has further emphasized the importance of contextual adaptability in maturity model development. Bozorg Mehri et al. [35], through a systematic review of organizational project management maturity models, identified organizational, project-related, technological, external, and individual factors as important dimensions of project management maturity. Their findings highlighted the limitations of rigid assessment structures and the need for adaptable frameworks that accommodate technological developments, stakeholder expectations, and changing operational conditions. These considerations are particularly relevant to construction organizations operating in developing regional environments, where managerial capabilities and contextual pressures may vary considerably across organizational settings.

The proposed CEM-MF is based on four domain-score summaries drawn from the approved survey and the observed respondent distributions. It is conceptually informed by prior construction management and maturity-model literature, but its classification thresholds are not derived from validated latent path weights or externally demonstrated developmental stages. Project Management Practices, Resource Management, Technological Integration, and Stakeholder Engagement are retained as provisional internal capability domains, with External Influences reported separately.

To operationalize the proposed framework, five progressive maturity levels are established through empirical quintile classifications derived from the study's respondent-level capability-score distributions. These classifications provide numerical boundaries for distinguishing relatively lower and higher observed capability profiles within the investigated sample. Unlike maturity models that rely exclusively on predetermined qualitative stages or externally established benchmarks, the proposed approach employs sample-referenced statistical thresholds to support systematic interpretation of construction engineering management capability levels. The resulting classifications are intended to facilitate capability diagnosis, sectoral comparison, identification of improvement priorities, and continuous development. Nevertheless, the empirical

quintile boundaries represent relative classifications within the observed sample and should not be interpreted as independently validated industry-wide maturity standards.

The combination of an exploratory SEM diagnostic and a separate transparent score-classification rule offers two different perspectives on construction management responses. The former was not validated as a six-domain reflective model, while the latter summarizes the relative position of respondents within this sample. Neither establishes causal improvement effects, nor does the framework currently certify the capability or maturity of an organization.

9) Synthesis and Research Gaps

While the literature offers significant insights into PLS-SEM's application in construction management and the development of organizational maturity models, several research gaps remain. First, the contextual application of SEM in geographically and economically constrained regions, such as Caraga, remains insufficiently documented. Second, comparative empirical evidence concerning reported Project Success and construction engineering management capability levels among public- and private-sector respondents in the Philippine construction context remains limited. Third, the integration of managerial, resource, technological, stakeholder, and external factors into a unified structural model requires further examination within region-specific construction environments. Lastly, despite the growing application of maturity assessment frameworks in construction management, limited evidence addresses the integration of PLS-SEM findings with empirically derived, five-level maturity classifications that reflect the observed capability distributions of construction professionals in developing regional contexts.

The present study seeks to address these gaps by examining the measurement quality and structural relationships among Project Management Practices, Resource Management, Technological Integration, Stakeholder Engagement, External Influences, and Project Success. It further compares reported Project Success and construction engineering management capability scores between public- and private-sector respondents and develops a proposed CEM-MF incorporating sample-derived maturity thresholds. In doing so, the investigation seeks to provide a more context-sensitive and empirically informed approach to construction engineering management, supporting capability assessment, sector-specific interpretation, and structured identification of improvement priorities within Region XIII (Caraga).

Thus, the integration of PLS-SEM and maturity assessment represents a complementary advancement toward a comprehensive, data-driven approach to construction engineering management. While PLS-SEM provides empirical evidence concerning the relationships associated with Project Success, the proposed CEM-MF translates observed management capability levels into interpretable maturity classifications. Their combined application offers a structured foundation for advancing scholarly inquiry and informing construction management improvement within the regional context of Caraga, where infrastructure development remains essential to economic and social progress.

B. Statement of the Problem

The study addresses the need to examine construction management factors associated with Project Success and to translate respondent-level findings into a transparent proposed maturity-oriented framework for the Caraga context. The questions correspond directly to the four research objectives and distinguish PLS-SEM estimation from subsequent sectoral score comparisons.

1) What are the reliability and validity characteristics of the reflective measurements of Project Management Practices, Resource Management, Technological Integration, Stakeholder Engagement, External Influences, and Project Success?

2) What are the directions, magnitudes, and explanatory contributions of the five hypothesized direct structural relationships with Project Success in the pooled PLS-SEM model?

3) How do observed Project Success scores and internal CEM capability scores differ between public- and private-sector respondents in Region XIII (Caraga)?

4) How can the validated measurements, estimated relationships, and pooled respondent-score distributions inform a proposed five-level Construction Engineering Management Maturity Framework with explicit numerical boundaries and separate contextual-exposure classifications?

C. Objectives of the Study

The overall objective is to examine the measurement and structural relationships associated with Project Success among construction professionals in Region XIII (Caraga), compare public- and private-sector score profiles, and propose an empirically traceable CEM maturity-oriented diagnostic framework. The specific objectives are as follows:

1) To assess the reflective measurement models for Project Management Practices, Resource Management, Technological Integration, Stakeholder Engagement, External Influences, and Project Success using indicator reliability, internal consistency, convergent validity, and discriminant validity criteria.

2) To estimate the five exploratory paths to Project Success in the pooled six-construct specification, reproduce the archived SmartPLS algorithm, and document independent resampling uncertainty and available model diagnostics, without claiming confirmatory construct validity.

3) To compare public- and private-sector respondents on their observed Project Success and internal CEM capability scores, reporting sector-specific descriptive profiles and appropriate verified distributional or mean-comparison tests where the data and assumptions permit.

4) To formulate a proposed CEM-MF using four equally weighted internal capability means, construct-specific and overall pooled percentile boundaries (P20, P40, P60, and P80), and a separate External Influences intensity classification, with limitations on organization-level application expressly stated.

D. Hypotheses of the Study

The pooled PLS-SEM hypotheses concern the five direct associations with Project Success. The public–private hypotheses concern score differences and are tested separately from the structural paths. No multi-group test of differences between structural path coefficients is specified in this revised design.

H1. Direct Effects (Structural Paths)

H_1a. Project Management Practices positively influence Project Success.

H_1a_0. The path coefficient between Project Management Practices and Project Success equals zero.

H_1b. Resource Management positively influences Project Success.

H_1b_0. The path coefficient between Resource Management and Project Success equals zero.

H_1c. Technological Integration positively influences Project Success.

H_1c_0. The path coefficient between Technological Integration and Project Success equals zero.

H_1d. Stakeholder Engagement positively influences Project Success.

H_1d_0. The path coefficient between Stakeholder Engagement and Project Success equals zero.

H_1e. Higher reported External Influences are negatively associated with Project Success.

H_1e_0. The path coefficient between External Influences and Project Success equals zero.

H2. Public-Private Sector (Score Comparisons)

H2a (Project Success): H_0: Public- and private-sector respondents have equal Project Success score distributions (or means, if a mean-based test is selected); H_1: these distributions (or means) differ. The selected estimand and test must be stated consistently.

H2b (Internal CEM-MF): H_0:The public- and private-sector overall internal capability score distributions (or means) are equal; H_1: they differ. Construct-specific tests, if reported, are supplementary and should be accompanied by an explicit multiple-testing policy.

E. Hypothesized Model

Fig. 1 illustrates the hypothesized structural relationships among the five exogenous constructs - Project Management Practices (PMP), Resource Management (RM), Technological Integration (TI), Stakeholder Engagement (SE), and External Influences (EI) - and the endogenous construct, Project Success (PS). The model specifies five direct paths corresponding to hypotheses H_1a-H_1e, providing the theoretical basis for examining their respective associations with Project Success through pooled PLS-SEM analysis. Positive relationships are hypothesized for PMP, RM, TI, and SE, whereas a negative relationship is hypothesized for EI, reflecting its operationalization as contextual pressure. Public- and private-sector classifications are considered separately under hypotheses H_2a and H_2b to examine differences in reported Project Success and internal CEM-MF capability scores, rather than differences in structural path coefficients.

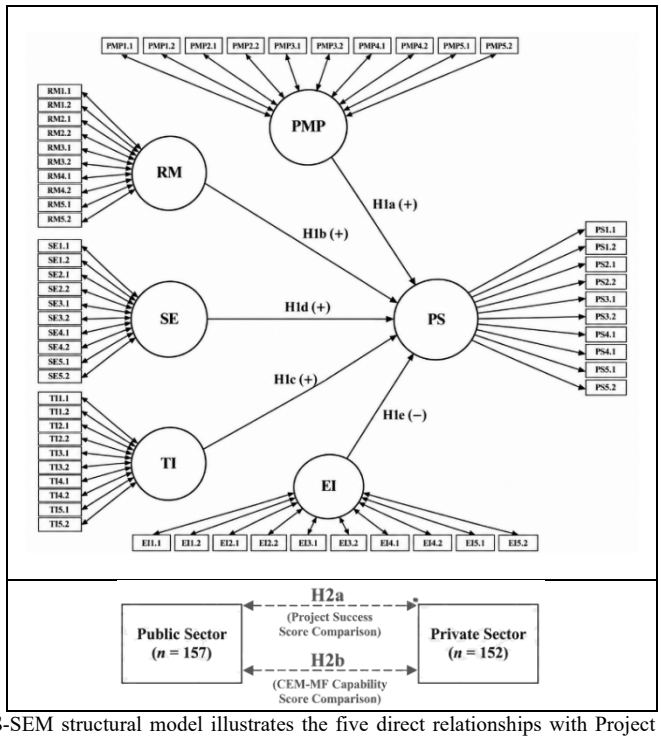


Fig. 1. The hypothesized PLS-SEM structural model illustrates the five direct relationships with Project Success (H_1a-H_1e), and the public–private sector differences (H_2a–H_2b) are assessed separately through respondent-level score comparisons.

F. Correlational Measures of the Study

Pearson correlations and supplementary ordinary least squares (OLS) regression are presented as exploratory or confirmatory score-level analyses, as appropriate to their documented assumptions. These analyses use observed scores and do not substitute for the latent-variable measurement and structural analyses conducted through PLS-SEM.

The supplementary score analyses are distinguished as follows:

1) Correlation analysis assesses the direction and strength of bivariate linear associations among the observed construct scores and Project Success. It does not establish causation.

2) Supplementary OLS regression estimates conditional linear associations on the original observed score scale. Its unstandardized B coefficients and R^2 must not be presented as standardized PLS-SEM paths or the maturity framework scoring weights.

The pooled PLS-SEM analysis estimates five exploratory structural paths to Project Success. Independently reproduced public–private questionnaire-domain summaries and a direct Mann–Whitney comparison of Project Success (H2a) describe respondent-level sectoral differences, but purposive recruitment and self-report prevent causal or population-representative conclusions.

G. Significance of the Study

This study, through the application of Partial Least Squares Structural Equation Modelling (PLS-SEM) and the development of a proposed Construction Engineering Management Maturity Framework (CEM-MF), seeks to contribute to the advancement of construction engineering management at regional, national, and international levels. By examining the relationships among critical management constructs and Project Success, the study provides an empirical foundation for capability assessment, evidence-informed decision-making, and continuous improvement. Beyond its regional application, the proposed framework offers methodological insights relevant to the broader international discourse on construction project performance, organizational maturity, technological integration, and sustainable infrastructure development. The following stakeholders may benefit from the study:

1) Construction Managers and Project Managers, the study provides a robust framework that enables construction and project managers to refine their decision-making processes. By understanding the interrelationships between key project variables, managers can optimize resource allocation, mitigate risks, and enhance overall project execution, thereby improving project outcomes in terms of time, cost, and quality.

2) *Public- and Private-Sector Organizations.* Sector-specific score distributions and capability profiles can inform targeted diagnostic assessments. The analysis compares reported scores and does not establish different structural coefficients or objectively audited organizational performance.

3) Policymakers and Government Agencies, government agencies responsible for the oversight and regulation of construction projects will benefit from this study's findings. By identifying the factors that most significantly impact project success, policymakers can craft more informed, evidence-based regulations and policies. These will contribute to the efficiency of public sector projects and promote a more robust infrastructure development agenda.

4) Academia and Researchers in Construction Engineering Management, this study makes a valuable contribution to the academic discourse on construction engineering management, particularly in the application of PLS-SEM for analyzing complex project dynamics. Scholars and researchers will benefit from the methodological approach and insights presented in this study, furthering future academic inquiry and fostering continued innovation in the field.

5) Construction Workers and Labor Forces, the implementation of optimized project management practices and more efficient resource allocation, as advocated by this study, will directly benefit construction workers. Enhanced project organization, improved safety protocols, and timely project delivery may contribute to better working conditions and increased job satisfaction, while minimizing labor-related risks.

6) Contractors and Subcontractors, the study's identification of key success factors and potential risk areas will assist contractors and subcontractors in improving their operational strategies. By adopting the insights provided, these stakeholders can enhance coordination, reduce cost overruns, and minimize delays, thus ensuring the timely and high-quality completion of projects.

7) Technology Providers, as the study delves into the integration of advanced technological tools, such as Building Information Modelling (BIM), Artificial Intelligence (AI), and the Internet of Things (IoT), technology providers will gain valuable insights into the role their innovations play in improving construction management. This will enable them to refine their products and services to better align with industry needs.

8) Regional Development and Economic Growth Stakeholders, in the specific context of Region XIII (Caraga), this study presents an opportunity to address regional challenges such as infrastructure gaps, resource constraints, and workforce limitations. The SEM-based framework developed through this study will guide regional stakeholders in optimizing construction projects, ultimately contributing to sustained regional economic growth and development.

9) Investors and Financial Institutions, those that fund construction projects will find this study particularly valuable in enhancing their risk assessment and decision-making processes. With data-driven insights on the factors influencing project success, they will be equipped to make more informed investment choices, improving the return on investment and minimizing exposure to risks.

10) Stakeholders in Environmental Planning, Regulatory Oversight, and Community Coordination, the study will clarify how external influences interact with project management, resource, technology, and stakeholder factors, thereby providing valuable guidance for stakeholders aiming to implement more responsive, compliant, and context-sensitive practices within the construction industry.

11) International Construction Industry and Global Research Community, beyond its regional setting, the study contributes to the international discourse on construction engineering management by presenting an integrated analytical approach that connects PLS-SEM findings with empirically derived maturity classifications. The proposed CEM-MF offers a preliminary methodological reference for examining management capabilities and contextual pressures in construction environments characterized by varying institutional capacities, technological readiness, and resource constraints. Its integration of structural analysis, sectoral comparisons, and sample-referenced maturity assessment may inform future cross-regional and international comparative investigations. Through subsequent replication, contextual adaptation, and external validation, the framework may contribute to the progressive development of construction management assessment methodologies and support broader efforts toward resilient, efficient, and sustainable infrastructure delivery.

H. Scope and Limitations of the Study

This study is a quantitative, non-experimental, cross-sectional investigation of the associations between five measured predictor constructs and Project Success among 309 construction professionals in Region XIII (Caraga). The four internal capabilities are subsequently summarized in a proposed CEM-MF; EI is measured and classified separately as contextual exposure. Public-private differences are assessed through score comparisons.

The purposive sample and self-reported measures limit statistical generalizability, eliminate any direct basis for causal claims, and may reflect professional-role, organization, and project clustering. The study does not establish that a respondent-level score constitutes a validated organizational audit or that a sample quintile is a universal maturity stage. Sampling-population totals, survey administration details, and original software outputs must be verified against primary records.

I. Theoretical Framework of the Study

The theoretical framework presented in the table offers a comprehensive and structured view of the key components influencing construction project outcomes, with Structural Equation Modelling serving as the analytical procedure used to test theory-based relationships rather than as a theory in itself. In alignment with the institutional guide, the framework is most defensibly anchored in the Resource-Based View, while Stakeholder Theory, Diffusion of Innovations, the Theory of Constraints, the Project Management Triangle, and Project Success Theory function as supporting perspectives. Each theoretical element contributes uniquely to understanding how various factors interplay to affect project success.

The Resource-Based View (RBV) highlights the importance of effectively utilizing valuable resources - human, financial, technological, and organizational - to achieve a competitive edge in construction management. Within this study, RBV primarily explains why strong project management practices, sound resource management, and purposeful technological integration can improve project success when they are organized and deployed as institutional capabilities. Stakeholder Theory explains why stakeholder engagement matters, because projects are implemented in relational environments where client, community, contractor, regulatory, and end-user interests can shape cooperation and performance. Diffusion of Innovations supports the technological integration construct by clarifying how digital tools such as BIM, AI-assisted analytics, and IoT-enabled systems are adopted, routinized, and translated into improved coordination and decision support.

Furthermore, the Project Management Triangle, comprising the interrelated constraints of time, cost, and quality, provides a foundational lens through which construction performance can be interpreted. At the same time, the Theory of Constraints explains how bottlenecks and limiting conditions can suppress throughput and project flow, making it especially relevant to the construct External Influences. Project Success Theory broadens the outcome domain by recognizing that successful projects are not judged only by the iron triangle, but also by satisfaction, functionality, safety, and value.

In sum, these theoretical foundations are integrated as mutually reinforcing perspectives for explaining construction project success in Region XIII (Caraga), with PLS-SEM acting as the unifying analytical procedure used to estimate and test the proposed relationships among the constructs.

Table 1 distinguishes the foundational literature for the Resource-Based View, Stakeholder Theory, Diffusion of Innovations, Theory of Constraints, and broader project-success criteria from more recent applied construction studies. These theoretical propositions inform the questionnaire domains but do not themselves validate a specific reflective measurement model or causal path.

TABLE 1. THEORETICAL FOUNDATIONS, CONSTRUCT LINKAGE, AND RELEVANCE TO CONSTRUCTION PROJECT SUCCESS

Theoretical foundation	Core proposition	Constructs informed	Expected connection to success
Resource-Based View (RBV)	Project performance improves when firms effectively mobilize valuable organizational, human, financial, and technological resources [69]; applied example [39].	Project Management Practices, Resource Management, Technological Integration	Stronger internal capabilities are expected to support better delivery performance and higher project success.
Stakeholder Theory	Project outcomes depend on how well stakeholder interests, expectations, communication, and participation are managed [70]; applied example [37].	Stakeholder Engagement	Better alignment and cooperation among stakeholders support smoother implementation and fewer project disruptions.
Diffusion of Innovation Theory	The adoption and routinization of new technologies influence how effectively organizations improve work processes and decisions [71]; applied example [20].	Technological Integration	More effective adoption of digital tools is expected to strengthen coordination, forecasting, and execution.
Theory of Constraints (TOC)	Project performance is limited by bottlenecks and critical constraints that must be identified and managed [72]; applied example [38].	External Influences, Resource Management	Regulatory, environmental, labor, material, and market constraints can weaken project flow and reduce success if not addressed.
Project Management Triangle (Time, Cost, Quality)	Time, cost, and quality are interdependent performance constraints that must be balanced in delivery [73]; applied example [53].	Project Success Interpretation; Project Management Practices	Stronger practices should help maintain balance among core delivery constraints.
Project Success Theory	Success extends beyond the iron triangle to include satisfaction, functionality, safety, and value [74]; applied example [61].	Project Success	The outcome construct should be interpreted as multidimensional rather than purely schedule-cost-quality based.

Table 2 locates the five candidate predictors and Project Success within the study's input–process–output framing, with representative applied research citations. Its conceptual mapping must be distinguished from successful empirical measurement validation.

TABLE 2. THEORETICAL FOUNDATIONS, FIVE EXOGENOUS CONSTRUCT RELATIONSHIPS WITHIN THE INPUT-OUTPUT-PROCESS FRAMEWORK

Phase	Component and operational meaning	Theoretical Lens
Input	Project Management Practices — (These include planning, scheduling, and execution strategies. These form the foundation for the project structure [31].)	Project Management Triangle (Time, Cost, Quality) [73]; Stakeholder Theory
Input	Resource Management — (This involves managing human, financial, and technological resources required for the project's execution [39].)	Resource-Based View (RBV) [69]
Input	Technological Integration — The incorporation of modern technologies (e.g., BIM, AI) to optimize efficiency and decision-making [41].	Diffusion of Innovations Theory [71]
Input	Stakeholder Engagement — Managing stakeholder expectations and relationships throughout the project [37].	Stakeholder Theory [70]
Input	External Influences — External environmental factors including regulatory policies, economic conditions, market dynamics, environmental requirements, and socio-political contexts that affect project execution and outcomes [38].	Theory of Constraints (TOC) [72]
Process	Structural Equation Modelling (SEM) — A tool to analyze the relationships between various factors (inputs) that influence project success [45].	Structural Equation Modelling (SEM) [3]; Theory of Constraints (TOC)
Process	Project Management Triangle — Balancing time, cost, and quality constraints within the project to ensure overall performance and success [53].	Project Management Triangle (Time, Cost, Quality) [73]
Output	Project Outcomes — The results of the construction project including success or failure, evaluated in terms of quality, cost, and time [61].	Project Success Theory [74]; Stakeholder Satisfaction

J. Conceptual Framework of the Study

The conceptual framework follows an Input-Process-Output structure. Inputs are five exogenous constructs measured through survey responses from public- and private-sector construction professionals. The process comprises pooled PLS-SEM measurement and structural analysis, supplementary public-private comparisons of Project Success and internal CEM capability scores, and pooled percentile classification. The endogenous outcome is Project Success, whereas the separate applied deliverable is the proposed CEM-MF.

