Developing and Validating a Next-Gen Digital Project Manager Competency Model for Construction's Digital Transformation

A thesis submitted to Auckland University of Technology in fulfilment of the requirements for the degree of

Doctor of Philosophy (PhD)

September 2025

School of Future Environment

Auckland University of Technology

By

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Abstract

The construction industry is undergoing rapid digital transformation, yet no empirically validated competency framework currently exists to guide Project Managers (PMs) in navigating this shift. Existing models are either generic or fragmented, failing to unite traditional competencies with emerging digital demands. This thesis addresses that gap by developing and validating a Next-Gen Digital PM Competency Model tailored to the Architecture, Engineering, and Construction (AEC) sector.

Adopting a five-phase mixed-methods design, the study systematically progressed from conceptual exploration to empirical validation. *First*, traditional PM competencies were identified through an intensive literature review and thematic categorisation, reaffirming their enduring relevance but also their insufficiency for digitally enabled delivery. *Second*, a Systematic Literature Review (SLR), NVivo-assisted thematic analysis, and Large Language Model (LLM) synthesis produced a standardised list of 55 digital competencies across skills, knowledge, and core personality traits, refined through expert validation. *Third*, these competencies were integrated into a taxonomy, distinguishing between unchanged, digitally enhanced, and newly emerged competencies. *Fourth*, the taxonomy was empirically tested through a survey of AEC professionals, with Exploratory Factor Analysis (EFA) revealing seven latent constructs encompassing 25 retained items. *Finally*, Confirmatory Factor Analysis (CFA) validated the model, producing a robust framework of seven interrelated constructs with 22 retained items, demonstrating strong reliability, convergent validity, and discriminant validity. The study is conceptually grounded in international literature and empirically validated using data collected from AEC professionals in New Zealand and Australia, providing a context-specific foundation for a model that is intended to be transferable, while its validation remains grounded in this specific context.

The validated Next-Gen Digital PM Competency Model makes three contributions. *Theoretically*, it unites fragmented competency traditions into a coherent, hybridised framework that reflects the realities of digital construction. *Methodologically*, it advances competency research through a novel combination of qualitative synthesis, taxonomy development, and sequential factor analysis. *Practically*, it establishes a validated backbone that functions as a stable yet adaptable foundation. While not a final endpoint, this model provides the basis for future development of guidelines, competency assessment instruments, and self-reflection tools that enable PMs and organisations to benchmark digital readiness and identify gaps in capability, ensuring its progressive operationalisation across workforce planning, professional certification, and training.

Beyond its immediate validation, the model also serves as a research and universal backbone, consolidating evidence across competencies, methodology, taxonomy integration, and empirical factor structure. Its stability provides a common reference point for PMs, organisations, and academia, while its adaptability allows contextual tailoring to legislation, culture, and technological maturity. In this way, the model functions as both a rigorous research construct and a practical platform for deployment, charting a clear pathway toward role-specific frameworks, assessment instruments, and international uptake.

By bridging traditional strengths with emerging digital demands, this thesis delivers an empirically grounded competency backbone that equips PMs to lead and adapt to the evolving digital future of construction.

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List of Abbreviations

AACE	American Association of Cost Engineers
AEC	Architecture, Engineering, and Construction
AI	Artificial Intelligence
AMA	American Management Association
AMOS	Analysis of Moment Structures
APM	Association for Project Management
AUT	Auckland University of Technology
AUTEC	Auckland University of Technology Ethics Committee
AVE	Average Variance Extracted
BC	Before Christ
BIM	Building Information Modelling
BS	British Standard
CAD	Computer-aided design
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CIOB	Chartered Institute of Building
CPM	Critical Path Method
CR	Composite Reliability
DigComp	Digital Competence Framework
DTs	Digital Twins
e-CF	e-Competence Framework
EFA	Exploratory Factor Analysis
EI	Emotional Intelligence
EM	Expectation-Maximisation
EU	European Union
EVM	Earned Value Management
FSE	Fuzzy Synthetic Evaluation
GDP	Gross Domestic Product
GFI	Goodness-of-Fit Index
HRD	Human Resource Development