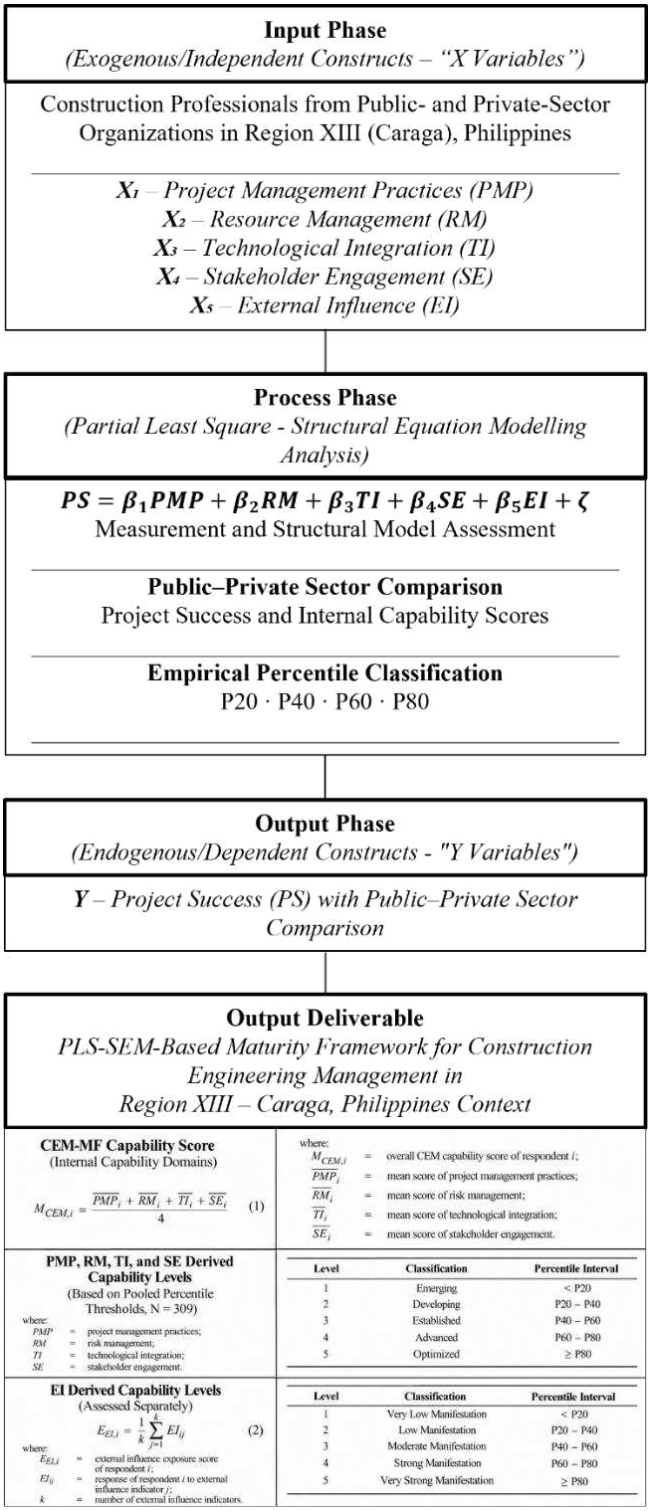


Fig. 2. Conceptual framework showing the five predictors of Project Success, pooled PLS-SEM analysis, supplementary public–private score comparison, and derivation of the proposed sample-referenced CEM-MF.

1) Input Phase

In the Input Phase, PMP, RM, TI, SE, and EI represent the exogenous model constructs. The empirical sample comprises 309 construction professionals, including 157 public-sector and 152 private-sector respondents. Sector is a comparison group rather than an additional modeled predictor. The terms correspond to the approved questionnaire domains.

X_1 - *Project Management Practices (PMP)*: project planning, scheduling, monitoring, coordination, and governance.

X_2 - *Resource Management (RM)*: allocation and control of human, financial, material, and equipment resources.

X_3 - *Technological Integration (TI)*: application of digital tools and coordinated project information systems.

X_4 - *Stakeholder Engagement (SE)*: participation, communication, conflict resolution, and interface coordination.

X_5 - *External Influences (EI)*: regulatory, economic, climatic, supply, labor, community, and approval-related contextual pressures.

2) Process Phase

In the Process Phase, the pooled measurement and structural models are assessed with SmartPLS. The five specified direct paths lead to Project Success. Public–private comparisons of observed Project Success and internal capability scores are reported separately; pooled respondent percentiles define the CEM-MF descriptive classification boundaries. These operations must not be confused with PLS-MGA.

a) *Structural model.* In a standardized path representation, the proposed direct-effects model is:

$$PS_i = \beta_1 PMP_i + \beta_2 RM_i + \beta_3 TI_i + \beta_4 SE_i + \beta_5 EI_i + \zeta_i. \qquad (1)$$

where PS is Project Success; PMP, RM, TI, SE, and EI are exogenous constructs; β_1–β_5 are structural path coefficients; ζ is the structural disturbance; and i identifies the observational unit. Equation (1) is a model specification, not the CEM-MF maturity-scoring rule.

b) *Project Success interpretation.* Schedule, cost, and quality form an important performance lens, but Project Success in the questionnaire additionally includes satisfaction, functionality, safety, and value. The structural model therefore must not be described as exclusively a time-cost-quality equation.

3) Output Phase

The Output Phase concerns Project Success as the single endogenous construct in the pooled PLS-SEM model. Sectoral comparisons concern observed scores, not separate endogenous constructs. The proposed CEM-MF is a subsequent research deliverable and must remain distinct from both PS and the standardized path equation.

a) *Project Success (Y).* The outcome represents reported multidimensional performance. The pooled model is specified once in (1), and the four-domain CEM-MF scoring procedure is presented separately in the framework development section.

The conceptual design thus separates model estimation, sector-specific observed-score comparison, and the later construction of a sample-referenced capability framework. No organizational maturity certification is inferred from the respondent distribution alone.

K. Definition of Terms

Operational definitions are given for the constructs and relevant project-management terminology. The predictor labels correspond to the approved instrument; the individual professional respondent is the survey observation, while any interpretation at the organization level is a proposed extension requiring aggregation and validation.

Artificial Intelligence (AI) refers to computational techniques that support prediction, optimization, pattern recognition, and decision support [46], [47]. In this study, AI is treated as one example of digital innovation subsumed under the broader construct Technological Integration rather than as a stand-alone latent variable.

Building Information Modelling (BIM) refers to a digital, model-based approach for coordinating design, information sharing, visualization, and planning across project participants [48], [49]. In this study, BIM is one of the technologies represented within the construct Technological Integration.

Construction Engineering Management (CEM) refers to the management of construction projects through integrated planning, coordination, execution, control, and performance evaluation [50]. In this study, it encompasses the integration of engineering knowledge with management principles to ensure the successful delivery of projects in terms of time, cost, quality, functionality, value, and stakeholder responsiveness.

Construction Engineering Management Maturity Framework (CEM-MF) refers to the proposed sample-referenced diagnostic framework derived from equally weighted respondent-level scores for Project Management Practices, Resource Management, Technological Integration, and Stakeholder Engagement. In this study, the framework classifies scores into five capability categories using pooled empirical percentile boundaries; it is not an externally validated organizational certification standard.

Construction Professional refers to a respondent who met the study's eligibility criteria through involvement in construction planning, technical implementation, design coordination, supervision, documentation, resource control, project administration, or related management activities within the specified geographical and temporal scope. In this study, the individual construction professional constitutes the unit of observation.

External Influences (EI) refer to exogenous contextual conditions that may facilitate or constrain project delivery, including regulatory, political, economic, environmental, labor-market, material-supply, community, and approval-related pressures [51]. In this study, External Influences is treated as a predictor construct directly linked to Project Success.

Internet of Things (IoT) refers to interconnected digital devices and sensors that generate and communicate real-time operational data [52], [53]. In the study, IoT is another example of the digital tools represented within Technological Integration.

Private-Sector Construction Respondents are professionals whose relevant project roles were associated with private-sector construction organizations or projects as defined in the screening records. Sector classification must be based on the recorded project or employment criterion and should not be inferred solely from project ownership or financing.

Project Management Practices (PMP) refer to the methodologies, strategies, tools, and processes that guide the management of construction projects from initiation through completion. These practices include project planning, risk management, resource allocation, and stakeholder communication [54]. In this study, Project Management Practices functions as an exogenous construct representing the managerial systems and routines that shape construction delivery performance.

Project Outcomes (PO) refer broadly to the observable results of project implementation [55]. In this study, the broad notion of project outcomes is operationalized more specifically through the endogenous construct Project Success.

Project Success (PS) refers to the degree to which a construction project meets its predetermined objectives, which typically include completing the project on time, within budget, and to the desired quality standards [56]. In this study, Project Success is interpreted as a multidimensional outcome rather than as a purely technical endpoint.

Public-Sector Construction Respondents are professionals whose relevant project roles were associated with public-sector agencies or construction projects as defined in the screening records. The classification rule must be applied consistently to government employees and private contractors working on publicly funded projects.

Resource Management (RM) is the systematic planning, allocation, and utilization of resources, such as human labor, construction materials, equipment, and financial capital, throughout the project lifecycle. Effective resource management is critical for maintaining project schedules and budgets, and in the study it functions as an exogenous construct linked to Project Success [57].

Stakeholder Engagement (SE) is the process of involving all parties who have an interest in the project, including clients, contractors, regulatory authorities, and end-users. Effective stakeholder engagement involves communication, collaboration, and alignment of goals throughout the project [58]. In the study model, Stakeholder Engagement is specified as an exogenous construct explaining variation in Project Success.

Structural Equation Modelling (SEM) refers to a family of multivariate procedures for estimating relationships among observed indicators and latent constructs [59]. In this dissertation, the specific approach used is Partial Least Squares Structural Equation Modelling (PLS-SEM), implemented in SmartPLS, to estimate the measurement and structural models of the study.

Technological Integration refers to the adoption and application of advanced construction technologies, including Building Information Modelling (BIM), Artificial Intelligence (AI), Internet of Things (IoT), and automation systems, to enhance construction processes [60]. In this study, Technological Integration functions as an exogenous construct representing the extent to which digital tools are embedded in planning, coordination, monitoring, and execution.

II. Materials and Methods

The study employed a cross-sectional research design involving respondent selection, questionnaire administration, data collection and management, pooled Partial Least Squares Structural Equation Modelling (PLS-SEM), public–private sector score comparisons, and the development of the proposed Construction Engineering Management Maturity Framework (CEM-MF).

Consistent with the analytical orientation of the study, PLS-SEM was employed through SmartPLS 4 to examine the structural relationships among the latent constructs. This methodological approach was considered appropriate because the study sought to explain and predict Project Success using multiple theoretically related constructs rather than merely describe isolated variables. PLS-SEM was selected for its suitability in examining predictive research models involving latent variables and specified structural relationships, particularly where the objective was to identify key factors associated with a target construct. Through this approach, the study established an empirical basis for developing a region-specific construction engineering management framework within the operational and institutional context of Caraga.

The analytical sequence comprised construct operationalization and respondent eligibility screening, survey administration and data quality assessment, measurement-model evaluation, pooled structural-path estimation, supplementary public–private sector score comparisons, and percentile-based CEM-MF classification. Measurement invariance assessment of composite models (MICOM) and PLS-

SEM multi-group analysis (PLS-MGA) were not performed, as the revised sectoral analysis focused on respondent-level score comparisons rather than differences in structural path coefficients.

A. Research Design

A quantitative, non-experimental, descriptive-correlational, cross-sectional survey design was employed. The unit of observation was the individual construction professional rather than an independently assessed construction firm or project. PLS-SEM was utilized to estimate the pooled structural relationships among the specified constructs, while public–private sector comparisons were conducted using respondent-reported Project Success and construction engineering management capability scores. Potential clustering of respondents within organizations was recognized as a consideration in interpreting the independence of observations and associated inferential results.

The research procedure comprised three interconnected stages: theoretical and construct specification; respondent screening, data collection, and measurement and structural model evaluation; and supplementary sectoral score comparison followed by the development of the proposed CEM-MF.

Stage 1. Variable Identification and Theoretical Framing. At the conceptual grounding stage, the latent constructs were identified and theoretically framed based on established literature in construction engineering management, project management, resource-based theory, stakeholder theory, systems thinking, and technology adoption. The following five exogenous constructs were identified:

1. *X_1 – Project Management Practices;*
2. *X_2 – Resource Management;*
3. *X_3 – Technological Integration;*
4. *X_4 – Stakeholder Engagement; and*
5. *X_5 – External Influences.*

Correspondingly, Project Success *(Y)* was specified as the endogenous construct. Each construct was conceptualized as a reflective latent variable, with its indicators assumed to represent manifestations of the underlying construct. This specification was aligned with the objective of examining the associations between managerial, resource-based, technological, relational, and contextual dimensions with construction project outcomes.

Project Success was operationalized as a multidimensional assessment encompassing schedule and budget performance, delivered quality, stakeholder satisfaction, functional outcomes, safety, and value. Its corresponding indicators are presented in Table 3.

TABLE 3. PROJECT SUCCESS INDICATORS AND LABELS

Construct	Indicator	Label
Project Success (PS)	The project was completed within the planned schedule.	PS1.1
	The project remained within the approved budget.	PS1.2
	The project met all required quality and performance standards.	PS2.1
	The project was delivered with minimal rework or defects.	PS2.2
	The project achieved high levels of client satisfaction.	PS3.1
	The end-users or beneficiaries expressed satisfaction with the outcomes.	PS3.2
	The project contributed to long-term operational improvements.	PS4.1
	The project achieved its intended functional objectives.	PS4.2
	Safety standards were consistently met throughout the project.	PS5.1
	The project provided value relative to cost, time, and quality.	PS5.2

Project Success (PS) indicators were adopted from Lamprou and Vagiona [61] and Beshah et al. [62].

Project Management Practices reflect the presence and perceived execution of planning, scheduling, risk and quality management, monitoring, documentation, coordination, and evidence-informed governance. The corresponding statements appear in Table 4.

TABLE 4. PROJECT MANAGEMENT PRACTICES INDICATORS AND LABELS

Construct	Indicator	Label
Project Management Practices (PMP)	Project goals and deliverables are clearly defined at the outset.	PMP1.1
	Project scheduling and time-management practices are systematically applied.	PMP1.2
	Risk management strategies are actively implemented throughout the project.	PMP2.1
	Quality assurance processes are embedded in each phase of project execution.	PMP2.2
	Project monitoring and evaluation systems are in place and regularly used.	PMP3.1
	Corrective actions are promptly implemented when deviations from the plan occur.	PMP3.2
	Communication among project teams is consistently effective.	PMP4.1
	Coordination with subcontractors and suppliers is well-managed and scheduled.	PMP4.2
	Leadership decisions are based on performance indicators and evidence.	PMP5.1
	Project documentation is consistently prepared and maintained.	PMP5.2

Project Management Practice (PMP) indicators were adopted from Shah et al. [63] and Kallow et al. [64].

Technological Integration concerns reported use and organizational embedding of digital platforms, interoperable information, monitoring tools, and supporting capability development. Table 5 presents the ten statements used to operationalize this construct.

TABLE 5. TECHNOLOGICAL INTEGRATION INDICATORS AND LABELS

Construct	Indicator	Label
Technological Integration (TI)	The organization uses BIM or project management software during planning.	TI1.1
	The integration of new technologies improves coordination and performance.	TI1.2
	AI or data analytics tools assist in project decision-making.	TI2.1
	Digital tools support real-time monitoring of project progress.	TI2.2
	Technological systems are compatible across teams and departments.	TI3.1
	The organization invests in upgrading software and digital systems.	TI3.2
	Adequate digital training is provided for technical staff.	TI4.1
	Construction documentation is digitized and easily accessible.	TI4.2
	Technology reduces errors or rework during project execution.	TI5.1
	The use of digital tools improves coordination with suppliers and subcontractors.	TI5.2

Technological Integration (TI) was adopted from Adekunle et al. [65].

Resource Management addresses the planning, deployment, monitoring, and adjustment of personnel, materials, equipment, and financial resources in construction delivery. These indicators are enumerated in Table 6.

TABLE 6. RESOURCE MANAGEMENT INDICATORS AND LABELS

Construct	Indicator	Label
Resource Management (RM)	Resource allocation aligns with project priorities and strategic objectives.	RM1.1
	Equipment, materials, and manpower are efficiently utilized.	RM1.2
	Financial resources are properly planned and controlled.	RM2.1
	Resource allocation adjustments are made promptly when project needs change.	RM2.2
	Resource shortages are identified and promptly resolved.	RM3.1
	Procurement processes are timely and ensure the availability of required materials.	RM3.2
	Staff training and capacity-building programs are regularly implemented.	RM4.1
	Workforce competency is assessed before assigning tasks.	RM4.2
	Equipment maintenance is scheduled and performed to avoid delays.	RM5.1
	Inventory management systems help track usage and prevent wastage.	RM5.2

Resource Management (RM) was adopted from Shah et al. [63] and Yıldız et al. [66].

Stakeholder Engagement represents practices involving stakeholder participation, communication, responsiveness, conflict resolution, feedback, and institutional coordination. Its measurement statements are provided in Table 7.

TABLE 7. STAKEHOLDER ENGAGEMENT INDICATORS AND LABELS

Construct	Indicator	Label

Stakeholder Engagement (SE)	Stakeholders are involved in project planning and execution.	SE1.1
	Stakeholder participation enhances project credibility and outcomes.	SE1.2
	Regular stakeholder meetings are conducted to align expectations.	SE2.1
	Communication with stakeholders is timely and clearly documented.	SE2.2
	Conflict-resolution mechanisms are transparent and effective.	SE3.1
	Stakeholder concerns are addressed within reasonable timeframes.	SE3.2
	Feedback from clients and end-users is systematically utilized.	SE4.1
	Stakeholders are informed of project changes in a systematic manner.	SE4.2
	Collaboration with LGUs and regulatory agencies is well-coordinated.	SE5.1
	Stakeholder engagement activities contribute to smoother project implementation.	SE5.2

Stakeholder Engagement (SE) indicators were adopted from Abolghasemi et al. [67] and Shah et al. [63].

External Influences captures respondents' assessments of regulatory, economic, political, environmental, labor, supply, and community conditions associated with construction delivery. Table 8 identifies the items used to operationalize this context-dependent construct. Because several statements describe the existence or influence of a condition rather than an explicitly adverse event, item-direction consistency must be established before a higher composite is interpreted categorically as greater harmful external pressure.

TABLE 8. EXTERNAL INFLUENCE INDICATORS AND LABELS

Construct	Indicator	Label
External Influences (EI)	Government regulations significantly affect project timelines.	EI1.1
	Political factors disrupt project continuity.	EI1.2
	Economic conditions influence material and labor costs.	EI2.1
	Market competition affects procurement and performance.	EI2.2
	Environmental conditions influence construction scheduling.	EI3.1
	Weather disturbances frequently delay construction activities.	EI3.2
	Availability of skilled labor is affected by regional economic activities.	EI4.1
	Fluctuations in material supply impact project progress.	EI4.2
	Community-related issues affect timelines.	EI5.1
	Regulatory approval processes significantly influence project scheduling.	EI5.2

External Influence (EI) indicators were adopted from Pedron et al. [68] and Shah et al. [63].

Stage 2. Empirical Data Acquisition. Primary data were collected through a structured questionnaire administered to eligible construction professionals involved in project planning, implementation, supervision, coordination, technical operations, documentation, or management across the five provinces of Region XIII (Caraga), Philippines. Relevant construction project experience within the preceding five years was established as an inclusion criterion. The mode and period of questionnaire administration, recruitment locations, institutional approvals, and survey completion records were subject to confirmation through the corresponding data collection documentation.

A criterion-based purposive sampling strategy was employed to identify respondents who satisfied the established eligibility requirements. Accordingly, the final dataset comprised 309 construction professionals, consisting of 157 public-sector and 152 private-sector respondents. These figures represented the achieved sample rather than the total population of construction professionals in the region. Consequently, potential selection bias and organizational or project-level clustering were recognized as considerations in interpreting the findings, particularly the observed differences between the two sectors.

Furthermore, sample adequacy was evaluated in relation to the structural complexity of the proposed PLS-SEM model, the research objectives, and the characteristics of the target population. Given that the structural model specified five direct predictor paths toward Project Success, the achieved sample exceeded the conventional ten-times rule, which suggested a preliminary minimum of 50 observations. Nevertheless, this heuristic was considered an initial reference rather than conclusive evidence of statistical power. A more rigorous assessment of sample adequacy would require consideration of the number of predictors, anticipated effect sizes, significance level, and desired statistical power. Accordingly, the achieved sample provided the empirical basis for pooled structural estimation and supplementary

public–private sector comparisons, although its adequacy for detecting smaller effects could not be conclusively established without a documented statistical power analysis.

Stage 3. Analytical Modelling through PLS-SEM. At the modelling stage, Partial Least Squares–Structural Equation Modelling was conducted using SmartPLS 4. The analysis proceeded through the sequential evaluation of the measurement model and structural model.

For the measurement model, the following criteria were examined:

1) *Indicator reliability*, using outer loadings, preferably ≥ 0.70, with indicators ≥ 0.60 were retained when theoretically justified;
2) *Internal consistency reliability*, using Cronbach's alpha and composite reliability, with values ≥ 0.70 considered acceptable;
3) *Convergent validity*, using Average Variance Extracted, with AVE ≥ 0.50;
4) *Discriminant validity*, using the Heterotrait–Monotrait ratio, with HTMT < 0.85 as a strict criterion and HTMT < 0.90 as a more lenient criterion; and
5) *Model fit assessment*, using the Standardized Root Mean Square Residual, with SRMR ≤ 0.08 as an acceptable reference point.

For the structural model, the following procedures were conducted:

1) *Collinearity assessment* using Variance Inflation Factor;
2) *Independent path-weighted PLS-SEM sensitivity bootstrapping with 5,000 respondent-level resamples;*
3) *Hypothesis testing* using t-values, p-values, and confidence intervals;
4) *Effect size assessment* using f^2 values;
5) *Explanatory power assessment* using R^2; and
6) *Predictive relevance assessment* using Q^2 and, where feasible, PLSpredict.

Project Success and five domain scores were recomputed directly from 309 matched respondent-level item records. The public–private comparison of Project Success, required for H2a, yielded $U = 257$, $p \approx 3.49 \times 10^{-50}$ (two-sided, tie-adjusted asymptotic test), Holm-adjusted $p \approx 1.05 \times 10^{-49}$ across six domain/outcome comparisons, and rank-biserial $r = -0.978$. All differences refer to this purposive, self-reported sample, not a causal sector effect.

To address possible common method bias, both procedural and statistical controls were applied. Procedural remedies included anonymity assurance, separation of predictor and outcome sections, and variation in item wording. Statistical remedies included Harman's single-factor test and full collinearity diagnostics.

B. Data Collection

10) *Study population and sampling.* The intended population comprises eligible professionals with direct construction project involvement in the five provinces of Region XIII (Caraga), including professionals associated with public- and private-sector work. The achieved sample consists of 157 public-sector and 152 private-sector respondents (N = 309).

Participants were purposively recruited based on direct professional involvement in construction project planning, execution, supervision, technical coordination, quality/control, documentation, or management; relevant experience; geographical eligibility; and consent. Inclusion must be linked to actual job responsibilities and project exposure rather than the occupational label "construction professional" alone.

The investigation used purposive recruitment rather than a known-probability sample. The 309 respondent IDs and their province/sector codes were reconciled against the original survey indicators on 31 October 2026. The sampled province counts were 58, 48, 63, 85, and 55, respectively, for Agusan del Norte, Agusan del Sur, Surigao del Norte, Surigao del Sur, and Dinagat Islands. Actual participating-organization counts and a defensible denominator for population coverage were not recoverable from these two respondent workbooks; hence neither population coverage nor a probability-based margin of error is claimed.

TABLE 9. PROVINCE-SPECIFIC SAMPLED RESPONDENTS AND PREVIOUSLY PLANNED RECRUITMENT SITES (NOT OBSERVED ORGANIZATION COUNTS)

Province	Sites (plan)	Sampled Respondents	% of Total
Agusan del Norte	3	58	18.8%
Agusan del Sur	3	48	15.5%
Surigao del Norte	4	63	20.4%
Surigao del Sur	4	85	27.5%
Dinagat Islands	4	55	17.8%
Total / Average	**18 planned**	**309**	**100%**

11) Survey Instrumentation. The study employed a structured survey questionnaire as the primary data collection instrument. The questionnaire was designed to measure the major latent constructs of the study, namely Project Management Practices, Resource Management, Technological Integration, Stakeholder Engagement, External Influences, and Project Success. The instrument used Likert-type scale items to quantify respondents' perceptions regarding the degree to which each construct was manifested in construction project implementation.

The questionnaire contains ten Likert-type items in each predictor domain and measures Project Success separately. The item notes identify both literature-informed and researcher-developed/contextualized formulations; accordingly, the scale should be described as literature-informed and contextualized unless source-by-source adoption and validation records establish stronger claims. Pilot-testing procedures, expert ratings, and actual administration records must be documented in the specified appendices before being asserted as verified.

12) Secondary Data. Secondary data served as contextual support for the interpretation of the findings. These included available project records, organizational documents, and contextual references related to project implementation. However, the inferential analysis reported in the study was based primarily on the finalized survey dataset.

C. Data Quality and Management

To ensure the analytical integrity of the dataset, data screening and quality control procedures were conducted prior to statistical analysis. The screening process verified the completeness, consistency, and suitability of responses for PLS-SEM estimation.

The final dataset consisted of 309 valid cases. Since all construct summaries reflected the full sample size, the dataset was treated as complete for listwise analysis. Responses were examined for missing values, outliers, and irregular response patterns. The distribution of responses across sectors and provinces was also documented to assess sample coverage and potential non-response patterns.

Common method bias was addressed through both procedural and statistical safeguards. Procedural safeguards included confidentiality assurance, voluntary participation, separation of predictor and outcome sections, and variation in item wording. Statistical diagnostics were also conducted to examine whether a single factor dominated the variance structure of the dataset.

D. Inclusion, Exclusion, and Withdrawal Criteria

To uphold methodological rigor and ethical propriety, the study established specific inclusion, exclusion, and withdrawal criteria. These criteria ensured that participants were appropriate to the research objectives and that their participation remained voluntary, informed, and ethically protected.

1) *Inclusion Criteria.* The inclusion criteria specified the qualifications required for participation in the study. Respondents were eligible if they met the following conditions:

   a) *Professional Role and Project Involvement.* The recruitment definition encompassed construction project management, engineering and technical personnel, and persons engaged in related project duties. The respondent profile contains 251 technical professionals, 48 middle managers, one top manager, five academics, and four support staff. All 309 records are retained in this descriptive analysis together of each person's actual construction-project duties, professional credentials (where relevant), and minimum exposure under an adviser-approved eligibility rule. The presence of academic or support titles alone cannot establish their eligibility or ineligibility.

   b) *Relevant Project Experience.* Respondents had to be involved in ongoing or recently completed construction projects within the last five years. This ensured sufficient familiarity with project management practices, resource allocation, stakeholder coordination, technological tools, external influences, and project success indicators.

   c) *Geographical and Sectoral Alignment.* Eligible respondents were required to be assigned to, or directly involved in, construction projects located within the five provinces of Region XIII (Caraga), Philippines. The study was limited to construction professionals affiliated with public-sector (government) or private-sector construction organizations, excluding respondents affiliated with non-governmental organizations (NGOs) and other entities outside the defined public–private sector classification.

   d) *Minimum Exposure.* Respondents had to possess adequate exposure to the organization, project, or role being assessed, preferably for at least six months, to ensure familiarity with relevant operational and managerial processes.

   e) *Voluntary Participation.* Respondents had to provide informed consent and demonstrate the capacity to understand and complete the questionnaire.

2) *Exclusion Criteria.* The exclusion criteria identified individuals who were not aligned with the empirical requirements of the study. The following were excluded:

   a) Individuals with no direct involvement in construction project implementation, supervision, coordination, technical work, documentation, or management;

   b) Construction professionals assigned exclusively to projects outside Region XIII, Caraga;

   c) Individuals with insufficient exposure to the project or organization being assessed;

   d) Individuals who participated in pilot testing, when their inclusion could compromise instrument validation; and

   e) Individuals who declined informed consent or were unable to complete the questionnaire.

3) *Withdrawal Criteria.* Participation in the study was voluntary, and respondents were allowed to withdraw at any stage. Respondents could discontinue participation without penalty, consequence, or adverse effect on their professional standing.

Upon withdrawal, data collection from the respondent ceased immediately. If the respondent requested the removal of previously submitted responses before anonymization and aggregation, such responses were excluded from the dataset in accordance with ethical data management procedures.

Respondents were also allowed to decline to answer specific items. Such partial non-response did not invalidate participation unless the missing responses compromised the minimum data requirements for construct-level analysis.

E. Data Analysis Techniques

The finalized dataset was analyzed descriptively and through a pooled PLS-SEM model. Supplementary observed-score analyses included correlations, OLS regression, public–private descriptive comparisons, and recorded Mann–Whitney tests for capability distributions. Pooled percentiles were used to construct the proposed maturity bands; these cutoffs were not inferred from the structural path coefficients.

1) Descriptive Statistics. Descriptive statistics were used to summarize the demographic and construct-level characteristics of the respondents. Frequencies and percentages were computed for demographic variables such as sex, age, professional designation, sector, experience, education, province, and project type. Means and standard deviations were computed for the indicators and composite constructs. This preliminary analysis provided an empirical profile of the sample and established the descriptive foundation for subsequent structural analysis.

2) Partial Least Squares–Structural Equation Modelling. PLS-SEM served as the principal analytical technique of the study. The method was used to evaluate the measurement properties of the reflective constructs and to estimate the hypothesized structural paths leading to Project Success. PLS-SEM was appropriate because the study aimed to explain and predict project success through multiple interrelated latent constructs.

The measurement model evaluation involved indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Outer loadings, Cronbach's alpha, composite reliability, AVE, and HTMT were examined. The use of these criteria followed established PLS-SEM evaluation procedures, where measurement validity is assessed before interpreting structural relationships.

The archived SmartPLS 4 algorithm supplied the original pooled path estimates, measurement diagnostics, R^2, f^2, VIF, and SRMR. Its coefficients were independently reproduced to numerical precision using the original 309 by 60 respondent matrix and a standardized, path-weighted Mode A PLS algorithm. A distinct Python-based sensitivity analysis then resampled the 309 respondents with replacement 5,000 times (random seed 20261031); 95% bias-corrected and accelerated (BCa) confidence intervals were estimated using 309 leave-one-out jackknife evaluations. Bootstrap t-values were calculated as the original coefficient divided by its bootstrap standard deviation; two-sided Student t approximations and Holm-adjusted p-values for the five paths were reported transparently. This procedure was not a native SmartPLS bootstrapping export. Model interpretation was conditional on the observed reflective validity failures. A reproducible SmartPLS Q^2/PLSpredict result was unavailable and was not inferred from R^2.

3) Public-Private Score Comparison. Public- and private-sector respondents were compared on Project Success scores and the four internal domain scores, together with the overall CEM-MF composite. Sector-specific means, dispersion, and five-level distributions describe the groups. The Mann–Whitney U comparisons of capability scores require source verification; an appropriately documented Project Success group test is still required for inferential claims about PS.

4) Supplementary Regression Analysis. Supplementary Ordinary Least Squares regression analysis was conducted to reinforce the interpretation of predictive relationships. This procedure served as an additional analytical lens for examining the extent to which Project

Management Practices, Resource Management, Technological Integration, Stakeholder Engagement, and External Influences predicted Project Success. The regression results were interpreted in relation to, but not as a replacement for, the PLS-SEM findings.

5) Data Quality and Assumption Diagnostics. Data quality procedures were implemented to ensure the reliability of the analysis. These included missing data inspection, outlier screening, response pattern examination, non-response pattern assessment, and common method bias diagnostics. Collinearity was assessed using VIF values, while common method bias was examined through procedural controls and statistical checks.

F. Hypothesis Testing

The direct-effects hypotheses address the five pooled structural relationships; H2a and H2b concern sectoral differences in Project Success and overall internal CEM capability scores, respectively. No hypothesis about cross-sector differences in path coefficients is tested in the revised study design.

1) *H1. Direct Effects.* The first set of hypotheses examined the direct effects of the exogenous constructs on Project Success.

   a) *H1a.* Project Management Practices positively influenced Project Success.

      $H1a_0$. The path coefficient between Project Management Practices and Project Success was equal to zero.

   b) *H1b.* Resource Management positively influenced Project Success.

      $H1b_0$. The path coefficient between Resource Management and Project Success was equal to zero.

   c) *H1c.* Technological Integration positively influenced Project Success.

      $H1c_0$. The path coefficient between Technological Integration and Project Success was equal to zero.

   d) *H1d.* Stakeholder Engagement positively influenced Project Success.

      $H1d_0$. The path coefficient between Stakeholder Engagement and Project Success was equal to zero.

   e) *H1e.* External Influences negatively influenced Project Success.

      $H1e_0$. The path coefficient between External Influences and Project Success was equal to zero.

   Each H1 hypothesis corresponds to an originally proposed structural path. Independent 5,000-resample sensitivity intervals and nominal test statistics were calculated for transparency; however, no formal confirmation of H1a–H1e is claimed because the six reflective constructs failed convergent and discriminant validity checks. Any future confirmatory hypothesis testing requires adviser-approved measurement redevelopment and fresh validation.

AI-assisted manuscript editing and coding support. OpenAI ChatGPT was used for editorial drafting and assistance in writing the independent verification scripts during manuscript revision. All numerical results used here were recalculated against the original respondent-level dataset and compared with the archived SmartPLS algorithm outputs where available. The authors remain responsible for verifying the appropriateness of the analysis, interpretation, participant eligibility and final manuscript content.

2) *H2. Public–Private Respondent Score Differences.* The second set of hypotheses examined differences in Project Success and overall internal Construction Engineering Management Maturity Framework (CEM-MF) capability scores between public- and private-sector respondents. The analysis focused on respondent-level score distributions and was conducted independently of the structural relationships estimated through the pooled Partial Least Squares Structural Equation Modelling (PLS-SEM) model.

(a) *H2a: Project Success.* This hypothesis examined whether a statistically significant difference existed in Project Success scores between public- and private-sector respondents. The null hypothesis (H_0) specified no difference in the distributions of Project Success scores between the two sectors, whereas the alternative hypothesis (H_1) specified a difference in their distributions.

(b) *H2b*: *Overall Internal CEM-MF Capability.* This hypothesis examined whether a statistically significant difference existed in overall internal CEM-MF capability scores between public- and private-sector respondents. The null hypothesis (H_0) specified no difference in the distributions of overall internal capability scores between the two sectors, whereas the alternative hypothesis (H_1) specified a difference in their distributions. The Mann–Whitney U test was employed to assess differences in the overall internal capability score distributions between the two independent groups.

These hypotheses concerned respondent-level differences in Project Success and construction engineering management capability scores. The sectoral comparisons were distinct from the pooled PLS-SEM structural analysis and did not constitute tests of differences in structural path coefficients. Furthermore, the observed differences were interpreted as cross-sectional associations rather than causal effects attributable to sector affiliation or independently validated measures of organizational maturity.

G. Data Collection Instrument

The primary data collection instrument was a structured survey questionnaire developed to measure the major constructs of the study. The instrument was organized into sections corresponding to the conceptual and structural model.

1) *Project Management Practices.* This section measured the extent to which formal project management practices were implemented. Items focused on project scheduling, planning, risk mitigation, coordination, monitoring, implementation control, and overall project governance.

2) *Resource Management.* This section assessed the allocation, utilization, and control of resources across construction projects. It covered human, financial, material, technical, and technological resources.

3) *Technological Integration.* This section examined the adoption and use of emerging and established construction technologies. These included Building Information Modelling, artificial intelligence-supported tools, Internet of Things applications, digital monitoring systems, and project management information systems.

4) *Stakeholder Engagement.* This section measured stakeholder participation throughout the project life cycle. It examined the involvement of clients, contractors, consultants, regulatory bodies, internal project teams, local government units, and affected communities.

5) *External Influences.* This section assessed contextual and environmental factors that affected project implementation. These included regulatory conditions, economic pressures, policy changes, funding constraints, environmental risks, and institutional factors.

6) *Project Success Metrics.* This section measured perceived project success using indicators related to time, cost, quality, client satisfaction, regulatory compliance, stakeholder satisfaction, and overall project effectiveness.

7) *Measurement Scale.* All survey items employed a five-point Likert-type scale. The scale produced quantifiable data suitable for descriptive analysis, regression analysis, and PLS-SEM estimation. Reflective measurement principles were applied in evaluating indicator reliability, construct reliability, convergent validity, and discriminant validity.

8) *Pilot Testing.* Prior to full administration, the survey instrument was pilot-tested among respondents resembling the target population. The pilot test assessed item clarity, comprehensibility, reliability, and construct alignment. Pilot findings were used to refine the questionnaire before final deployment.

H. Model Specification

The model was specified using an Input-Process-Output orientation, allowing the study to conceptualize how managerial, technological, resource-based, stakeholder-related, and contextual factors shaped project success.

1) *Input Constructs.* The input constructs represented the foundational determinants of construction project performance. These included Project Management Practices, Resource Management, Technological Integration, Stakeholder Engagement, and External Influences.

2) *Process Orientation.* The process dimension reflected the operational translation of inputs into construction project implementation. It involved coordination, monitoring, resource deployment, technological application, stakeholder communication, and adaptive response to contextual constraints.

3) *Output Construct.* The output construct was Project Success. It was operationalized through time performance, cost efficiency, quality achievement, stakeholder satisfaction, regulatory compliance, and overall project effectiveness.

Within the PLS-SEM framework, the exogenous constructs were specified as predictors of Project Success. This enabled the estimation of direct structural paths and the evaluation of how each construct contributed to project performance within the regional construction environment.

I. Procedural Framework of the Study

The study followed a systematic procedural framework comprising five interrelated phases: (1) Formulation and Grounding, (2) Design and Engagement, (3) Data Collection and Management, (4) Modelling and Analytical Assessment, and (5) Synthesis, Framework Development, and Research Translation. These phases established a sequential methodological process encompassing theoretical conceptualization, research preparation, data collection, statistical analysis, and the development of the proposed Construction Engineering Management Maturity Framework (CEM-MF). Table 10 presents the consolidated procedural framework, including the corresponding activities, methodological considerations, and intended outputs.

1) Formulation and Grounding Phase

This phase established the conceptual and theoretical foundations of the study. It situated the investigation within the construction engineering management context of Region XIII (Caraga), identified the relevant constructs, formulated the conceptual framework, and defined the geographical, sectoral, and methodological boundaries. The phase also incorporated institutional ethical requirements and participant protection considerations into the research design.

2) Design and Engagement Phase

This phase operationalized the research design and facilitated institutional and participant engagement. It encompassed questionnaire development and contextualization, identification of eligible construction professionals, coordination with potential public- and private-sector respondent sources, and the establishment of informed consent and participant recruitment procedures. These activities supported the systematic preparation of the research instrument and the implementation of the purposive sampling approach.

3) Data Collection and Management Phase

This phase involved the administration, retrieval, screening, coding, and preparation of survey responses. The collected data were examined for completeness, consistency, and suitability for the specified statistical procedures. The resulting dataset comprised 309 valid respondent records, providing the empirical basis for descriptive analysis, pooled Partial Least Squares Structural Equation Modelling (PLS-SEM), public–private sector score comparisons, and subsequent capability classification.

4) Modelling and Analytical Phase

This phase constituted the principal statistical assessment of the study. It involved the evaluation of measurement quality, estimation of the hypothesized structural relationships between five predictor constructs and Project Success, and examination of model explanatory and predictive statistics. Public–private sector comparisons were conducted using respondent-level Project Success and internal construction engineering management capability scores. The analytical procedures also incorporated the computation of empirical percentile boundaries for the proposed CEM-MF, thereby maintaining alignment with the four research objectives.

5) Synthesis, Framework Development, and Research Translation Phase

This phase integrated the empirical findings with the theoretical foundations of the study and translated the results into a proposed framework for construction engineering management capability assessment. It involved the formulation of five empirical capability levels, identification of construct-specific improvement priorities, and development of sector-sensitive managerial recommendations. The resulting CEM-MF provided a sample-referenced diagnostic approach for interpreting management capabilities and identifying potential areas for continuous improvement.

Table 10 summarizes the methodological progression of the study, demonstrating the alignment of theoretical development, research design, data preparation, statistical modelling, and framework formulation. The integrated procedures provided a systematic basis for examining the relationships associated with Project Success, comparing public- and private-sector respondent profiles, and developing the proposed CEM-MF within the regional context of Caraga.

TABLE 10. PROCEDURAL FRAMEWORK OF THE STUDY

Procedural Phase			
Formulation and Grounding Phase			
Item No.	**Procedural Step Description**	**Theoretical/ Conceptual Consideration**	**Output**
1.1	The study was situated within the context of construction project complexities in Region XIII (Caraga), Philippines.	Scope and Limitations Statement	Defined Research Locale and Contextual Boundaries
1.2	The Resource-Based View (RBV), Theory of Constraints (TOC), Project Management Triangle, and Stakeholder Theory were integrated into the study's theoretical framework.	Theoretical Framework	Integrated Theoretical Foundation

1.3	The research constructs were mapped within an Input–Process–Output (IPO) conceptual framework.	Conceptual Framework	Operationalized Variables for SEM
1.4	The geographical, sectoral, and model-based limitations were defined, while relevant economic and regulatory constraints were acknowledged.	Scope and Limitations	Established Boundaries for Interpretation
1.5	Institutional ethical review was undertaken, and informed consent protocols and data-handling safeguards were established before data collection.	Research Ethics	Ethical Clearance
Design and Engagement Phase			
Item No.	**Procedural Step Description**	**Ethical and Operational Consideration**	**Output**
2.1	A structured survey questionnaire was developed and contextualized according to the specified latent constructs and observed indicators. The instrument was pretested to assess reliability, with Cronbach's alpha ($\alpha \geq 0.70$) used as a criterion.	Psychometric Reliability and Validity	Validated and Contextualized Survey Instrument
2.2	Formal request letters were distributed to identified public- and private-sector institutions across the five provinces of Caraga, with a minimum of 10 institutions per province.	Voluntary Participation	Institutional Coordination
2.3	A provincial contact matrix was developed, comprising at least five public-sector and five private-sector institutional contacts per province, with corresponding contact information.	Sampling Framework	Institutional Contact Matrix
2.4	Research orientations were conducted through Zoom or email to communicate the study's objectives, ethical considerations, and survey administration procedures.	Informed Consent	Participant Orientation and Consent Documentation
Data Collection and Management Phase			
Item No.	**Procedural Step Description**	**Measurement Framework**	**Output**
3.1	Structured survey instruments were administered to eligible construction professionals across the identified public- and private-sector organizations.	Five-point Likert Scale	Quantitative Dataset for PLS-SEM
3.2	Available secondary project information, including time, cost, quality, and technological integration records, was examined to supplement the contextual interpretation of the survey findings.	Supplementary Project Information	Supporting Documentary Evidence
3.3	Survey responses were screened for completeness, consistency, and potential outliers. Data quality assessments were conducted to establish the suitability of the dataset for subsequent statistical analysis.	Data Screening and Quality Assessment	Final Analysis-Ready Dataset
Modeling and Analytical Phase			
Item No.	**Procedural Step Description**	**Tool**	**Output**
4.1	The reflective measurement model was assessed using indicator reliability, internal consistency reliability, convergent validity, and discriminant validity criteria, including composite reliability ($CR \geq 0.70$), average variance extracted ($AVE \geq 0.50$), and the heterotrait–monotrait ratio ($HTMT < 0.85$).	SmartPLS	Measurement Model Assessment Results
4.2	The structural model was specified to examine the relationships between five exogenous constructs and Project Success. Structural path coefficients, statistical significance, explanatory power, and predictive relevance were evaluated through PLS-SEM.	SmartPLS	Structural Path Coefficients, Significance Statistics, R^2, and Predictive Assessment Results
4.3	Public- and private-sector respondents were compared using observed Project Success and internal CEM capability scores. Sector-specific descriptive statistics and available	Statistical Analysis	Public–Private Sector Comparison Results

	nonparametric comparisons were examined independently of the pooled structural model.		
4.4	The overall internal CEM-MF capability scores were computed from the four equally weighted internal capability constructs. Pooled empirical percentile boundaries were subsequently derived to establish five capability classifications.	Statistical Analysis	CEM-MF Composite Scores and Five-Level Empirical Classification
4.5	Model diagnostics were examined to assess collinearity, model fit, and potential statistical limitations. Relevant diagnostic criteria included variance inflation factors (VIF) and the standardized root mean square residual (SRMR).	SmartPLS	Model Diagnostic Results
Synthesis, Knowledge Transfer, and Policy Translation Phase			
Item No.	**Procedural Step Description**	**Stakeholder Relevance**	**Output**
5.1	The PLS-SEM findings were interpreted in relation to the theoretical foundations of the study, particularly the Resource-Based View, Theory of Constraints, Project Management Triangle, and Stakeholder Theory.	Theoretical Alignment	Results and Discussion
5.2	Sector-specific recommendations were formulated based on the identified construction engineering management capability profiles and differences between public- and private-sector respondents.	Industry Application	Strategic Recommendations
5.3	The proposed Construction Engineering Management Maturity Framework (CEM-MF) was developed by integrating the empirical findings with the five-level capability classification procedure.	Framework Development	Proposed Five-Level CEM-MF
5.4	The research findings were prepared for dissemination through academic presentations and relevant construction industry forums.	Knowledge Dissemination	Research Dissemination Materials
5.5	The research findings were consolidated into a scientific manuscript and submitted for consideration in a peer-reviewed academic journal.	Scholarly Contribution	Journal Manuscript Submission

To support the identification of potential respondent sources, an institutional contact directory was developed covering public- and private-sector construction-related organizations across the five provinces of Region XIII (Caraga). The directory served as a reference for institutional coordination and purposive respondent recruitment rather than as a probability-based sampling frame. Table 11 presents the identified organizations and offices according to geographical location and sectoral classification.