ICB	Individual Competence Baseline
ICSS	Interpersonal Communication Skills Scale
ICT	Information and Communication Technology
Industry 4.0	Fourth Industrial Revolution
IoT	Internet of Things
IPD	Integrated Project Delivery
IPMA	International Project Management Association
JCA	Job Competence Assessment
KMO	Kaiser–Meyer–Olkin
KSA	Knowledge, Skill, and Attitude
LLM	Large Language Model
LOD	levels of detail
LR	literature review
MEP	Mechanical, Electrical, and Plumbing
MLE	Maximum Likelihood Estimation
NEC	New Engineering Contract
O&M	Operation and Maintenance
PAF	Principal Axis Factoring
PAS	Publicly Available Specification
PCA	Principal Component Analysis
PERT	Program Evaluation Review Technique
PM	Project manager
PMBOK	Project Management Body of Knowledge
PMCD	Project Manager Competency Develop
PMI	Project Management Institute
PMOs	Project Management Offices
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
RMSEA	Root Mean Square Error of Approximation
ROs	Research Objectives
RQs	Research Questions

SDs	Standard Deviations
SEM	Structural Equation Modelling
SFBE	Skills Framework for the Built Environment
SFIA	Skills Framework for the Information Age
SLR	Systematic Literature Review
SPSS	IBM SPSS Statistics
SRMR	Standardised Root Mean Square Residual
TLI	Tucker–Lewis Index
UK	United Kingdom
US	United States
VDC	Virtual Design and Construction
VR	Virtual Reality
VUCA	Volatility, Uncertainty, Complexity, and Ambiguity
α	Cronbach's Alpha
Δ	delta
λ	lambda
χ^2/df	Chi-square to degrees of freedom ratio

ATTESTION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed ………………………………………

Omar A. Owais

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Chapter Number:	Chapter 3
Manuscript Title:	Evolving Project Manager Competencies in the Dynamic Construction Industry: A Comprehensive Framework for Success
Publication Status:	**Published**
Reference if published:	Owais, O. A., Poshdar, M., Ying, F., Ghaffarian Hoseini, A., & Jaafar, K. (2025b). *Evolving project manager competencies in the dynamic construction industry: A comprehensive framework for success*. In M. Sutrisna et al. (Eds.), *Creating Capacity and Capability: Embracing Advanced Technologies and Innovations for Sustainable Future in Building Education and Practice* (Lecture Notes in Civil Engineering, Vol. 562, pp. 171–182). Springer Nature Singapore. https://doi.org/10.1007/978-981-96-1181-2_14.