TABLE 11. DIRECTORY OF KEY PUBLIC AND PRIVATE SECTOR ORGANIZATIONS SAMPLING FRAMEWORK IN REGION XIII (CARAGA, PHILIPPINES), BY PROVINCE

Region XIII (Caraga, Philippines)	
Sector	**Organization / Office**
Province of Agusan del Norte (incl. Butuan City)	
Public	DPWH Region XIII – Regional Office
	DPWH Butuan District Engineering Office
	DPWH Agusan del Norte DEO
	DTI Regional Office
	NIA Region XIII
Private	Equi-Parco Construction Co.
	Triparco Development Corporation
	ADFIL Corporation
	RFB Construction Corporation
	UKC Builders, Inc.
Province of Agusan del Sur	
Public	DPWH Agusan del Sur 1st DEO (Prosperidad)

	DPWH Agusan del Sur 2nd DEO (San Francisco)
	DTI Agusan del Sur – Provincial Office
	NIA – Agusan del Sur
	DSWD Regional Field Office XIII
Private	AgSur Builders Co.
	Jones Construction & Trading Corp.
	S&M Builders & Contractors
	Maramag Construction Co.
	Pamalihi Builders & Development Corp.
Province of Surigao del Norte	
Public	DPWH 1st DEO – Surigao City
	DPWH 2nd DEO – Dapa (Siargao)
	DTI Surigao del Norte – Provincial Office
	NIA – Surigao del Norte
	PSA RSSO XIII
Private	Surigao Builders, Inc.
	Siargao Builders & Construction Inc.
	ConDes Builders & Eng'g Services
	Maxima Builders & Constructors Inc.
	Surigao Green Builders & Supply
Province of Surigao del Sur	
Public	DPWH 1st DEO – Tandag (Bislig area)
	DPWH 2nd DEO – Whole Province
	DTI Surigao del Sur – Provincial Office
	NIA – Surigao del Sur
	PSA RSSO XIII
Private	Bislig Contractors Co.
	CarCan Builders & Suppliers
	St. Michael Builders, Inc.
	Dalena Builders & Development Corp.
	Mindanao Builders Group
Province of Dinagat Islands	
Public	DPWH Dinagat Islands DEO
	DTI Dinagat Islands – Provincial Office
	NIA – Dinagat Islands
	PSA RSSO XIII
	DSWD Region XIII – Field Office
Private	Dinagat Island Builders & Development Inc.
	Islandwide Construction Services
	Coastal Builders & Suppliers
	Mayor's Construction Group
	DI Contractors & Developers Inc.

J. Ethical Considerations

In adherence to established ethical standards, the study observed procedures intended to protect the rights, privacy, and welfare of all participants.

First, *informed consent was secured from all respondents.* Participants were informed of the purpose of the study, the voluntary nature of their participation, the confidentiality of their responses, and their right to withdraw at any stage.

Second, *confidentiality and anonymity were maintained throughout the study*. Collected data were de-identified, stored securely, and reported only in aggregate form. No personal or organizational information was disclosed in a manner that could identify individual respondents.

Third, *data integrity and transparency were upheld*. The researcher documented the survey instrument, data collection procedures, screening protocols, and analytical methods to ensure replicability and scholarly accountability.

Finally, *ethical clearance was obtained prior to full implementation*. The study complied with institutional research ethics requirements and applied appropriate safeguards in the collection, handling, analysis, and reporting of data.

In synthesis, the methodological framework of the study provided a rigorous and contextually grounded basis for examining construction project success in Region XIII, Caraga. Through the integration of descriptive analysis, supplementary regression, and PLS-SEM, the study was able to evaluate both the measurement quality of the constructs and the structural relationships among the determinants of project success. This methodological architecture ensured that the study remained theoretically coherent, empirically defensible, ethically sound, and practically relevant to construction engineering management in the region.

III. Results and Discussion

This section presents and discusses the empirical findings of the study in accordance with the four research objectives. The discussion encompasses the measurement quality of the study constructs, their structural relationships with Project Success, the comparative profiles of public- and private-sector respondents, and the development of the proposed Construction Engineering Management Maturity Framework (CEM-MF). Descriptive and inferential results are presented and interpreted in relation to the corresponding research objectives, providing an empirical basis for evaluating construction engineering management practices and identifying opportunities for capability improvement within Region XIII (Caraga).

The demographic and professional characteristics of the 309 purposively selected construction professionals were examined to establish the composition of the study sample. Table 12 presents the distribution of respondents according to sex, age, sectoral affiliation, professional designation, experience, educational attainment, work location, and project classification.

Table 12. Demographic and Professional Profile of Respondents

Characteristic	Category	n	%
Sex	Male	159	51.5
	Female	150	48.5
Age (years)	21–30	83	26.9
	31–40	70	22.7
	41–50	80	25.9
	Over 50	76	24.6
Sector	Public	157	50.8
	Private	152	49.2
Professional Designation	Top Management (CEO, Director, Dean)	1	0.3
	Middle Management (Project Manager)	48	15.5
	Technical/Professional (Engineer, Architect)	251	81.2
	Academic (Professor, Instructor)	5	1.6
	Support Staff (CAD, Assistant, Clerk)	4	1.3
Experience	<5 years	60	19.4
	5–10 years	62	20.1
	11–15 years	64	20.7
	16–20 years	63	20.4
	>20 years	60	19.4
Highest Educational Attainment	Undergraduate Degree (i.e., BS or equivalent undergraduate qualification)	271	87.7
	Master's Degree (i.e., MS, MEng, or equivalent postgraduate qualification)	36	11.7
	Doctoral Degree (i.e., PhD, DEng, or equivalent terminal degree)	2	0.6
Work Location by Province	Agusan del Sur	48	15.5
	Agusan del Norte	58	18.8
	Surigao del Norte	63	20.4
	Surigao del Sur	85	27.5
	Dinagat Islands	55	17.8
Type of Project	Vertical	149	48.2

	Horizontal	76	24.6
	Residential	45	14.6
	Commercial	18	5.8
	Institutional	11	3.6
	Industrial	9	2.9
	Other/Not specified	1	0.3

To establish the sample composition of the study and contextualize the characteristics of the sampled construction professionals, the demographic profile of the respondents was first examined. The final dataset comprised 309 valid responses. As presented in Table 12, the sample consisted of 159 male respondents, representing 51.5%, and 150 female respondents, representing 48.5%. This distribution indicated relatively balanced participation between male and female construction professionals, suggesting that the empirical perspectives obtained were not disproportionately concentrated within a single sex category.

In terms of age composition, the respondents represented a broad range of age groups within the construction sector. The largest age group consisted of respondents aged 21–30 years, comprising 83 individuals or 26.9% of the sample. This was followed by respondents aged 41–50 years, with 80 individuals or 25.9%; respondents over 50 years old, with 76 individuals or 24.6%; and respondents aged 31–40 years, with 70 individuals or 22.7%. The relatively balanced distribution across age categories suggested that the study captured perspectives from construction professionals of varying ages and career stages.

With respect to professional designation, the sample was predominantly composed of technical and professional personnel. Specifically, 251 respondents, or 81.2%, were engineers, architects, or similarly situated technical professionals. Meanwhile, 48 respondents, or 15.5%, occupied middle management roles, particularly as project managers or project supervisors. The remaining respondents were distributed across top management, academic, and support staff positions. This profile indicated that the findings were substantially grounded in the perceptions of respondents who were directly involved in technical implementation, project coordination, and construction management activities.

Regarding sectoral affiliation, the respondents were almost equally distributed between public- and private-sector construction organizations. Public-sector respondents accounted for 157 individuals, or 50.8% of the sample, while private-sector respondents comprised 152 individuals, or 49.2%. This near-equivalent sectoral distribution strengthened the comparative basis of the study by providing relatively balanced respondent groups for examining differences in reported Project Success and construction engineering management capability scores.

In relation to professional experience, the respondents demonstrated a well-distributed range of exposure to construction work. Specifically, the largest group consisted of respondents with 11–15 years of experience, comprising 64 individuals or 20.7% of the sample. This was followed by those with 16–20 years of experience, with 63 respondents or 20.4%; those with 5–10 years of experience, with 62 respondents or 20.1%; and those with less than five years and more than 20 years of experience, with 60 respondents each or 19.4% per category. This distribution indicated that the data were informed by respondents with varying degrees of professional tenure, ranging from early-career practitioners to highly experienced construction professionals.

Regarding educational attainment, the majority of respondents possessed bachelor's degrees or equivalent undergraduate qualifications, comprising 271 individuals or 87.7% of the sample. Meanwhile, 36 respondents, or 11.7%, held master's degrees or equivalent postgraduate qualifications, while two respondents, or 0.6%, possessed doctoral degrees or equivalent terminal qualifications. This distribution indicated

that the sample was predominantly composed of degree-qualified construction professionals, with a smaller proportion having attained advanced academic qualifications.

Geographically, the respondents were distributed across the five provinces of Region XIII (Caraga). The largest representation came from Surigao del Sur, with 85 respondents, or 27.5% of the sample. This was followed by Surigao del Norte, with 63 respondents or 20.4%; Agusan del Norte, with 58 respondents or 18.8%; Dinagat Islands, with 55 respondents or 17.8%; and Agusan del Sur, with 48 respondents or 15.5%. This provincial distribution reflected the geographical coverage of the achieved sample and provided a regionally contextualized basis for examining construction engineering management practices within Caraga.

With respect to project classification, the largest proportion of respondents was involved in vertical construction projects, accounting for 149 individuals, or 48.2% of the sample. Horizontal projects, including roads, bridges, and related infrastructure, involved 76 respondents, or 24.6%. Residential projects accounted for 45 respondents, or 14.6%, followed by commercial projects with 18 respondents or 5.8%, institutional projects with 11 respondents or 3.6%, industrial projects with nine respondents or 2.9%, and other or unspecified project types with one respondent or 0.3%. This distribution indicated that the study captured project experiences across diverse construction typologies, although vertical and horizontal construction constituted the predominant reported project categories.

A. Descriptive Profiles and Reflective Measurement Diagnostics

To determine the perceived level of manifestation of the major latent constructs, descriptive statistics were computed for Project Management Practices, Resource Management, Technological Integration, Stakeholder Engagement, External Influences, and Project Success. Each construct was measured using a five-point scale, with higher mean values indicating stronger perceived presence or greater manifestation of the construct. The descriptive results provided an initial empirical portrait of the managerial, technological, relational, contextual, and performance-related conditions characterizing construction projects in Region XIII.

TABLE 13. DESCRIPTIVE STATISTICS – PROJECT MANAGEMENT PRACTICES (N=309)

Item	Minimum	Maximum	Mean	Std. Deviation
$PMP_1.1$	2.00	5.00	3.52	0.99
$PMP_1.2$	2.00	5.00	3.50	0.92
$PMP_2.1$	2.00	5.00	3.54	0.94
$PMP_2.2$	2.00	5.00	3.47	0.89
$PMP_3.1$	2.00	5.00	3.40	0.98
$PMP_3.2$	2.00	5.00	3.48	0.96
$PMP_4.1$	2.00	5.00	3.50	0.97
$PMP_4.2$	2.00	5.00	3.51	0.93
$PMP_5.1$	2.00	5.00	3.51	0.90
$PMP_5.2$	2.00	5.00	3.50	0.95
PMP (mean)	**2.20**	**4.70**	**3.49**	**0.54**

For Project Management Practices, Table 13 showed the descriptive statistics for Project Management Practices. The item means ranged from 3.40 to 3.54, with an overall construct mean of 3.49 and a standard deviation of 0.54. This result indicated that project management practices were generally observed among the sampled construction organizations. However, relative to the other constructs, Project Management Practices obtained one of the lower overall mean values, suggesting that further enhancement was necessary in planning, scheduling, monitoring, control, and project governance systems.

TABLE 14. DESCRIPTIVE STATISTICS – RESOURCE MANAGEMENT (N=309)

Item	Minimum	Maximum	Mean	Std. Deviation

RM_1.1	2.00	5.00	3.49	0.98
RM_1.2	2.00	5.00	3.49	1.01
RM_2.1	2.00	5.00	3.57	0.91
RM_2.2	2.00	5.00	3.51	0.91
RM_3.1	2.00	5.00	3.52	0.91
RM_3.2	2.00	5.00	3.48	0.98
RM_4.1	2.00	5.00	3.51	0.94
RM_4.2	2.00	5.00	3.51	0.95
RM_5.1	2.00	5.00	3.48	0.96
RM_5.2	2.00	5.00	3.61	0.95
RM (mean)	**2.20**	**4.70**	**3.52**	**0.55**

In relation to Resource Management, the descriptive results for Resource Management were presented in Table 14. The item means ranged from 3.48 to 3.61, with an overall construct mean of 3.52 and a standard deviation of 0.55. This finding indicated that respondents generally perceived resource allocation, utilization, and control as functioning at a favorable level. Among the constructs, Resource Management emerged as one of the stronger dimensions, suggesting that construction organizations in the region placed considerable operational emphasis on managing human, financial, material, and technical resources.

TABLE 15. DESCRIPTIVE STATISTICS – TECHNOLOGICAL INTEGRATION (N=309)

Item	Minimum	Maximum	Mean	Std. Deviation
TI_1.1	2.00	5.00	3.53	1.00
TI_1.2	2.00	5.00	3.47	0.94
TI_2.1	2.00	5.00	3.54	0.92
TI_2.2	2.00	5.00	3.46	0.99
TI_3.1	2.00	5.00	3.47	0.93
TI_3.2	2.00	5.00	3.58	0.97
TI_4.1	2.00	5.00	3.46	0.95
TI_4.2	2.00	5.00	3.47	0.95
TI_5.1	2.00	5.00	3.48	0.97
TI_5.2	2.00	5.00	3.49	0.91
TI (mean)	**2.40**	**4.80**	**3.50**	**0.56**

With respect to Technological Integration, Table 15 provided the item-level and overall descriptive statistics. The item means ranged from 3.46 to 3.58, with an overall construct mean of 3.50 and a standard deviation of 0.56. This result showed that digital tools, project monitoring technologies, and technology-supported management practices were moderately integrated into construction project implementation. Although the mean suggested a favorable level of adoption, it also implied that technological integration remained an area for strategic expansion, particularly in relation to advanced digital systems, real-time monitoring, and data-driven project decision-making.

TABLE 16. DESCRIPTIVE STATISTICS – STAKEHOLDER ENGAGEMENT (N=309)

Item	Minimum	Maximum	Mean	Std. Deviation
SE_1.1	2.00	5.00	3.52	1.01
SE_1.2	2.00	5.00	3.56	1.02
SE_2.1	2.00	5.00	3.47	0.95
SE_2.2	2.00	5.00	3.51	0.93
SE_3.1	2.00	5.00	3.58	0.91
SE_3.2	2.00	5.00	3.60	0.97
SE_4.1	2.00	5.00	3.47	0.94
SE_4.2	2.00	5.00	3.49	0.97
SE_5.1	2.00	5.00	3.50	0.93
SE_5.2	2.00	5.00	3.52	0.95
SE (mean)	**2.10**	**5.00**	**3.52**	**0.57**

In terms of Stakeholder Engagement, the descriptive statistics summarized in Table 16 showed generally favorable assessments. The item means ranged from 3.47 to 3.60, with an overall construct mean of 3.52 and a standard deviation of 0.57. This indicated that stakeholder participation, communication, consultation, and coordination were generally practiced within construction projects. The favorable mean

further suggested that construction organizations recognized the importance of engaging clients, contractors, consultants, regulatory bodies, local government units, and community stakeholders throughout the project life cycle.

TABLE 17. DESCRIPTIVE STATISTICS – EXTERNAL INFLUENCES (N=309)

Item	Minimum	Maximum	Mean	Std. Deviation
EI_1.1	2.00	5.00	3.51	0.98
EI_1.2	2.00	5.00	3.50	0.96
EI_2.1	2.00	5.00	3.59	0.94
EI_2.2	2.00	5.00	3.55	0.93
EI_3.1	2.00	5.00	3.52	0.97
EI_3.2	2.00	5.00	3.60	0.98
EI_4.1	2.00	5.00	3.52	0.99
EI_4.2	2.00	5.00	3.61	0.94
EI_5.1	2.00	5.00	3.52	0.97
EI_5.2	2.00	5.00	3.59	0.92
EI (mean)	**2.20**	**4.80**	**3.55**	**0.58**

Regarding External Influences, Table 17 displayed the descriptive results. The item means ranged from 3.50 to 3.61, with an overall construct mean of 3.55 and a standard deviation of 0.58. This construct obtained the highest overall mean among all dimensions, indicating that external conditions were strongly perceived by respondents as salient factors affecting construction project implementation. These conditions may have included regulatory requirements, funding constraints, environmental considerations, economic fluctuations, and other contextual pressures that shaped project delivery within the region.

TABLE 18. DESCRIPTIVE STATISTICS –PROJECT SUCCESS (N=309)

Item	Minimum	Maximum	Mean	Std. Deviation
PS_1.1	2.00	5.00	3.50	0.99
PS_1.2	2.00	5.00	3.47	0.96
PS_2.1	2.00	5.00	3.57	0.97
PS_2.2	2.00	5.00	3.47	0.95
PS_3.1	2.00	5.00	3.51	0.97
PS_3.2	2.00	5.00	3.54	0.94
PS_4.1	2.00	5.00	3.56	0.95
PS_4.2	2.00	5.00	3.49	0.90
PS_5.1	2.00	5.00	3.47	0.93
PS_5.2	2.00	5.00	3.41	0.97
PS (mean)	**2.30**	**4.70**	**3.50**	**0.56**

For Project Success, the descriptive profile of this endogenous construct was shown in Table 18. The item means ranged from 3.41 to 3.57, with an overall construct mean of 3.50 and a standard deviation of 0.56. This finding indicated that respondents generally perceived construction projects in Region XIII, Caraga, as having achieved a moderately favorable level of success. The result suggested that project outcomes were relatively positive, although measurable room for improvement remained in relation to cost performance, time completion, quality delivery, stakeholder satisfaction, and other performance-related objectives.

TABLE 19. OVERALL MEANS FOR EACH CONSTRUCT

Variable	Mean	Std. Deviation
PMP	3.4935	0.5394
RM	3.5178	0.5525
TI	3.4958	0.5583
SE	3.5210	0.5671
EI	3.5492	0.5778
PS	**3.4990**	**0.5581**

Overall, Table 19 consolidated the mean scores and standard deviations of the six constructs. The mean values were clustered around 3.50 on a five-point scale, indicating generally favorable perceptions across all dimensions. External Influences obtained the highest mean

score at 3.5492, followed by Stakeholder Engagement at 3.5210 and Resource Management at 3.5178. Project Success, Technological Integration, and Project Management Practices also obtained favorable mean values, although their slightly lower scores suggested areas where improvement could still be pursued. The standard deviations, ranging from approximately 0.54 to 0.58, reflected moderate dispersion around the means. This suggested that while respondents generally shared positive assessments, some variability existed in their experiences of project management practices, resource availability, technological integration, stakeholder engagement, external pressures, and project success.

1) Reflective Measurement Model Evaluation

The original six-domain reflective measurement specification was examined as an exploratory diagnostic. Assessments used exported outer loadings, pooled Cronbach's alpha, composite reliability (ρc), average variance extracted (AVE), and the full heterotrait–monotrait (HTMT) estimates. These metrics must be interpreted before attempting substantive latent structural inference. The original specification did not satisfy recommended reflective convergent and discriminant validity criteria.

Pooled Cronbach's alpha estimates ranged from 0.771 to 0.806 and composite reliability (ρc) ranged from 0.829 to 0.851. These pooled internal-consistency values alone do not establish valid separate constructs. When recalculated separately, Cronbach's alpha varied from −0.077 to 0.300 in the public sector and from −0.082 to 0.451 in the private sector, indicating marked within-group instability. Therefore claims that all six latent constructs reliably measure distinct dimensions are not supported.

The authentic SmartPLS 4 export reported AVE values of 0.328 (PMP), 0.339 (RM), 0.343 (TI), 0.349 (SE), 0.364 (EI), and 0.343 (PS), all below the 0.50 reference criterion for convergent validity. Its 60 original outer loading estimates spanned 0.478 (TI5.2) to 0.651 (TI3.2), rather than the previously stated 0.65–0.92 range. The intended reflective measurement specification consequently failed the usual convergent-validity assessment.

Discriminant validity was not established: all 15 SmartPLS HTMT point ratios ranged from 0.899 to 1.028, exceeding the conservative 0.85 criterion. Independent 5,000-resample BCa intervals for all 15 ratios are presented in Supplementary Table S1; Fornell–Larcker comparisons appear in Supplementary Table S2. Every one of the original 60 outer loadings was below 0.70. Complete outer and cross-loadings are reported in Appendix C. The original reflective scales must not be characterized as psychometrically validated.

The original SmartPLS pooled reliability results were alpha = 0.771–0.806 and composite reliability = 0.829–0.851, but all six AVE measures were below 0.50. Full construct-level and pairwise HTMT outputs are retained for transparent review; the original reflective measurement specification cannot be characterized as psychometrically validated. No item-removal or model-combination procedure was applied to manufacture compliance.

TABLE 20. SMARTPLS-VERIFIED POOLED MEASUREMENT INDICES (REFLECTIVE VALIDITY NOT ESTABLISHED)

Construct	Cronbach's α	Composite Reliability (ρc)	AVE
PMP	0.771	0.829	0.328
RM	0.783	0.836	0.339
TI	0.786	0.838	0.343
SE	0.793	0.842	0.349
EI	0.806	0.851	0.364
PS (Y)	0.786	0.839	0.343

SUPPLEMENTARY TABLE S1. FULL HTMT MATRIX AND INDEPENDENT BCA 95% INTERVALS (5,000 RESAMPLES)

Pair	HTMT	BCa 95% lower	BCa 95% upper
RM–PMP	0.975	0.922	1.023
TI–PMP	0.991	0.902	1.038
TI–RM	0.997	0.941	1.043
SE–PMP	0.986	0.924	1.032
SE–RM	1.000	0.944	1.045
SE–TI	0.992	0.931	1.038
EI–PMP	0.900	0.761	0.979
EI–RM	0.946	0.864	1.003
EI–TI	0.947	0.792	1.015
EI–SE	0.899	0.787	0.972
PS–PMP	0.997	0.948	1.038
PS–RM	1.028	0.982	1.065
PS–TI	1.021	0.964	1.062
PS–SE	0.980	0.917	1.024
PS–EI	0.957	0.838	1.022

SUPPLEMENTARY TABLE S2. FORNELL–LARCKER MATRIX OF THE ORIGINAL POOLED REFLECTIVE SPECIFICATION

Construct	PMP	RM	TI	SE	EI	PS
PMP	+0.573	+0.759	+0.775	+0.775	-0.710	+0.780
RM	+0.759	+0.582	+0.783	+0.790	-0.752	+0.809
TI	+0.775	+0.783	+0.586	+0.785	-0.753	+0.806
SE	+0.775	+0.790	+0.785	+0.591	-0.724	+0.779
EI	-0.710	-0.752	-0.753	-0.724	+0.604	-0.765
PS	+0.780	+0.809	+0.806	+0.779	-0.765	+0.585

Note. Diagonal values are square roots of AVE; off-diagonal values are latent-score correlations. No pair demonstrates adequate discriminant separation under the displayed criteria.

B. Exploratory Structural Model and Measurement Limitations

The structural model examined the relationships between five exogenous constructs-Project Management Practices (PMP), Resource Management (RM), Technological Integration (TI), Stakeholder Engagement (SE), and External Influences (EI)-and the endogenous construct, Project Success (PS). Partial Least Squares Structural Equation Modelling (PLS-SEM) was employed to estimate the direction and relative magnitude of these relationships using the pooled dataset comprising 309 construction professionals from the public and private sectors in Region XIII (Caraga). The analysis was intended to determine the extent to which the specified management and contextual constructs were associated with reported project outcomes.

The original archived SmartPLS algorithm was independently reproduced to numerical precision for five standardized structural paths, R^2, all 60 reflective outer loadings, all 15 HTMT ratios, f^2, and inner VIF. It does not contain a native dated bootstrap report or a documented Q^2/PLSpredict value. A separately performed 5,000-resample row-bootstrap therefore provides exploratory uncertainty estimates, but the latent structural coefficients remain unvalidated because all six AVEs and 15 HTMT comparisons fail established reflective measurement criteria.

The archived SmartPLS algorithm output estimated positive standardized paths from RM ($\beta = 0.258$), TI ($\beta = 0.234$), PMP ($\beta = 0.183$), and SE ($\beta = 0.122$) to reported PS, and a negative path from EI ($\beta = -0.176$) to reported PS. The original manuscript's alternative path coefficients were inconsistent with this source output. These estimates describe exploratory conditional associations in this sample; their direction alone does not establish statistically supported hypotheses or causal effects.

Among the four internal domains in the archived exploratory solution, RM had the numerically largest coefficient, followed by TI, PMP, and SE. This descriptive ranking is specific to the unvalidated original reflective specification and should not be used to infer substantive

superiority or significant differences between effects. Conceptual implications should instead be framed as hypotheses for later validated research.

TI had a source-verified original standardized coefficient of $\beta = 0.234$, while SE had $\beta = 0.122$. Independent bootstrap BCa intervals excluded zero for both exploratory paths. These associations nevertheless do not establish causal effects of technological integration or stakeholder engagement because the original reflective measurement specification did not establish convergent or discriminant validity.

The original SmartPLS coefficient for EI was negative ($\beta = -0.176$), reflecting a sample-specific conditional association in the original exploratory solution. The measured scale includes heterogeneous regulatory, economic, environmental, supply-chain, and community pressures; the coefficient is not evidence of a universal causal effect of each external condition. The failure of measurement validity further limits interpretation.

The archived pooled SmartPLS algorithm yielded $R^2 = 0.7699$ and SRMR = 0.0496. Neither value resolves the failure of reflective measurement quality. A previously reported $R^2 = 0.724$ and SRMR = 0.061 did not match the dated source workbook. Q^2 was not computed as a verified final-model statistic; no numerical Q^2 claim is therefore made.

An independent 5,000-resample path-weighted PLS sensitivity bootstrap, with 309 participant-level jackknife evaluations for BCa acceleration, was conducted on the original 309 by 60 indicator matrix. Table 21 provides the coefficient, bootstrap standard error, approximate t and p values, five-path Holm adjustment, BCa interval, f^2, and inner VIF for each exploratory path. This does not replace a native SmartPLS bootstrap export or validate the six reflective constructs. Since convergent and discriminant validity failed, the original H1a–H1e hypotheses are not accepted as confirmatory latent effects.

Table 21. Exploratory PLS-SEM Paths and Independent 5,000-Resample Bootstrap Estimates

Path	β	Boot. SE	|t| approx.	p approx.	95% BCa CI	f^2	VIF
PMP -> PS	+0.183	0.060	3.050	0.0025	[+0.075, +0.311]	0.044	3.30
RM -> PS	+0.258	0.052	4.932	<0.001	[+0.152, +0.359]	0.078	3.72
TI -> PS	+0.234	0.060	3.901	<0.001	[+0.118, +0.349]	0.063	3.80
SE -> PS	+0.122	0.052	2.345	0.0197	[+0.022, +0.225]	0.018	3.68
EI -> PS	-0.176	0.053	3.339	<0.001	[-0.279, -0.079]	0.047	2.88

Note. Bootstrapping was independently performed in Python; approximate p-values and Holm correction concern five exploratory associations. All intervals exclude zero, but none establishes confirmatory H1a–H1e acceptance because convergent and discriminant validity failed. Q^2 was not reported without a reproducible predictive analysis.

The pooled structural model provides an empirical basis for examining the relationships between construction management practices, contextual influences, and reported Project Success. However, these structural relationships are analytically distinct from the proposed Construction Engineering Management Maturity Framework (CEM-MF). The PLS-SEM coefficients estimate conditional associations with Project Success, whereas the CEM-MF uses respondent-level capability scores to establish descriptive, sample-referenced classifications. The framework therefore draws upon the measured management domains without treating structural path coefficients as maturity thresholds or automatically assigning greater maturity weight to predictors with larger coefficients.

Because AVE and HTMT did not meet their recommended criteria, the original six-factor PLS-SEM should be considered an unsuccessful exploratory measurement specification, not a validated predictive model. The reproducible sectoral contrasts and descriptive four-domain CEM-MF may inform hypothesis generation but do not themselves validate distinct latent constructs or organizational maturity stages.

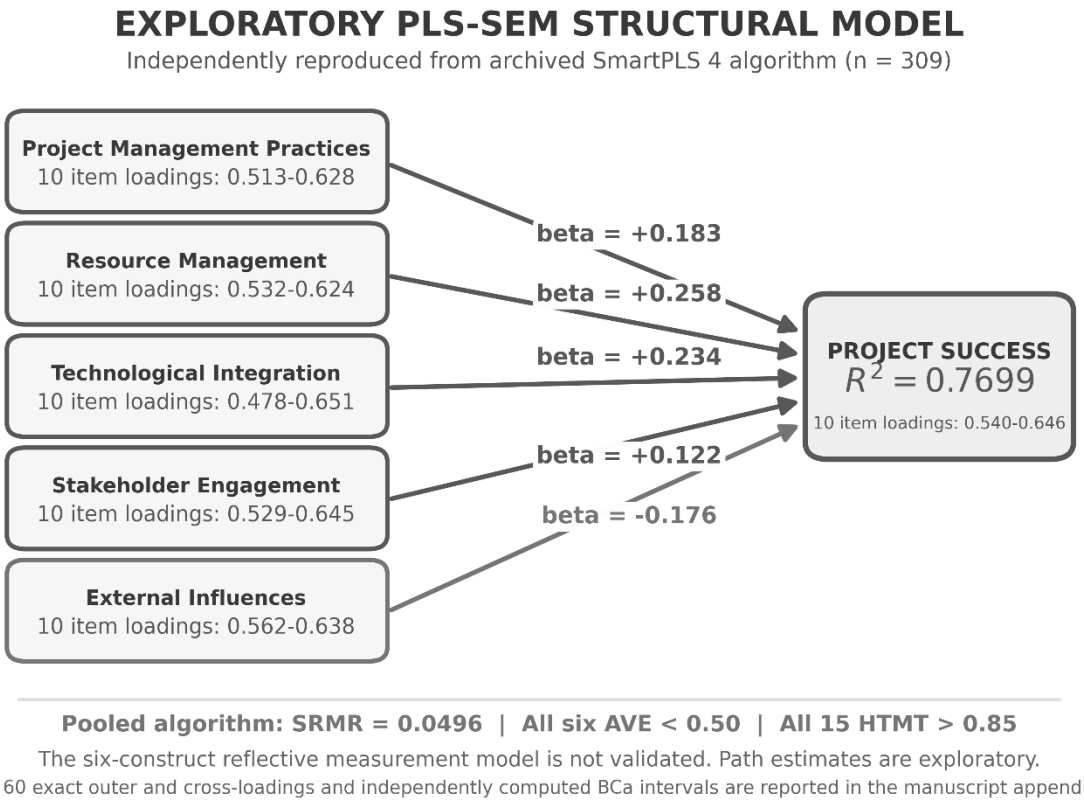


Fig. 3. High-resolution reconstruction of the archived pooled exploratory structural model. Path values reproduce the SmartPLS 4 algorithm; item-loading ranges are source verified, with all 60 individual outer and cross-loadings available in Appendix C. The reflective measurement specification did not establish validity.

The provisional CEM-MF is an equally weighted descriptive composite of four questionnaire domain means (PMP, RM, TI, SE). Its pooled empirical quintiles are reproducible from the 309 survey records. However, because the underlying reflective scales lack adequate validation, the resulting labels are descriptive, sample-dependent categories rather than demonstrated organizational maturity levels.

The proposed framework is organized around four developable internal constructs (PMP, RM, TI, and SE), with External Influences assessed separately as contextual pressure. Proposed resilience processes are implementation recommendations, not an empirically observed fifth internal capability scale.

C. Supplementary Observed-Score Correlations and Ordinary Least Squares Regression

To examine preliminary linear associations among the observed questionnaire-domain means, Pearson correlations were estimated against respondent-level Project Success. Table 22 presents the corresponding observed-score associations, which should not be conflated with confirmed reflective latent-construct validity. Strong pooled correlations may partly reflect between-sector differences and cannot establish causal effects.

Table 22. Pearson Correlations with Project Success

Variable	Pearson Correlation	Sig. (2-tailed)	N
PMP	0.777	< .001	309
RM	0.808	< .001	309
TI	0.804	< .001	309
SE	0.775	< .001	309
EI	–0.763	< .001	309

External Influences was inversely correlated with reported Project Success in the pooled respondent dataset ($r = -0.763$, two-sided $p < .001$). These unadjusted observed-score correlations may reflect both sector-related response distributions and other shared method effects; they do not identify causal relationships or independently validate the reflective model.

Table 23. Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.875	0.766	0.763	0.27196

Independently recomputed from the 309 respondent records, the observed-score OLS model had $R = 0.8754$, $R^2 = 0.7664$, adjusted $R^2 = 0.7625$, and residual standard error = 0.2720. These values describe fitted questionnaire-domain means, not the SmartPLS latent-model $R^2 = 0.7699$ or an externally validated prediction rule.

Table 24. ANOVA for Regression Model

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	73.520	5	14.704	198.809	< 0.001
Residual	22.410	303	0.074		
Total	**95.930**	**308**			

An independent least-squares reproduction confirmed the OLS omnibus test, $F(5, 303) = 198.809$, $p \approx 2.02 \times 10^{-93}$. The model explains a large share of the observed within-sample variance in mean Project Success ratings. Such fit is not evidence of causal effects, population prediction accuracy, or adequate discrimination among the original reflective constructs.

Recomputed OLS slopes (B; two-sided p) were PMP 0.1897 ($p = .00031$), RM 0.2623 ($p < .00001$), TI 0.2320 ($p = .000024$), and SE 0.1182 ($p = .0240$), holding the other four observed questionnaire-domain means constant. Thus the previous claim that each predictor had $p < .001$ was incorrect: Stakeholder Engagement met the nominal .05 threshold but not .001. These tests concern observed composite scores and are separate from unverified SmartPLS path-bootstrap hypotheses.

The recomputed EI slope was $B = -0.1701$ (two-sided $p = .00022$). The corresponding observed-score standardized slopes were PMP $\beta = 0.1834$, RM $\beta = 0.2597$, TI $\beta = 0.2321$, SE $\beta = 0.1202$, and EI $\beta = -0.1761$. Their numerical similarity to archived SmartPLS paths does not make the two analytical models interchangeable. Without a credible sampling frame, independent outcomes, and validated measurement, no causal or population-generalizable effect is inferred.

The supplementary observed-score OLS prediction equation, with coefficients rounded for presentation, is:

$$PS = 1.2899 + 0.1897(PMP) + 0.2623(RM) + 0.2320(TI) + 0.1182(SE) - 0.1701(EI) \quad (1)$$

For transparency, this equation uses domain means obtained by averaging each respondent's ten original questionnaire items. Its slopes describe conditional associations in the pooled 309-record sample. Because reflective measurement validation failed, it is not used to assign CEM-MF maturity categories or claim significant latent structural paths.

The supplementary analysis showed positive associations of PMP, RM, TI and SE with Project Success and a negative association for EI with Project Success. The OLS model reported $R^2 = 0.766$. These results support further examination of internal capability and contextual exposure, but OLS coefficients are not PLS-SEM standardized path coefficients or CEM-MF scoring weights.

D. Public–Private Sector Comparisons

The sector comparison uses observed Project Success and the five self-reported questionnaire-domain means; it does not compare validated latent paths. A direct Mann–Whitney test of Project Success was reproduced from the 309 respondent records (public n = 157; private n = 152; U = 257; two-sided Holm-adjusted p < .001; rank-biserial r = −0.978). Sectoral distributions and provisional capability classifications are shown in the following tables; selection, common-method effects, and unverified clustering limit inference.

The framework's proposed domains have conceptual, rather than confirmed causal, links to the study's original theoretical lenses. The Resource-Based View motivates attention to developable planning, resource, and information capabilities; Stakeholder Theory motivates examining coordination and participation; the Theory of Constraints motivates investigation of bottlenecks and contextual barriers. Because discriminant validity failed, these lenses should guide subsequent measurement redesign, not be represented as empirically verified explanations for the five exploratory paths.

E. Proposed Construction Engineering Management Maturity Framework

1) Empirical and Instrumental Basis of the Proposed CEM-MF

The proposed CEM-MF draws on the content of the original questionnaire and reproducible observed respondent-score distributions. Four internal questionnaire domains—Project Management Practices, Resource Management, Technological Integration, and Stakeholder Engagement—form a transparently equal-weighted descriptive composite. The original SmartPLS coefficients remain exploratory because the six-domain reflective measurement specification did not meet convergent or discriminant validity thresholds; they do not provide validated domain weights or construct evidence for the maturity stages.

The CEM-MF uses an equal-weight mean of four ten-item internal domain scores, with construct-specific and overall percentile bands calculated from the pooled N = 309 respondents. These are sample-referenced descriptive capability classes. They cannot be presented as independent empirical validation of the proposed organizational process-stage descriptions.

The principal proposed applied output is a provisional Construction Engineering Management Maturity Framework (CEM-MF) covering the four internal questionnaire domains. Its labels preserve a direct connection to the measured item content. The five empirical categories describe relative respondent ratings within the 309-person reference sample, not independently verified organizational development stages.

The framework distinguishes (i) questionnaire measurement, (ii) pooled structural associations with PS, (iii) empirically calculated respondent-score bands, and (iv) proposed process-stage improvement activities. Only the first three have descriptive or analytical support from the present survey, and the final stage requires independent prospective organizational validation.

2) Construct-Specific Maturity Classification and Interpretation

a) Project Management Practices obtained an overall mean of 3.4935 (SD = 0.5394), corresponding to Level 3 – Intermediate Capability within the empirical range of $3.20 < x \leq 3.70$. The highest-rated indicator concerned the implementation of risk management strategies (M = 3.54), while the lowest concerned the regular utilization of project monitoring and evaluation systems (M = 3.40). These findings indicated

relatively stronger reported implementation of risk control than systematic performance monitoring, highlighting opportunities to strengthen corrective-control mechanisms, project governance, and documentation practices.

Table 25. PROJECT MANAGEMENT PRACTICES (PMP): EMPIRICAL LEVELS AND INDICATOR BASIS

CEM-MF Level	Numerical Range	Indicator Codes Used	Qualification
Level 1 – Lower Capability	$1.00 \leq x \leq 3.00$	$PMP_{1}.1$, $PMP_{1}.2$, $PMP_{2}.1$, $PMP_{2}.2$, $PMP_{3}.1$, $PMP_{3}.2$, $PMP_{4}.1$, $PMP_{4}.2$, $PMP_{5}.1$, $PMP_{5}.2$	Lower overall manifestation of the measured PMP practices across scope and scheduling, risk and quality control, monitoring and corrective action, coordination, governance, and documentation.
Level 2 – Emerging Capability	$3.00 < x \leq 3.20$	$PMP_{1}.1$–$PMP_{5}.2$	Emerging manifestation of the same PMP practices; the measured practices are evident but remain comparatively limited or uneven across the assessed project setting.
Level 3 – Intermediate Capability	$3.20 < x \leq 3.70$	$PMP_{1}.1$–$PMP_{5}.2$	Intermediate manifestation of the measured PMP practices; the practices are generally evident across the assessed project setting.
Level 4 – Advanced Capability	$3.70 < x \leq 4.00$	$PMP_{1}.1$–$PMP_{5}.2$	Strong manifestation of the measured PMP practices across the assessed project setting.
Level 5 – Leading Capability	$4.00 < x \leq 5.00$	$PMP_{1}.1$–$PMP_{5}.2$	Very strong manifestation of the measured PMP practices, reflected by consistently high agreement with the approved PMP statements.

b) Resource Management. Resource Management recorded an overall mean of 3.5178 (SD = 0.5525), corresponding to Level 3 – Intermediate Capability within the range of $3.30 < x \leq 3.80$. Inventory management obtained the highest rating (M = 3.61), whereas procurement responsiveness and scheduled equipment maintenance recorded the lowest ratings (M = 3.48). This pattern reflected comparatively stronger inventory-control practices, while suggesting opportunities to improve resource availability, procurement coordination, and preventive maintenance within construction operations.

Table 26. RESOURCE MANAGEMENT (RM): EMPIRICAL LEVELS AND INDICATOR BASIS

CEM-MF Level	Numerical Range	Indicator Codes Used	Qualification
Level 1 – Lower Capability	$1.00 \leq x \leq 3.00$	$RM_{1}.1$, $RM_{1}.2$, $RM_{2}.1$, $RM_{2}.2$, $RM_{3}.1$, $RM_{3}.2$, $RM_{4}.1$, $RM_{4}.2$, $RM_{5}.1$, $RM_{5}.2$	Lower manifestation of the measured RM practices involving allocation, utilization, financial control, shortage mitigation, procurement, workforce capability, equipment maintenance, and inventory control.
Level 2 – Emerging Capability	$3.00 < x \leq 3.30$	$RM_{1}.1$–$RM_{5}.2$	Emerging manifestation of the measured RM practices; the practices are present but are not yet strongly manifested across the assessed setting.
Level 3 – Intermediate Capability	$3.30 < x \leq 3.80$	$RM_{1}.1$–$RM_{5}.2$	Intermediate manifestation of the measured RM practices; resource-management systems are generally evident.
Level 4 – Advanced Capability	$3.80 < x \leq 4.10$	$RM_{1}.1$–$RM_{5}.2$	Strong manifestation of the measured RM practices across resource planning, control, availability, competency, equipment, and inventory systems.
Level 5 – Leading Capability	$4.10 < x \leq 5.00$	$RM_{1}.1$–$RM_{5}.2$	Very strong manifestation of the complete set of measured RM practices.

c) Technological Integration. The construct yielded an overall mean of 3.4958 (SD = 0.5583), placing the construct at Level 3 – Intermediate Capability within the range of $3.20 < x \leq 3.80$. Investment in software and digital system upgrades received the highest rating (M = 3.58), while real-time digital monitoring and technical staff training obtained the lowest ratings (M = 3.46). These findings suggested that reported technological investment was more evident than its systematic application in project monitoring and workforce development, indicating opportunities for improving digital competency and technology-enabled coordination.