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Chapter Number:	Chapter 4
Manuscript Title:	From competency mapping to digital twin integration: Developing a next-gen digital project manager model for smart construction
Publication Status:	**Published**
Reference if published:	Owais, O. A., Poshdar, M., Ghaffarian Hoseini, A., Ying, F., Jaafar, K., Sarhan, S., & Sheikhkhoshkar, M. (2025c). *From competency mapping to digital twin integration: Developing a next-gen digital project manager model for smart construction*. Journal of Information Technology in Construction, 30, 1431–1458. https://doi.org/10.36680/j.itcon.2025.058.
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Chapter Number:	Chapter 4
Manuscript Title:	Digital competencies framework for project managers: Digital twins as an exemplar in the smart built environment.
Publication Status:	**Published**
Reference if published:	Owais, O. A., Poshdar, M., Ghaffarian Hoseini, A., Ying, F., Jaafar, K., Sarhan, S., & Sheikhkhoshkar, M. (2025a). *Digital competencies framework for project managers: Digital twins as an exemplar in the smart built environment*. In A. Ghaffarian Hoseini, A. Ghaffarian Hoseini, A. Rahimian, & B. Purushothaman (Eds.), *Proceedings of the International Conference on Smart and Sustainable Built Environment (SASBE 2024)* (Lecture Notes in Civil Engineering, Vol. 591, pp. 639–648). Springer Nature Singapore. https://doi.org/10.1007/978-981-96-4051-5_62.
AUTHOR SURNAME: (order as per manuscript)	**CONTRIBUTION** (May copy from the guidelines above)
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Chapter Number:	Chapter 4
Manuscript Title:	Strategic leadership for digital transformation: Mapping next-gen project manager competencies to human-centric change in construction.
Publication Status:	**Accepted for Publication**
Reference if published:	Owais, O. A., Bidhendi, A., Poshdar, M., Jaafar, K., & Berry, T.-A. (in press). *Strategic leadership for digital transformation: Mapping next-gen project manager competencies to human-centric change in construction. Proceedings of the Global Digital Innovation Conference (GDI 2025).*
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Chapter Number:	Chapter 5
Manuscript Title:	Digitally ready, competently aligned: A novel taxonomy classification of the next-gen digital project manager competency for construction.
Publication Status:	**Accepted for Publication**
Reference if published:	Owais, O. A., Poshdar, M., Ghaffarian Hoseini, A., Ghaffarian Hoseini, A., & Kineber, A. F. (in press). *Digitally ready, competently aligned: A novel taxonomy classification of the next-gen digital project manager competency for construction. Proceedings of the Global Digital Innovation Conference (GDI 2025).*
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Chapter Number:	Chapter 6
Manuscript Title:	Empirical validation of the next-gen digital project manager competency framework through exploratory factor analysis.
Publication Status:	**Published**
Reference if published:	Owais, O. A., Poshdar, M., Ghaffarian Hoseini, A., Jaafar, K., & Sarhan, S. (2026). *Empirical validation of the next-gen digital project manager competency framework through exploratory*

	factor analysis. *Smart and Sustainable Built Environment*. Advance online publication. https://doi.org/10.1108/SASBE-11-2025-0698.

AUTHOR SURNAME: (order as per manuscript)	CONTRIBUTION (May copy from the guidelines above)
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Chapter Number:	Chapter 7
Manuscript Title:	Confirmatory factor analysis of a next-gen digital project manager competency model for construction digital transformation.
Publication Status:	**Unpublished/Ready for submission for Publication**
Reference if published:	

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ACKNOWLEDGEMENTS

I would like to express my **profound and heartfelt gratitude** to my primary supervisor, **Associate Professor Mani Poshdar**, whose exceptional guidance, encouragement, and unwavering support have been the cornerstone of this doctoral journey. From the very first day, he treated me not merely as a student but as a colleague, fostering an environment of respect, trust, and collaboration that continually inspired me to excel. His mentorship, vision, and generosity of time were not only instrumental in shaping this thesis, but also in shaping me as a researcher and scholar. I could not have asked for a more dedicated and inspiring supervisor, and this achievement would not have been possible without his continuous belief in me.

My sincere thanks also go to **Professor Ali GhaffarianHoseini**, Head of the Built Environment Department and my current secondary supervisor, for his invaluable encouragement, insightful feedback, and continued support that added great strength and direction to this research. I am also especially grateful to **Dr. Fei Ying**, who served as my secondary supervisor during the first two years of this journey; her thoughtful guidance and constructive advice laid a strong foundation for the progress that followed. I further wish to acknowledge **Associate Professor Kamal Jaafar and Dr. S. Sarhan** for their valuable input, collaboration, and above all their encouragement, belief in my potential, and constant support, which enriched both the scope of this study and my confidence as a researcher.

I would like to acknowledge the **Auckland University of Technology (AUT)** for providing an intellectually stimulating research environment and the necessary resources to complete this work. I am particularly grateful for the support of the **Vice-Chancellor Doctoral Scholarship**, which enabled me to fully dedicate myself to this research.