Table 27. TECHNOLOGICAL INTEGRATION (TI): EMPIRICAL LEVELS AND INDICATOR BASIS

CEM-MF Level	Numerical Range	Indicator Codes Used	Qualification
Level 1 – Lower Capability	$1.00 \leq x \leq 2.90$	$TI_1.1$, $TI_1.2$, $TI_2.1$, $TI_2.2$, $TI_3.1$, $TI_3.2$, $TI_4.1$, $TI_4.2$, $TI_5.1$, $TI_5.2$	Lower manifestation of the measured digital-planning, analytics, monitoring, interoperability, digital-training, documentation, coordination, and error-reduction practices.
Level 2 – Emerging Capability	$2.90 < x \leq 3.20$	$TI_1.1$–$TI_5.2$	Emerging manifestation of technological integration; some of the measured digital practices are evident but remain comparatively limited.
Level 3 – Intermediate Capability	$3.20 < x \leq 3.80$	$TI_1.1$–$TI_5.2$	Intermediate manifestation of technological integration; the measured digital practices are generally evident.
Level 4 – Advanced Capability	$3.80 < x \leq 4.00$	$TI_1.1$–$TI_5.2$	Strong manifestation of the measured TI practices across planning, decision support, monitoring, infrastructure, competency, documentation, and coordination.
Level 5 – Leading Capability	$4.00 < x \leq 5.00$	$TI_1.1$–$TI_5.2$	Very strong manifestation of the complete set of approved TI indicators.

d) Stakeholder Engagement. Stakeholder Engagement obtained an overall mean of 3.5210 (SD = 0.5671), corresponding to Level 3 – Intermediate Capability within the range of $3.20 < x \leq 3.80$. Timely resolution of stakeholder concerns received the highest rating (M = 3.60), followed by transparent conflict-resolution mechanisms (M = 3.58). Conversely, regular stakeholder meetings and systematic integration of client feedback recorded the lowest ratings (M = 3.47). These results indicated comparatively stronger responsiveness to stakeholder concerns than formalized consultation and feedback mechanisms, emphasizing opportunities to strengthen communication, participation, and institutional coordination.

Table 28. STAKEHOLDER ENGAGEMENT (SE): EMPIRICAL LEVELS AND INDICATOR BASIS

CEM-MF Level	Numerical Range	Indicator Codes Used	Qualification
Level 1 – Lower Capability	$1.00 \leq x \leq 3.00$	$SE_1.1$, $SE_1.2$, $SE_2.1$, $SE_2.2$, $SE_3.1$, $SE_3.2$, $SE_4.1$, $SE_4.2$, $SE_5.1$, $SE_5.2$	Lower manifestation of the measured stakeholder participation, communication, issue management, feedback, change communication, and institutional-coordination practices.
Level 2 – Emerging Capability	$3.00 < x \leq 3.20$	$SE_1.1$–$SE_5.2$	Emerging manifestation of stakeholder-engagement practices; engagement mechanisms are evident but remain comparatively limited.
Level 3 – Intermediate Capability	$3.20 < x \leq 3.80$	$SE_1.1$–$SE_5.2$	Intermediate manifestation of the measured stakeholder-engagement practices.
Level 4 – Advanced Capability	$3.80 < x \leq 4.10$	$SE_1.1$–$SE_5.2$	Strong manifestation of stakeholder participation, alignment, communication, conflict resolution, feedback integration, and institutional coordination.
Level 5 – Leading Capability	$4.10 < x \leq 5.00$	$SE_1.1$–$SE_5.2$	Very strong manifestation of the complete set of approved SE practices.

e) External Influences. External Influences recorded the highest overall construct mean of 3.5492 (SD = 0.5778), corresponding to Moderate External Influence within the empirical range of $3.30 < x \leq 3.80$. Material supply fluctuations (M = 3.61) and weather-related disruptions (M = 3.60) were the most strongly reported indicators, followed by economic conditions and regulatory approval processes (M = 3.59). These findings highlighted the relevance of supply, climatic, economic, and regulatory conditions in construction project

implementation. Unlike the four internal capability constructs, External Influences represented contextual exposure rather than organizational maturity and was therefore classified separately.

Table 29. EXTERNAL INFLUENCE (EI): EMPIRICAL LEVELS AND INDICATOR BASIS

EI Band	Numerical Range	Indicator Codes Used	Qualification
Very Low External Influence	$1.00 \leq x \leq 2.90$	$EI_1.1$–$EI_5.2$	Very low reported manifestation of regulatory, political, economic, climatic, labor/material, community, and approval-related pressures.
Low External Influence	$2.90 < x \leq 3.30$	$EI_1.1$–$EI_5.2$	Low reported manifestation of the measured external pressures.
Moderate External Influence	$3.30 < x \leq 3.80$	$EI_1.1$–$EI_5.2$	Moderate manifestation of the measured contextual pressures affecting project implementation.
High External Influence	$3.80 < x \leq 4.10$	$EI_1.1$–$EI_5.2$	Strong manifestation of the measured external pressures, indicating greater exposure to conditions that may constrain project delivery.
Very High External Influence	$4.10 < x \leq 5.00$	$EI_1.1$–$EI_5.2$	Very strong manifestation of the measured external pressures, indicating substantial contextual exposure across the assessed EI domains.

f) Project Success. Project Success obtained an overall mean of 3.4990 (SD = 0.5581), reflecting the respondents' assessments of multidimensional construction project performance. Quality and performance compliance received the highest rating (M = 3.57), followed by contributions to long-term operational improvements (M = 3.56), whereas value achievement relative to cost, time, and quality received the lowest rating (M = 3.41). These findings suggested comparatively stronger reported quality compliance and operational contribution, while identifying integrated project value as an area warranting further assessment. Project Success remained the endogenous outcome construct and was not included in the CEM-MF maturity classification.

g) Overall Interpretation. Collectively, the pooled mean scores placed Project Management Practices, Resource Management, Technological Integration, and Stakeholder Engagement within Level 3 – Intermediate Capability, while External Influences reflected Moderate contextual intensity. These classifications represented sample-referenced capability and contextual profiles rather than externally validated organizational maturity stages. The descriptive differences among indicators provided a basis for identifying potential improvement priorities, whereas the relationships between the five predictor constructs and Project Success were examined separately through the pooled PLS-SEM structural model.

Table 30. Pooled Empirical Percentile Boundaries

Measure	P20	P40	P60	P80
PMP	3.00	3.20	3.70	4.00
RM	3.00	3.30	3.80	4.10
TI	2.90	3.20	3.80	4.00
SE	3.00	3.20	3.80	4.10
Overall CEM-MF	3.000	3.125	3.875	4.050
EI intensity	2.90	3.30	3.80	4.10

The 309-record dataset confirms the displayed four-domain CEM-MF percentile boundaries. Linear empirical quantiles (the default NumPy method) give P20 = 3.000, P40 = 3.125, P60 = 3.875, and P80 = 4.050. These are pooled, sample-dependent cut-points and are not independently validated professional maturity standards.

Table 31. Empirical CEM-MF Level Decision Matrix

Measure	Level 1	Level 2	Level 3	Level 4	Level 5
PMP	$1.00 \leq x \leq 3.00$	$3.00 < x \leq 3.20$	$3.20 < x \leq 3.70$	$3.70 < x \leq 4.00$	$4.00 < x \leq 5.00$
RM	$1.00 \leq x \leq 3.00$	$3.00 < x \leq 3.30$	$3.30 < x \leq 3.80$	$3.80 < x \leq 4.10$	$4.10 < x \leq 5.00$
TI	$1.00 \leq x \leq 2.90$	$2.90 < x \leq 3.20$	$3.20 < x \leq 3.80$	$3.80 < x \leq 4.00$	$4.00 < x \leq 5.00$
SE	$1.00 \leq x \leq 3.00$	$3.00 < x \leq 3.20$	$3.20 < x \leq 3.80$	$3.80 < x \leq 4.10$	$4.10 < x \leq 5.00$
Overall CEM-MF	$1.000 \leq x \leq 3.000$	$3.000 < x \leq 3.125$	$3.125 < x \leq 3.875$	$3.875 < x \leq 4.050$	$4.050 < x \leq 5.000$

Use the unrounded score x. For example, PMP = 3.70 remains Level 3, while PMP > 3.70 and ≤ 4.00 is Level 4. A ten-item mean of integer responses changes in increments of 0.10, so the first attainable individual PMP score above 3.70 is 3.80. Smaller increments may arise when averaging multiple respondents; a displayed target of 3.71 is not attainable as a complete single-respondent ten-item mean.

Table 32. Public and Private Sector Aggregate Classifications

Measure	Public mean	Public band	Private mean	Private band
PMP	3.046	Level 2	3.955	Level 4
RM	3.046	Level 2	4.005	Level 4
TI	3.013	Level 2	3.994	Level 4
SE	3.033	Level 2	4.025	Level 4
Overall CEM-MF	3.035	Level 2	3.995	Level 4
EI	**4.036**	**High intensity**	**3.046**	**Low intensity**

Classification of a sector mean must be distinguished from respondent-level distribution. Table 33 shows the variation concealed by aggregate classifications; Fig. 4 provides the corresponding graphical comparison.

Table 33. Overall Empirical CEM-MF Level Distribution by Sector

Sector	Level 1	Level 2	Level 3	Level 4	Level 5
Public (n = 157)	74 (47.1%)	51 (32.5%)	31 (19.7%)	0 (0.0%)	1 (0.6%)
Private (n = 152)	0 (0.0%)	0 (0.0%)	34 (22.4%)	63 (41.4%)	55 (36.2%)

Note: Percentages use each sector's sample size and may not sum to exactly 100% because of rounding. Overall, 125 of 157 public respondents (79.6%) fall within Levels 1–2, while 118 of 152 private respondents (77.6%) fall within Levels 4–5. One public respondent falls in Level 5, so the public-sector Level 2 aggregate should not be generalized to every respondent.

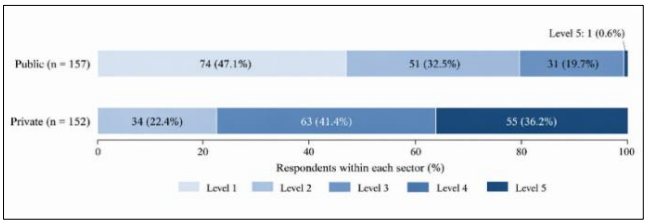


Fig. 4. Distribution of respondent-level empirical CEM-MF bands using identical pooled cut-points for public and private sectors.

The six respondent-level comparisons (PMP, RM, TI, SE, EI, and PS) were independently reproduced from the 309 raw indicator records using two-sided, tie-corrected Mann–Whitney tests, with Holm adjustment across six comparisons. Project Success is now directly examined for H2a (U = 257, rank-biserial r = −0.978), with the private respondents reporting higher scores. Comparisons remain observational and subject to selection and measurement limitations.

Table 34. Verified Public–Private Mann–Whitney Comparisons (Including Project Success)

Measure	U for public group	Two-sided p
PMP	458.5	< .001
RM	164.0	< .001
TI	222.0	< .001
SE	172.0	< .001
EI	23530.5	< .001
PS (H2a)	257.0	< .001†
Overall CEM-MF	151.0	< .001

For Project Success (H2a), the public group (n = 157, M = 3.022) and private group (n = 152, M = 3.992) differed in this sample (U = 257, two-sided $p \approx 3.49 \times 10^{-50}$, six-test Holm-adjusted $p \approx 1.05 \times 10^{-49}$, rank-biserial $r = -0.978$). The five domain U statistics in Table 34 also match the respondent records. The results cannot be interpreted causally, generalized using a probability margin of error, or treated as evidence of different latent structural paths.

H) End User Assessment and Improvement Procedure

First, define the assessment unit and period. An individual completes the same forty internal-capability items with reference to a specified project or organization and period. For an organization-level pilot assessment, obtain informed responses from relevant roles, predefine the aggregation method, examine within-organization agreement and retain the respondent profile. Applying respondent-derived cut-points to an organizational average is a provisional extension requiring validation.

Second, compute the four ten-item means and classify each against Table 31. Average those four means to obtain the overall CEM-MF score and classify it using the overall row. Do not include EI or Project Success, do not average level numbers, and do not round before classification. Assess EI separately using Table 29.

Third, examine the item profile within each construct. Low-rated items identify issues for investigation, such as scheduling, risk control, corrective action, resource continuity, digital interoperability or stakeholder communication. Confirm each issue against project records and staff explanations. A level label alone does not identify the weakest process.

Fourth, agree an improvement plan with an accountable owner, completion date, resources and evidence of implementation. The current band's upper boundary is the next threshold to exceed; it is not sufficient merely to reach that boundary. The smallest attainable score increase depends on whether the score represents a ten-item individual mean or an aggregation of several respondents.

Fifth, reassess using the same instrument, assessment unit and fixed reference thresholds. Review process evidence and objective project outcomes alongside the score. Recomputing the percentiles for every assessment would change the benchmark and obscure improvement. Any later recalibration should identify a new reference sample and version of the scoring rule.

I) Illustrative Classification and Management Interpretation

For an illustrative organizational aggregate, let PMP = 3.50, RM = 3.55, TI = 3.85 and SE = 3.90. PMP and RM fall in Level 3; TI and SE fall in Level 4. The overall score is (3.50 + 3.55 + 3.85 + 3.90)/4 = 3.700, which is Level 3 because $3.125 < 3.700 \leq 3.875$. The numerical gaps to the next boundaries are 0.20 for PMP, 0.25 for RM and 0.175 for the overall composite; each boundary must be exceeded to enter the next band.

This hypothetical example is an organizational aggregate, not a claimed observed respondent. The manager would first investigate weak PMP and RM items, select feasible corrective actions, and check their execution through schedules, risk and quality records, resource plans and other project evidence. Stronger TI and SE scores do not remove the need to check particular low-rated items within those dimensions.

If the same illustrative organization has EI = 3.90, contextual pressure is High. The supplementary OLS equation gives $\hat{Y} = 1.290 + 0.190(3.50) + 0.262(3.55) + 0.232(3.85) + 0.118(3.90) - 0.170(3.90) = 3.576$. The resulting fitted Project Success score of 3.576 represented a different analytical measure from the overall CEM-MF capability score of 3.700. Specifically, the former was derived from the supplementary regression model, whereas the latter represented the equally weighted composite of the four internal capability dimensions. Neither value constituted a probability of project success or demonstrated that a particular management intervention would produce a causal improvement in project outcomes.

F. Discussion of Findings Against Theory and Prior Research

1) Interpretation, Theoretical Alignment, and Contrasting Evidence

The objective was to examine five construction-management domains in relation to reported Project Success and to propose an applied maturity framework. Source-verified questionnaire correlations and public–private contrasts are substantial, but the originally planned latent structural hypotheses are not confirmed: all six reflective AVEs were 0.328–0.364 and all 15 HTMT ratios were 0.899–1.028. This contradicts the original modelling premise that six adequately distinct reflective variables had been measured. Thus positive numerical path signs cannot be presented as convergent evidence for claims of high construct validity or validated project-success prediction, even when a pooled R^2 appears large.

Within the Resource-Based View, organized project practices and resource continuity are plausible management capabilities. The archived RM ($\beta = 0.258$), TI ($\beta = 0.234$), and PMP ($\beta = 0.183$) signs are conceptually compatible with that perspective. Related construction research includes Homthong et al.'s [32] study of whole-life performance factors, Lv et al.'s [39] investigation of project governance and organizational resilience, and Naji et al.'s [40] analysis of critical success factors. These are relevant themes, not replicated latent effect magnitudes. In fact, the present model's low within-sector alpha and failed discriminant validity oppose a straightforward interpretation of the five predictors as independently established capabilities; the original claim that PMP had the largest path is specifically contradicted by the archived output.

2) Stakeholders, Constraints, Sector Differences, and Alternative Explanations

Stakeholder Theory motivates examining participation, communication, and interface governance, while the Theory of Constraints motivates attention to bottlenecks and external exposure. The exploratory SE path is positive ($\beta = 0.122$) and EI is negative ($\beta = -0.176$), directions conceptually consistent with studying stakeholder engagement and constraints. Wu et al. [37] investigated stakeholder engagement in sustainable project management; Tipu et al. [38] examined environmental uncertainty in public–private projects. Li et al. [36] discussed BIM skills, Kim et al. [41] smart technologies, Ke et al. [42] construction-management innovation, and Zhang et al. [43] and Wang et al. [44] digital-twin technologies. These related studies address distinct interventions, contexts, and outcomes. The present data cannot demonstrate that any particular technology, stakeholder practice, or external mitigation causes greater success, and therefore do not reproduce those studies' substantive estimates or mechanisms.

The large observed Project Success sector contrast (public $M = 3.022$, private $M = 3.992$, $U = 257$, Holm-adjusted $p < .001$) warrants further investigation; it does not establish that private projects perform objectively better. Shrestha et al. [28] compared highway procurement approaches, and Alazaiza et al. [45] examined value management and building-project success using PLS-SEM, highlighting different outcomes and populations from the Caraga respondent comparison. Plausible competing explanations here include project portfolios, role

composition, unmeasured organizational clustering, regulatory exposure, and reporting styles. No project ratings were linked to independently audited schedule, cost, quality, or safety records. The provisional CEM-MF therefore captures relative self-reported scores, not a proven maturity-to-performance mechanism, and prospective organizational validation is essential.

IV. Conclusions and Recommendations

A. Conclusion

This study examined the relationships between five construction engineering management constructs and reported Project Success among 309 purposively selected construction professionals in Region XIII (Caraga), Philippines. Through the integration of Partial Least Squares Structural Equation Modelling (PLS-SEM), public–private sector comparisons, and empirical maturity classification, the investigation provides a quantitative foundation for the proposed Construction Engineering Management Maturity Framework (CEM-MF). The following conclusions correspond to the four research objectives.

1) Measurement quality. Although pooled alpha and composite-reliability estimates exceeded 0.70, the original SmartPLS reflective specification did not establish convergent validity (all AVE = 0.328–0.364; outer loadings 0.478–0.651) or discriminant validity (all pooled HTMT = 0.899–1.028). Reliability within public and private groups was markedly weaker. The six-domain latent measurement model therefore remains unvalidated, and original structural coefficients are treated as exploratory descriptions only.

2) Exploratory structural estimates. The archived SmartPLS 4 model produced RM $\beta = 0.258$, TI $\beta = 0.234$, PMP $\beta = 0.183$, SE $\beta = 0.122$, and EI $\beta = -0.176$, with $R^2 = 0.770$ and SRMR = 0.050. Independent 5,000-resample BCa intervals excluded zero for all five exploratory paths, but all 60 outer loadings, all six AVE statistics, and all 15 HTMT ratios failed the specified reflective measurement standards. Consequently, these intervals cannot justify confirmatory H1a–H1e acceptance. No unverified Q^2 or population-generalized predictive claim is made.

3) Public–private sector comparisons. The respondents comprised 157 public and 152 private participants. The Project Success scores differed (public M = 3.022; private M = 3.992; Mann–Whitney U = 257; Holm-adjusted $p < 0.001$; rank-biserial $r = -0.978$). Four internal-capability domain means were generally higher in the private group, while reported external-pressure intensity was higher in the public group. These large self-reported contrasts represent associations within a purposively recruited sample and must not be described as causal or population-representative differences.

4) Development of the Construction Engineering Management Maturity Framework. The proposed CEM-MF integrates the four internal capability domains—Project Management Practices, Resource Management, Technological Integration, and Stakeholder Engagement—through an equally weighted composite and five empirically derived maturity classifications. The pooled percentile boundaries of 3.000, 3.125, 3.875, and 4.050 provide numerical criteria for distinguishing relative capability levels within the investigated sample. External Influences is assessed separately as a contextual-exposure dimension, while Project Success remains the principal performance outcome. Accordingly, the framework offers a structured diagnostic reference for assessing reported management capabilities, identifying

improvement priorities, and supporting continuous organizational learning. Its classifications remain sample-referenced and require external validation before broader application as established organizational maturity standards.

Overall, the study provides a reproducible descriptive assessment of questionnaire-domain scores, a directly tested public–private comparison, an independently reproducible exploratory bootstrap, and a provisional four-domain CEM-MF scoring algorithm. Because six-domain reflective validity failed, the structural paths remain hypothesis-generating. Future work requires a documented eligibility screen, verified organization units, a credible regional population frame, adviser-approved measurement redevelopment, independent replication, and evaluation against audited project outcomes before the framework can be generalized.

B. Recommendations

Based on the findings and the proposed CEM-MF, the following recommendations are advanced to support evidence-informed construction management, organizational capability development, and subsequent research.

1) Construction firms and project managers. Planning, coordination, resource continuity, digital information, and stakeholder processes remain important practical considerations, but the source-verified exploratory path ranking is RM, TI, PMP, and SE—not the ranking previously claimed. Because measurement validity has not been established, organizations should prioritize improvements using objective project records, expert judgment, and locally validated assessments rather than the original path magnitudes alone.

2) Digital and Information Management. Construction organizations should strengthen Technological Integration as an embedded organizational capability rather than treating digital transformation as the acquisition of stand-alone technologies. Improvement initiatives should encompass digital planning and Building Information Modelling (BIM), data-driven decision support, systems interoperability, digital competency development, and technology-enabled coordination. The implementation of BIM, project management information systems, analytics, and related technologies should be aligned with established workflows, information standards, personnel responsibilities, and measurable operational requirements.

3) Stakeholder and Interface Governance. Construction organizations should institutionalize systematic stakeholder engagement throughout project planning, implementation, monitoring, and evaluation. Particular attention should be directed toward stakeholder participation, communication and expectation alignment, conflict resolution, feedback integration, change communication, and institutional coordination. The adoption of stakeholder registers, consultation schedules, issue-resolution mechanisms, communication protocols, and escalation procedures may strengthen coordination and responsiveness across project interfaces.

4) Contextual Risk Management and Resilience. Construction organizations should establish structured monitoring and response mechanisms for External Influences, particularly those associated with regulatory and political conditions, economic and market fluctuations, environmental and climatic disturbances, labor and material availability, and community and approval constraints. Contextual risk assessments should be integrated into project planning and monitoring systems through scenario analysis, contingency arrangements, alternative resource strategies, approval tracking, and recovery procedures. These measures may strengthen organizational preparedness and adaptive responses to changing project conditions.

5) Sector-Sensitive Framework Application. Public- and private-sector organizations should apply the same pooled empirical classification boundaries when undertaking comparisons within the study's reference population. Capability assessments should examine construct-specific scores, respondent-level distributions, and contextual differences rather than relying exclusively on aggregate sector means. Sector-specific improvement initiatives should be informed by identified capability gaps while accounting for differences in project characteristics, institutional requirements, professional roles, and organizational conditions. Subsequent applications should avoid interpreting respondent-reported capability differences as evidence of distinct structural relationships or independently verified organizational performance.

6) Performance Measurement and Organizational Learning. Construction organizations should establish integrated performance-monitoring systems linking project management practices, resource utilization, technological capabilities, stakeholder engagement, and contextual exposure with measurable project outcomes. Performance indicators should encompass schedule, cost, quality, safety, functionality, and stakeholder satisfaction, supplemented by periodic capability reassessments. Identified deficiencies should inform corrective actions, process improvement, management reviews, and organizational learning. Repeated maturity assessments should employ consistent scoring procedures and fixed reference thresholds to support meaningful comparisons over time.

7) Professional and Institutional Capability Development. Academic institutions, professional organizations, government agencies, and construction firms should develop continuing professional development initiatives aligned with the empirical domains of the proposed CEM-MF. Training programs should emphasize project governance and controls, resource optimization, digital construction management, stakeholder coordination, and contextual risk preparedness. Professional development effectiveness should be evaluated through demonstrated competency, implementation of improved management practices, and subsequent performance evidence rather than training participation alone.

8) Future Research and Framework Validation. Future investigations should examine the reproducibility, reliability, and external applicability of the proposed CEM-MF through independent datasets, expert evaluation, organizational pilot studies, and longitudinal assessments. Particular attention should be directed toward validating the empirical maturity boundaries, examining within-organization agreement, assessing the stability of capability classifications, and establishing their relationships with independently verified project performance indicators. Further studies may employ probability-based sampling where feasible, incorporate broader geographical and institutional contexts, and investigate whether capability improvements are associated with subsequent changes in construction project outcomes. Replication across other Philippine regions and international construction environments may also establish the framework's contextual adaptability and potential contribution to broader construction engineering management scholarship.

ABBREVIATIONS

AI: Artificial Intelligence; AVE: Average Variance Extracted; BIM: Building Information Modelling; CEM: Construction Engineering Management; CEM-MF: Construction Engineering Management Maturity Framework; CR: Composite Reliability; EI: External Influences; HTMT: Heterotrait–Monotrait Ratio; IoT: Internet of Things; MICOM: Measurement Invariance of Composite Models; OLS: Ordinary Least Squares; PLS-MGA: Partial Least Squares Multi-Group Analysis; PLS-SEM: Partial Least Squares Structural Equation Modelling; PMP: Project Management Practices; PS: Project Success; Q^2: Predictive Relevance; R^2: Coefficient of Determination; RBV: Resource-Based

View; RM: Resource Management; SE: Stakeholder Engagement; SEM: Structural Equation Modelling; SRMR: Standardized Root Mean Square Residual; TI: Technological Integration; TOC: Theory of Constraints; VIF: Variance Inflation Factor.

Declarations

In accordance with the journal's reporting requirements and established principles of research transparency and academic integrity, the relevant declarations concerning funding, competing interests, ethical approval and consent, publication consent, data, materials and code availability, and author contributions are presented in the succeeding subsections.

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Conflict of Interests or Competing Interests

The authors declare that they have no conflict of interest or competing interests.

Ethics Approval and Consent to Participate

Ethical clearance for this study was obtained from the University of Mindanao Ethics Review Committee (UMERC) prior to full implementation (UMERC Protocol No. UMERC-2026-042, Protocol Version No. 1). Informed consent was obtained from all 309 respondents prior to their participation. Respondents were informed of the purpose of the study, the voluntary nature of participation, the confidentiality of their responses, and their right to withdraw without penalty. The collected data were handled confidentially, de-identified, and reported in aggregate form to protect participants' identities.

Consent for Publication

Not applicable. The manuscript does not include identifiable individual participant information, photographs, or other materials requiring separate consent for publication.

Data Availability

The datasets generated and/or analysed during the current study are not publicly available because of confidentiality commitments made to participants. De-identified research data may be requested from the corresponding author, subject to the scope of informed consent and applicable institutional policies governing data disclosure. The survey instrument and scoring procedures are described in the appendices; additional non-identifying materials may be available upon reasonable request under the same restrictions.

Materials Availability

The research instrument and the scoring and classification procedures are described in the manuscript appendices. Additional non-identifying study materials may be requested from the corresponding author, subject to applicable institutional permissions and restrictions.

Code Availability

The original pooled model was analysed using SmartPLS 4. Independent Python code was used to reproduce the archived algorithm estimates and run 5,000 participant-level bootstrap sensitivity analyses, including BCa confidence intervals, HTMT intervals, and nonparametric sector comparisons. The computational scripts are not held in a public repository; they may be requested from the corresponding author, where permissible under institutional policy. The original participant-level dataset is not included in distributed code.

Authors' Contributions

Sophia Gold G. Comendador (SGGC), as the corresponding author, contributed to the conceptualization and methodological development of the study, preparation of the research instrument, investigation, data collection and management, formal analysis, interpretation of findings, development of the proposed Construction Engineering Management Maturity Framework (CEM-MF), and preparation of the original manuscript.

Marie Fe Y. Lacsado (MFYL), as the co-author, provided research supervision, methodological guidance, substantive scholarly review, and constructive recommendations that contributed to the refinement of the research framework and manuscript. Both authors reviewed and approved the final manuscript for submission.

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APPENDIX A

PROCEDURAL COMPUTATION – BASIS FOR THE PROPOSED CONSTRUCTION ENGINEERING MANAGEMENT MATURITY FRAMEWORK (CEM-MF)

Appendix A sets out the computational basis for the proposed Construction Engineering Management Maturity Framework (CEM-MF), establishing a reproducible analytical sequence from the numerical coding of questionnaire responses to the derivation of respondent-level construct means, the construction of an overall internal capability index, and the application of empirically derived classification boundaries. In addition, it explains the separate treatment of External Influences (EI), the use of common percentile thresholds for public–private sector comparisons, and the procedures for summarizing the resultant capability classifications.

The framework was developed for the 309 construction professionals represented in the Region XIII (Caraga) survey, comprising 157 respondents associated with the public sector and 152 associated with the private sector. Accordingly, the resulting classification intervals are referenced to the pooled empirical distribution of this sample. They constitute proposed descriptive benchmarks rather than independently established or universally transferable standards of organizational maturity. In methodological terms, the capability-scoring procedure is distinct from the partial least squares structural equation modelling (PLS-SEM) analysis through which the relationships between the five predictors and Project Success (PS) were examined.

A1. Overview of the Respondent-Level Computation Procedure

The CEM-MF was operationalized through a sequential procedure encompassing response coding, construct-level score computation, composite index formation, percentile calibration, capability classification, and sector-specific aggregation. Throughout the initial stages, each construction professional served as an independent scoring unit for descriptive purposes; sector-level summaries were derived only after the corresponding respondent-level values had been established. This sequence safeguards the distinction between the measurement of individual perceptions and subsequent characterization of groups of respondents.

Table A.1 provides a consolidated account of the computational stages and their associated data requirements. In particular, it delineates the construction of the four internal capability domains, the treatment of EI and PS as analytically separate variables, and the application of the same pooled classification boundaries to public- and private-sector respondents.

TABLE A.1 SUMMARY OF THE RESPONDENT-LEVEL SCORING, COMPUTATION, AND CLASSIFICATION PROCEDURES FOR THE CONSTRUCTION ENGINEERING MANAGEMENT MATURITY FRAMEWORK (CEM-MF)

Step	Computation	Formula / Rule	Data Used	Output / Evidence
1	Code questionnaire responses	Strongly Agree = 5; Agree = 4; Neutral = 3; Disagree = 2; Strongly Disagree = 1	Approved questionnaire	Numeric item scores (1–5)
2	Compute PMP mean per respondent	Mean of 10 PMP item ratings	$PMP_{1.1}$–$PMP_{5.2}$	One PMP score per respondent
3	Compute RM mean per respondent	Mean of 10 RM item ratings	$RM_{1.1}$–$RM_{5.2}$	One RM score per respondent
4	Compute TI mean per respondent	Mean of 10 TI item ratings	$TI_{1.1}$–$TI_{5.2}$	One TI score per respondent
5	Compute SE mean per respondent	Mean of 10 SE item ratings	$SE_{1.1}$–$SE_{5.2}$	One SE score per respondent

6	Compute EI mean per respondent	Mean of 10 EI item ratings	$EI_{1.1}$–$EI_{5.2}$	One EI exposure score per respondent
7	Compute overall internal CEM-MF score	(PMP + RM + TI + SE) / 4	Four internal construct means	Overall respondent capability score
8	Exclude EI from internal composite	Do not include EI in CEM-MF average	EI measures contextual pressure	EI retained separately
9	Exclude Project Success	Do not include PS in maturity score	$PS_{1.1}$–$PS_{5.2}$	PS remains outcome variable
10	Pool respondent-level scores	Sort all 309 scores separately for each measure	N = 309	Pooled reference distributions
11	Calculate empirical cut-points	Obtain P20, P40, P60, and P80	Pooled respondent scores	Four boundaries per measure
12	Assign levels 1–5	L1 ≤ P20; L2 (P20,P40]; L3 (P40,P60]; L4 (P60,P80]; L5 > P80	Construct/overall means	Empirical capability classification
13	Classify EI separately	Same percentile rule; external influence intensity labels	EI respondent means	Very Low to Very High EI
14	Apply common sector benchmark	Apply pooled cut-points to both sectors	Public n = 157; Private n = 152	Comparable sector classifications
15	Compute sector means	Sector mean = total score / sector n	Respondent scores by sector	Public/private construct profile
16	Compute level frequencies	Count respondents in each numerical interval	Respondent-level classifications	Frequency in Levels 1–5
17	Compute level percentages	(Level frequency / sector n) × 100	Frequency and sector n	Sector level distributions
18	Reassessment rule	Reuse unchanged pooled thresholds in follow-up assessments	Later assessment scores	Comparable score change over time

As established in Table A.1, percentile classification was undertaken only after computing the relevant respondent-level scores. Consequently, the stages describing group means and category frequencies do not redefine the underlying maturity index; rather, they provide supplementary summaries of the individual classifications for the two sectors.

A2. Raw Indicator to Construct Calculations

The quantitative instrument comprises five exogenous constructs, each represented by ten questionnaire statements arranged into five indicator pairs. Responses were coded on a five-point ordered scale, with 1 corresponding to Strongly Disagree and 5 to Strongly Agree. For the purposes of the proposed CEM-MF, item values within each construct were assigned equal arithmetic weights, and the respondent-specific score was calculated as the mean of those values. Under the assumption that all ten item responses are available, the computations for respondent i are specified in (A.1)–(A.5).

$$\overline{PMP}_i = \frac{\sum_{j=1}^{10} PMP_{ij}}{10} \quad \text{(A.1)}$$

$$\overline{RM}_i = \frac{\sum_{j=1}^{10} RM_{ij}}{10} \quad \text{(A.2)}$$

$$\overline{TI}_i = \frac{\sum_{j=1}^{10} TI_{ij}}{10} \quad \text{(A.3)}$$

$$\overline{SE}_i = \frac{\sum_{j=1}^{10} SE_{ij}}{10} \quad \text{(A.4)}$$

$$\overline{EI}_i = \frac{\sum_{j=1}^{10} EI_{ij}}{10} \quad \text{(A.5)}$$

In these expressions, i indexes the respondent, while j indexes the ten questionnaire indicators in the sequence 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2, 5.1, and 5.2. Thus, each construct mean represents a within-domain aggregation of the respondent's coded assessments and remains bounded between 1.00 and 5.00. Because each item is integer-valued, a mean obtained from ten complete, equally weighted responses

can vary only in increments of 0.10. This arithmetic property also establishes an important validity check for subsequently presented respondent-level examples.

Although the EI mean is computed using the same arithmetic procedure, its conceptual meaning differs from that of the internal management capabilities. Specifically, an increase in EI denotes a higher reported intensity of external conditions or pressures rather than an improvement in organizational capability. It is therefore retained as a separate contextual measure in the ensuing calculations.

A.3. Derivation of the Overall Internal CEM-MF Capability Index

Following the computation of the individual construct means, the proposed overall CEM-MF index was obtained by aggregating the four internal dimensions: Project Management Practices, Resource Management, Technological Integration, and Stakeholder Engagement. Each dimension contributed an equal one-fourth share to the composite, thereby providing a transparent measure of internal capability without introducing weights derived from the structural path coefficients. The respondent-level index is expressed in (A.6).

$$M_{CEM,i} = \frac{\overline{PMP}_i + \overline{RM}_i + \overline{TI}_i + \overline{SE}_i}{4} \quad \text{(A.6)}$$

External Influences was deliberately excluded because the construct represents contextual exposure, whereas Project Success was excluded because it constitutes the endogenous outcome of the PLS-SEM model. Accordingly, the index describes the combined level of four internal management domains and must not be construed as an empirically optimized prediction equation for project success. Under complete integer-scored responses, each of the four construct means changes by $\Delta\overline{X} = \frac{1}{10} = 0.10$ so the equal-weight composite changes in theoretical increments of $\Delta M_{CEM} = \frac{0.10}{4} = 0.025$.

This distinction is central to the interpretation of the proposed maturity framework: standardized PLS-SEM coefficients estimate conditional associations between constructs, while the CEM-MF composite is a deliberately defined descriptive scoring rule. The latter is therefore not a substitute for the former, and neither should be interpreted as providing organization-level certification without further validation.

A.4. Empirical Percentile Computation

To establish score intervals that reflected the distribution of capability assessments in the study sample, the 309 respondent-level values for each measured domain and for the overall internal CEM-MF index were considered separately. Four reference points corresponding:

$$P_{20},\ P_{40},\ P_{60},\ P_{80}$$

were used to delineate five ordered categories. The use of pooled distributions provides a common descriptive benchmark across sector groups, rather than generating different thresholds for public- and private-sector respondents.

The boundaries are summarized in Table A.2. These figures are sample-dependent percentile values and should be interpreted as empirical reference points rather than normative minimum performance requirements. In particular, repeated observations at identical scale scores may produce uneven frequencies across the five categories, even when the intended reference points are quintiles.

TABLE A.2 POOLED EMPIRICAL PERCENTILE BOUNDARIES (N=309)

Measure	P20	P40	P60	P80
PMP	3.00	3.20	3.70	4.00
RM	3.00	3.30	3.80	4.10
TI	2.90	3.20	3.80	4.00
SE	3.00	3.20	3.80	4.10
EI intensity	2.90	3.30	3.80	4.10
Overall CEM-MF	3.000	3.125	3.875	4.050

The pooled percentiles displayed in Table A.2 were verified by applying the linear-interpolation empirical quantile definition (NumPy method="linear") to the original 309 respondent-level item means and four-domain composite scores. The cut-points are reference-sample descriptive summaries; they require external validation before operational certification or wider transfer.

A.5. Five-Level Classification Rules

On the basis of the pooled percentile boundaries, the proposed CEM-MF defines five ascending internal capability categories: Emerging (Level 1), Developing (Level 2), Established (Level 3), Advanced (Level 4), and Optimized (Level 5). Classification is undertaken separately for each internal domain and for the overall composite, using the boundaries appropriate to the measure being evaluated. For an individual score x, the lowest category includes scores up to and including the 20th-percentile boundary; subsequent categories are open at the preceding boundary and closed at their upper boundary, with the final category extending to the scale maximum of 5.00.

More formally, Level 1 comprises $1.00 \leq x \leq P20$, Level 2 comprises $P20 < x \leq P40$, Level 3 comprises $P40 < x \leq P60$, Level 4 comprises $P60 < x \leq P80$, and Level 5 comprises $P80 < x \leq 5.00$. These mutually exclusive intervals ensure that a score equal to a boundary is assigned unambiguously to the lower of the two adjoining levels. The numerical decision matrix resulting from this convention is presented in Table A.3.

TABLE A.3 CONSTRUCT-SPECIFIC EMPIRICAL CEM-MF DECISION MATRIX

Measure	Level 1	Level 2	Level 3	Level 4	Level 5
PMP	$1.00 \leq x \leq 3.00$	$3.00 < x \leq 3.20$	$3.20 < x \leq 3.70$	$3.70 < x \leq 4.00$	$4.00 < x \leq 5.00$
RM	$1.00 \leq x \leq 3.00$	$3.00 < x \leq 3.30$	$3.30 < x \leq 3.80$	$3.80 < x \leq 4.10$	$4.10 < x \leq 5.00$
TI	$1.00 \leq x \leq 2.90$	$2.90 < x \leq 3.20$	$3.20 < x \leq 3.80$	$3.80 < x \leq 4.00$	$4.00 < x \leq 5.00$
SE	$1.00 \leq x \leq 3.00$	$3.00 < x \leq 3.20$	$3.20 < x \leq 3.80$	$3.80 < x \leq 4.10$	$4.10 < x \leq 5.00$
Overall CEM-MF	$1.000 \leq x \leq 3.000$	$3.000 < x \leq 3.125$	$3.125 < x \leq 3.875$	$3.875 < x \leq 4.050$	$4.050 < x \leq 5.000$

As Table A.3 indicates, the same numerical score may correspond to different capability levels depending on the construct being classified. This is a direct consequence of deriving the boundaries separately for each domain. The labels therefore signify relative standing within the respective sample-referenced score distribution and should not, by themselves, be read as externally validated developmental stages or evidence that a particular organization has achieved a certified capability level.

A.6. External Influences: Separate Intensity Classification

External Influences (EI) is calculated from its ten coded items using (A.5), but is reported as contextual exposure rather than as a fifth internal maturity capability. Higher EI scores indicate stronger reported external pressures. Whereas the CEM-MF composite concerns the four internal management capabilities, External Influences was assessed as a distinct measure of perceived contextual pressure. In this

respect, a higher EI mean indicates greater reported exposure to regulatory, economic, environmental, workforce, supply-chain, or related external constraints, rather than superior maturity. The EI score was therefore classified using its own pooled percentiles and a terminology system reflecting intensity rather than capability.

Table A.4 specifies five ordered EI bands extending from Very Low to Very High External Influence. This separate reporting structure allows the contextual conditions experienced by respondents to be examined alongside, but not incorporated into, the internal capability assessment.

TABLE A.4 EMPIRICAL EXTERNAL INFLUENCE INTENSITY CLASSIFICATION

EI Mean	Classification
$1.00 \leq x \leq 2.90$	Very Low External Influence
$2.90 < x \leq 3.30$	Low External Influence
$3.30 < x \leq 3.80$	Moderate External Influence
$3.80 < x \leq 4.10$	High External Influence
$4.10 < x \leq 5.00$	Very High External Influence

A.7. Illustrative Respondent Computation

To demonstrate the procedure without representing the calculation as an observed record, a hypothetical respondent is considered with complete construct means of PMP = 3.50, RM = 3.50, TI = 3.90, SE = 3.90, and EI = 3.90. These selected values are compatible with averages obtained from ten complete, equally weighted, integer-coded items and are used solely to illustrate the decision rules. The illustration does not add a new observation to the empirical sample.

Under the domain-specific thresholds of Table A.3, PMP = 3.50 falls within Level 3 (Established), because $3.20 < 3.50 \leq 3.70$. Similarly, RM = 3.50 is assigned to Level 3 because $3.30 < 3.50 \leq 3.80$. The TI score of 3.90 is assigned to Level 4 (Advanced), because $3.80 < 3.90 \leq 4.00$, whereas SE = 3.90 is likewise assigned to Level 4 (Advanced) within the interval $3.80 < 3.90 \leq 4.10$. The four construct means sum to 14.80, yielding an overall CEM-MF score of 3.70. The corresponding overall score is calculated as follows:

$$\mathrm{M}_{\mathrm{CEM}} = \frac{3.50 + 3.50 + 3.90 + 3.90}{4} = \frac{14.80}{4} = 3.70 \tag{A.7}$$

A.8. Application to Public and Private Sectors

The sectoral application of the framework was undertaken using the same pooled percentile boundaries derived from all 309 respondents. Thus, the 157 public-sector and 152 private-sector respondents were assessed against a common descriptive reference system. This procedure ensures that an identical individual score receives the same numerical classification irrespective of sector affiliation and avoids constructing sector-specific benchmarks that would not be directly comparable.

After the individual scores were obtained, sector-level means were calculated by summing the relevant respondent means within each group and dividing by the corresponding number of respondents. Taking PMP as an illustrative construct, the public- and private-sector means are calculated according to (A.8) and (A.9), respectively.

$$\overline{PMP}_{\mathrm{Public}} = \frac{\sum_{i=1}^{157} \overline{PMP}_i}{157} \tag{A.8}$$

$$\overline{PMP}_{\text{Private}} = \frac{\sum_{i=1}^{152} \overline{PMP}_i}{152} \quad \text{(A.9)}$$

The same aggregation procedure applies to RM, TI, SE, EI, and the overall CEM-MF. Table A.5 presents the sector-level mean values together with the empirical categories into which those group means fall. Importantly, a classification assigned to a sector mean does not signify that every respondent, or even the modal respondent, in that sector has the same level. Individual-level frequency distributions are therefore reported separately.

TABLE A.5 REPORTED SECTOR-LEVEL MEAN SCORES AND EMPIRICAL CLASSIFICATIONS

Measure	Public Mean	Public Class.	Private Mean	Private Class.
PMP	3.046	Level 2	3.955	Level 4
RM	3.046	Level 2	4.005	Level 4
TI	3.013	Level 2	3.994	Level 4
SE	3.033	Level 2	4.025	Level 4
Overall CEM-MF	3.035	Level 2	3.995	Level 4
EI intensity	4.036	High	3.046	Low

The summaries indicate that the public-sector group means for the internal domains and overall index lie within the Level 2 intervals, whereas the corresponding private-sector group means lie within Level 4. In contrast, the EI sector means correspond to High intensity for public-sector respondents and Low intensity for private-sector respondents. These are descriptive comparisons of respondent-level score aggregates; their interpretation must not be extended to statistically significant group differences without appropriate inferential tests, nor do they imply public–private differences in PLS-SEM structural path coefficients.

The public–private domain means and overall CEM-MF classifications in Table A.5 were independently reproduced from 309 matched original indicator records using equal-weight arithmetic means and linear empirical quantiles on 31 October 2026. The classifications remain sample-referenced and do not establish externally validated organizational performance or maturity categories.

A.9. Sectoral Level Frequencies, Proportions, and Reassessment

To supplement the comparison of sector-level means, individual respondents were tabulated according to their assigned overall CEM-MF classification. For each sector s and level ℓ, the observed category frequency was divided by the number of respondents within that sector and multiplied by 100 to obtain a within-sector percentage. The general calculation is expressed in (A.10).

$$\text{Percentage}_{s,\ell} = \frac{f_{s,\ell}}{n_s} \times 100 \quad \textit{(A.10)}$$

In this expression, $f_{s,l}$ denotes the number of respondents belonging to level ℓ in sector s, and n_s is the total number of respondents in that sector. Table A.6 presents the distribution of overall internal CEM-MF classifications. The percentages are rounded to one decimal place and should therefore be interpreted subject to minor rounding differences.

TABLE A.6 REPORTED OVERALL EMPIRICAL LEVEL DISTRIBUTION BY SECTOR

Sector	Level 1	Level 2	Level 3	Level 4	Level 5
Public (n = 157)	74 (47.1%)	51 (32.5%)	31 (19.7%)	0 (0.0%)	1 (0.6%)
Private (n = 152)	0 (0.0%)	0 (0.0%)	34 (22.4%)	63 (41.4%)	55 (36.2%)

Based on the frequencies, 125 of the 157 public-sector respondents, equivalent to: $\frac{74+51}{157} \times 100 = 79.6\%$, were classified in Levels 1 and 2. Conversely, 118 of the 152 private-sector respondents, equivalent to $\frac{63+55}{152} \times 100 = 77.6\%$, were classified in Levels 4 and 5. These percentages characterize the distribution of self-reported capability scores within the sampled groups and do not constitute objective

evaluations of the two sectors as institutional populations. In addition, their validity depends on the accuracy of the respondent-level classifications from which the frequencies were generated.

For prospective reassessment, the initial pooled cut-points should be retained when the analytical objective is to evaluate change against an unchanged empirical baseline. Recalculating quintile boundaries at each subsequent assessment would modify the reference standard and could obscure whether differences in assigned levels reflect genuine score changes or merely shifts in the comparison distribution. Accordingly, the use of fixed original cut-points is recommended for longitudinal comparability, while any adaptation of the framework for organization-level auditing would require independent validation of its measurement properties, aggregation procedures, and contextual applicability.

A.10 Computational Interpretation and Reproducibility

Taken together, the preceding procedures establish a transparent computational pathway connecting the study questionnaire to the proposed CEM-MF categories. The approach preserves the analytical distinction between respondent-reported internal capability, contextual exposure, the outcome construct Project Success, and the PLS-SEM model used to examine their statistical relationships. Moreover, its common percentile reference provides a consistent descriptive basis for comparing individual and sector-level score profiles within the achieved sample.

The resulting five-level classifications should therefore be understood as proposed, sample-referenced diagnostic categories, rather than as validated evidence of developmental progression or universal organizational competence. Replication of the specific numerical thresholds and sector results requires access to the complete 309-record dataset, the instrument coding key, the stated percentile-estimation convention, and the procedures used to manage incomplete or otherwise ineligible responses. These requirements delimit the evidentiary reach of the present appendix while enabling its computational rules to be examined and, where appropriate, independently reproduced.

APPENDIX B

ADOPTED AND CONTEXTUALIZED SURVEY QUESTIONNAIRE

General Instructions

This survey is designed to assess the relationships between key project management factors and project outcomes in construction agencies and firms across **Region XIII (Caraga)**. Please read each statement carefully and indicate your level of agreement using the **5-point Likert scale** below, marking **[✓]** in the box that best represents your answer:

Scale	[5]	[4]	[3]	[2]	[1]
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

Section I – Respondent Profile

Variable	Response Options				
Gender	☐ [1] Male	☐ [2] Female			
Age	☐ [1] 21–30	☐ [2] 31–40	☐ [3] 41–50	☐ [4] 51+	
Position/Designation	☐ [1] Top Management (Director, CEO, Dean)	☐ [2] Middle Management (Project Manager, Dept Head)	☐ [3] Technical/Professional (Engineer, Architect)	☐ [4] Academic (Professor, Instructor)	☐ [5] Support Staff (CAD, Assistant, Clerk)
Sector	☐ [1] Public	☐ [2] Private			
Years of Experience	☐ [1] <5	☐ [2] 5–10	☐ [3] 11–15	☐ [4] 16–20	☐ [5] >20
Highest Educational Attainment	☐ [1] Undergraduate Degree (e.g., BS or equivalent undergraduate qualification)	☐ [2] Master's Degree (e.g., MS, MEng, or equivalent postgraduate qualification)	☐ [3] Doctoral Degree (e.g., PhD, DEng, or equivalent terminal degree)		
Province (Work Location)	☐ [1] Agusan del Norte	☐ [2] Agusan del Sur	☐ [3] Surigao del Norte	☐ [4] Surigao del Sur	☐ [5] Dinagat Islands
Type of Project	☐ [1] Vertical	☐ [2] Horizontal	☐ [3] Residential	☐ [4] Commercial	☐ [5] Institutional	☐ [6] Industrial

Section II – Project Management Practices (PMP)

Code	Indicator	5	4	3	2	1
PMP_1	**Scope Definition & CPM Scheduling**					
$PMP_1.1$	Project goals and deliverables are clearly defined at the outset.	☐	☐	☐	☐	☐
$PMP_1.2$	Project scheduling and time-management practices are systematically applied.	☐	☐	☐	☐	☐
PMP_2	**Risk Control & QA/QC**					
$PMP_2.1$	Risk management strategies are actively implemented throughout the project.	☐	☐	☐	☐	☐
$PMP_2.2$	Quality assurance processes are embedded in each phase of project execution.	☐	☐	☐	☐	☐
PMP_3	**Progress Monitoring & Corrective Control**					
$PMP_3.1$	Project monitoring and evaluation systems are in place and regularly used.	☐	☐	☐	☐	☐
$PMP_3.2$	Corrective actions are promptly implemented when deviations from the plan occur.	☐	☐	☐	☐	☐
PMP_4	**Site Coordination & Trade Interface**					
$PMP_4.1$	Communication among project teams is consistently effective.	☐	☐	☐	☐	☐
$PMP_4.2$	Coordination with subcontractors and suppliers is well-managed and scheduled.	☐	☐	☐	☐	☐
PMP_5	**Project Governance & Documentation Control**					
$PMP_5.1$	Leadership decisions are based on performance indicators and evidence.	☐	☐	☐	☐	☐
$PMP_5.2$	Project documentation is consistently prepared and maintained.	☐	☐	☐	☐	☐

Section III – Resource Management (RM)

Code	Indicator	5	4	3	2	1
RM_1	**Resource Allocation & Utilization Efficiency**					
$RM_1.1$	Resource allocation aligns with project priorities and strategic objectives.	☐	☐	☐	☐	☐
$RM_1.2$	Equipment, materials, and manpower are efficiently utilized.	☐	☐	☐	☐	☐
RM_2	**Financial Planning & Cost Control**					
$RM_2.1$	Financial resources are properly planned and controlled.	☐	☐	☐	☐	☐
$RM_2.2$	Resource allocation adjustments are made promptly when project needs change.	☐	☐	☐	☐	☐

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Section III – Resource Management (RM)							
Code	**Indicator**	**5**	**4**	**3**	**2**	**1**
RM_3	**Resource Availability & Shortage Mitigation**					
$RM_{3.1}$	Resource shortages are identified and promptly resolved.	☐	☐	☐	☐	☐
$RM_{3.2}$	Procurement processes are timely and ensure the availability of required materials.	☐	☐	☐	☐	☐
RM_4	**Workforce Competency & Capacity Development**					
$RM_{4.1}$	Staff training and capacity-building programs are regularly implemented.	☐	☐	☐	☐	☐
$RM_{4.2}$	Workforce competency is assessed before assigning tasks.	☐	☐	☐	☐	☐
RM_5	**Equipment & Inventory Control Systems**					
$RM_{5.1}$	Equipment maintenance is scheduled and performed to avoid delays.	☐	☐	☐	☐	☐
$RM_{5.2}$	Inventory management systems help track usage and prevent wastage.	☐	☐	☐	☐	☐
Section IV – Technological Integration (TI)							
Code	**Indicator**	**5**	**4**	**3**	**2**	**1**
TI_1	**Digital Planning & BIM Integration**					
$TI_{1.1}$	The organization uses BIM or project management software during planning.	☐	☐	☐	☐	☐
$TI_{1.2}$	The integration of new technologies improves coordination and performance.	☐	☐	☐	☐	☐
TI_2	**Data-Driven Decision Support Systems**					
$TI_{2.1}$	AI or data analytics tools assist in project decision-making.	☐	☐	☐	☐	☐
$TI_{2.2}$	Digital tools support real-time monitoring of project progress.	☐	☐	☐	☐	☐
TI_3	**Systems Interoperability & Digital Infrastructure**					
$TI_{3.1}$	Technological systems are compatible across teams and departments.	☐	☐	☐	☐	☐
$TI_{3.2}$	The organization invests in upgrading software and digital systems.	☐	☐	☐	☐	☐
TI_4	**Digital Competency & Training Systems**					
$TI_{4.1}$	Adequate digital training is provided for technical staff.	☐	☐	☐	☐	☐
$TI_{4.2}$	Construction documentation is digitized and easily accessible.	☐	☐	☐	☐	☐
TI_5	**Technology-Enabled Coordination & Error Reduction**					
$TI_{5.1}$	Technology reduces errors or rework during project execution.	☐	☐	☐	☐	☐
$TI_{5.2}$	The use of digital tools improves coordination with suppliers and subcontractors.	☐	☐	☐	☐	☐
Section V – Stakeholder Engagement (SE)							
Code	**Indicator**	**5**	**4**	**3**	**2**	**1**
SE_1	**Stakeholder Participation & Planning Integration**					
$SE_{1.1}$	Stakeholders are involved in project planning and execution.	☐	☐	☐	☐	☐
$SE_{1.2}$	Stakeholder participation enhances project credibility and outcomes.	☐	☐	☐	☐	☐
SE_2	**Stakeholder Communication & Alignment Mechanisms**					
$SE_{2.1}$	Regular stakeholder meetings are conducted to align expectations.	☐	☐	☐	☐	☐
$SE_{2.2}$	Communication with stakeholders is timely and clearly documented.	☐	☐	☐	☐	☐
SE_3	**Conflict Resolution & Issue Management**					
$SE_{3.1}$	Conflict-resolution mechanisms are transparent and effective.	☐	☐	☐	☐	☐
$SE_{3.2}$	Stakeholder concerns are addressed within reasonable timeframes.	☐	☐	☐	☐	☐
SE_4	**Feedback Integration & Change Communication**					
$SE_{4.1}$	Feedback from clients and end-users is systematically utilized.	☐	☐	☐	☐	☐
$SE_{4.2}$	Stakeholders are informed of project changes in a systematic manner.	☐	☐	☐	☐	☐
SE_5	**Institutional Coordination & External Linkages**					
$SE_{5.1}$	Collaboration with LGUs and regulatory agencies is well-coordinated.	☐	☐	☐	☐	☐
$SE_{5.2}$	Stakeholder engagement activities contribute to smoother project implementation.	☐	☐	☐	☐	☐
Section VI – Project Success (PS)							
Code	**Indicator**	**5**	**4**	**3**	**2**	**1**
PS_1	**Schedule & Cost Performance**					
$PS_{1.1}$	The project was completed within the planned schedule.	☐	☐	☐	☐	☐
$PS_{1.2}$	The project remained within the approved budget.	☐	☐	☐	☐	☐
PS_2	**Quality Compliance & Defect Minimization**					
$PS_{2.1}$	The project met all required quality and performance standards.	☐	☐	☐	☐	☐
$PS_{2.2}$	The project was delivered with minimal rework or defects.	☐	☐	☐	☐	☐
PS_3	**Client & End-User Satisfaction**					

Section VI – Project Success (PS)						
Code	**Indicator**	**5**	**4**	**3**	**2**	**1**
$PS_{3}.1$	The project achieved high levels of client satisfaction.	□	□	□	□	□
$PS_{3}.2$	The end-users or beneficiaries expressed satisfaction with the outcomes.	□	□	□	□	□
PS_4	**Functional Performance & Operational Value**					
$PS_{4}.1$	The project contributed to long-term operational improvements.	□	□	□	□	□
$PS_{4}.2$	The project achieved its intended functional objectives.	□	□	□	□	□
PS_5	**Safety Performance & Project Value Optimization**					
$PS_{5}.1$	Safety standards were consistently met throughout the project.	□	□	□	□	□
$PS_{5}.2$	The project provided value relative to cost, time, and quality.	□	□	□	□	□

Section VII – External Influences (EI)						
Code	**Indicator**	**5**	**4**	**3**	**2**	**1**
EI_1	**Regulatory & Political Environment**					
$EI_{1}.1$	Government regulations significantly affect project timelines.	□	□	□	□	□
$EI_{1}.2$	Political factors disrupt project continuity.	□	□	□	□	□
EI_2	**Economic Conditions & Market Dynamics**					
$EI_{2}.1$	Economic conditions influence material and labor costs.	□	□	□	□	□
$EI_{2}.2$	Market competition affects procurement and performance.	□	□	□	□	□
EI_3	**Environmental & Climatic Impacts**					
$EI_{3}.1$	Environmental conditions influence construction scheduling.	□	□	□	□	□
$EI_{3}.2$	Weather disturbances frequently delay construction activities.	□	□	□	□	□
EI_4	**Labor Market & Resource Availability**					
$EI_{4}.1$	Availability of skilled labor is affected by regional economic activities.	□	□	□	□	□
$EI_{4}.2$	Fluctuations in material supply impact project progress.	□	□	□	□	□
EI_5	**Community & Approval Constraints**					
$EI_{5}.1$	Community-related issues affect timelines.	□	□	□	□	□
$EI_{5}.2$	Regulatory approval processes significantly influence project scheduling.	□	□	□	□	□

Appendix C. Complete Reflective Measurement Diagnostics

Source-verified individual item outer and cross-loadings for all six original reflective domains (N = 309). The bolded diagnostic conclusion is that all 60 intended outer loadings are below 0.70. Cross-loadings reproduce the archived pooled algorithm to numerical precision; they do not establish discriminant validity. The full 15-pair HTMT BCa results appear in Supplementary Table S1 and Fornell–Larcker values in Supplementary Table S2.

Indicator	PMP	RM	TI	SE	EI	PS
EI1.1	-0.447	-0.497	-0.483	-0.452	+0.619	-0.457
EI1.2	-0.424	-0.424	-0.480	-0.408	+0.593	-0.430
EI2.1	-0.390	-0.437	-0.425	-0.391	+0.581	-0.449
EI2.2	-0.449	-0.453	-0.453	-0.467	+0.624	-0.487
EI3.1	-0.449	-0.496	-0.481	-0.461	+0.629	-0.472
EI3.2	-0.393	-0.480	-0.494	-0.478	+0.638	-0.508
EI4.1	-0.443	-0.465	-0.437	-0.501	+0.628	-0.489
EI4.2	-0.430	-0.434	-0.417	-0.401	+0.562	-0.455
EI5.1	-0.458	-0.469	-0.462	-0.414	+0.592	-0.432
EI5.2	-0.405	-0.380	-0.413	-0.379	+0.564	-0.428
PMP1.1	+0.619	+0.471	+0.459	+0.424	-0.391	+0.463
PMP1.2	+0.596	+0.429	+0.451	+0.458	-0.413	+0.460
PMP2.1	+0.596	+0.446	+0.437	+0.426	-0.441	+0.441
PMP2.2	+0.527	+0.389	+0.391	+0.414	-0.341	+0.410
PMP3.1	+0.628	+0.522	+0.516	+0.529	-0.455	+0.509
PMP3.2	+0.592	+0.437	+0.499	+0.462	-0.461	+0.481
PMP4.1	+0.532	+0.381	+0.408	+0.430	-0.384	+0.411
PMP4.2	+0.572	+0.415	+0.444	+0.406	-0.440	+0.447
PMP5.1	+0.513	+0.398	+0.347	+0.431	-0.313	+0.398
PMP5.2	+0.539	+0.443	+0.463	+0.449	-0.408	+0.432
PS1.1	+0.466	+0.502	+0.464	+0.453	-0.508	+0.613
PS1.2	+0.428	+0.474	+0.461	+0.412	-0.442	+0.543
PS2.1	+0.452	+0.449	+0.430	+0.475	-0.424	+0.540
PS2.2	+0.446	+0.440	+0.451	+0.425	-0.433	+0.576
PS3.1	+0.443	+0.495	+0.476	+0.474	-0.431	+0.576
PS3.2	+0.449	+0.511	+0.509	+0.487	-0.476	+0.624

PS4.1	+0.469	+0.495	+0.480	+0.412	-0.416	+0.568
PS4.2	+0.412	+0.408	+0.460	+0.413	-0.401	+0.588
PS5.1	+0.413	+0.411	+0.450	+0.467	-0.427	+0.571
PS5.2	+0.568	+0.535	+0.531	+0.531	-0.504	+0.646
RM1.1	+0.453	+0.618	+0.470	+0.499	-0.447	+0.481
RM1.2	+0.476	+0.624	+0.495	+0.469	-0.456	+0.489
RM2.1	+0.429	+0.533	+0.459	+0.415	-0.405	+0.443
RM2.2	+0.438	+0.575	+0.405	+0.428	-0.406	+0.429
RM3.1	+0.371	+0.532	+0.373	+0.377	-0.382	+0.438
RM3.2	+0.439	+0.582	+0.460	+0.506	-0.435	+0.491
RM4.1	+0.453	+0.592	+0.467	+0.482	-0.451	+0.471
RM4.2	+0.443	+0.624	+0.505	+0.500	-0.454	+0.500
RM5.1	+0.444	+0.544	+0.450	+0.490	-0.486	+0.466
RM5.2	+0.468	+0.589	+0.465	+0.422	-0.451	+0.493
SE1.1	+0.528	+0.508	+0.537	+0.645	-0.502	+0.535
SE1.2	+0.482	+0.466	+0.489	+0.627	-0.436	+0.496
SE2.1	+0.391	+0.495	+0.426	+0.605	-0.417	+0.447
SE2.2	+0.441	+0.437	+0.390	+0.569	-0.379	+0.420
SE3.1	+0.380	+0.442	+0.462	+0.556	-0.381	+0.390
SE3.2	+0.505	+0.530	+0.465	+0.606	-0.490	+0.500
SE4.1	+0.480	+0.466	+0.444	+0.599	-0.436	+0.481
SE4.2	+0.442	+0.446	+0.482	+0.589	-0.416	+0.430
SE5.1	+0.414	+0.429	+0.423	+0.529	-0.392	+0.409
SE5.2	+0.489	+0.441	+0.512	+0.574	-0.404	+0.466
TI1.1	+0.504	+0.484	+0.637	+0.469	-0.496	+0.525
TI1.2	+0.472	+0.442	+0.570	+0.454	-0.431	+0.462
TI2.1	+0.470	+0.427	+0.544	+0.453	-0.464	+0.444
TI2.2	+0.485	+0.483	+0.631	+0.505	-0.450	+0.532
TI3.1	+0.407	+0.448	+0.581	+0.407	-0.463	+0.426
TI3.2	+0.495	+0.507	+0.651	+0.528	-0.485	+0.518
TI4.1	+0.393	+0.448	+0.539	+0.470	-0.419	+0.453
TI4.2	+0.449	+0.472	+0.616	+0.448	-0.485	+0.488
TI5.1	+0.472	+0.490	+0.592	+0.478	-0.369	+0.481
TI5.2	+0.377	+0.376	+0.478	+0.372	-0.338	+0.368

APPENDIX D
CHANGED HISTORY

Version No.	Revision Date	Revision Note
Version 1.0	14 October 2026	Initial manuscript submitted and received by the journal. The manuscript underwent technical checking on the same date. An amendment was subsequently requested on 16 October 2026.
Version 1.1	17 October 2026	Amended manuscript received by the journal in response to the technical check. The submission successfully passed the technical check on 19 October 2026 and progressed to editorial assignment. An editor was assigned on 20 October 2026, followed by a request for further revision.
Version 2.0	01 November 2026	Revised manuscript submitted, incorporating amendments to the Declarations section to align its headings, sequence, and corresponding statements with the journal's prescribed requirements, including Funding, Conflict of Interest/Competing Interests, Ethics Approval and Consent to Participate, Consent for Publication, Data Availability, Materials Availability, Code Availability, and Authors' Contributions.