DEDICATION

To my beloved wife, **Elize Samaan**, whose unwavering love, patience, and encouragement have been my anchor throughout this journey. You have walked beside me through every struggle, carried me with your strength when I felt weak, and reminded me to keep going when the path seemed impossible. Your sacrifices, understanding, and constant belief in me made this achievement possible, and every step of this path has been brighter because of you. This achievement is as much a celebration of your devotion as it is of my work.

To my precious daughter, **Christina Owais**, whose joy, laughter, and innocence reminded me of what truly matters in life. You are my greatest inspiration and the reason I strive to be better every day. May this work one day stand as proof of how much you motivated me, and as a reminder that this success belongs to us as a family.

To my late father, **Azmi Owais**, whose memory continues to guide and inspire me every day. I know you would be tremendously proud if you were still alive, and I carry your values, love, and strength in every step I take. Every page of this thesis carries a part of you, and I dedicate it in your honour, with the hope that I have made you proud. To my mother, **Muna**, for your endless prayers, unconditional love, and pride that carried me through the hardest moments, your faith in me has been a constant source of motivation and comfort throughout this journey. To my father-in-law, **Asaad**, and mother-in-law, **Ezdehar**, for welcoming me as a son into your family and for your encouragement and support along the way, I dedicate this achievement with deepest gratitude.

To my brothers, sisters, and extended family, thank you for your encouragement, motivation, and love. To my friends, near and far, who stood beside me with constant support and belief in my abilities, your companionship has meant more than words can capture. This thesis is dedicated to all of you who shared in my journey and lifted me when I needed it most.

Chapter 1 General Introduction

1.1 Research Background

The twenty-first century has unfolded against a backdrop of profound global transformation, where technological advancement, geopolitical shifts, and environmental imperatives are converging at unprecedented speed and scale (Schwab, 2017; Brynjolfsson & McAfee, 2014; World Economic Forum, 2023). The accelerating pace of change has disrupted established economic orders, challenged traditional business paradigms, and redefined what it means to remain competitive in the global economy. Industries are no longer evolving in isolation but are increasingly interconnected within a complex web of digital, economic, and socio-political interdependencies. The interplay between innovation, sustainability, and resilience is now a decisive factor in shaping organisational strategies, compelling leaders to rethink how value is created, delivered, and sustained in the long term.

The early decades of the twenty-first century have been defined by unprecedented technological acceleration, shifting socio-economic priorities, and mounting global challenges that demand more agile and innovative organisational responses (Schwab, 2017). Across industries, the rapid convergence of emerging technologies with complex societal needs has created both transformative opportunities and disruptive pressures. Organisations are not merely adjusting operational processes but are rethinking entire business models to thrive in environments characterised by Volatility, Uncertainty, Complexity, and Ambiguity (VUCA) (Bennett & Lemoine, 2014). The construction industry, traditionally slower to change due to its project-based and fragmented nature, is now at a critical inflection point (Shojaei & Burgess, 2022). Market competition, climate imperatives, urban population growth, and the need for more sustainable infrastructure have combined with a surge in technological capability to place digital adoption at the heart of long-term competitiveness. In parallel, globalisation has intensified the flow of capital, talent, and information, heightening competitive pressures while also enabling cross-border collaboration on an unprecedented scale. Against this backdrop, the capacity of industries to adapt to digital disruption has become a determining factor in their contribution to national economic resilience and global market relevance (Pittri et al., 2025).

The global economy itself is undergoing a profound structural shift underpinned by three interconnected concepts: digitisation, digitalisation, and digital transformation. *Digitisation* refers to the technical process of converting analogue information into a digital format, enabling efficient storage, processing, and transmission of data (Yoo et al., 2010). This foundational step has allowed industries to reduce physical record-keeping, streamline communication, and enable computational analysis on a scale previously impossible. *Digitalisation* builds upon digitisation by integrating these digital capabilities into core operational processes, fundamentally reshaping how value is created, delivered, and maintained (Parviainen et al., 2017). It is at this stage that digital tools transition from being supplementary to becoming embedded in everyday workflows, reshaping work practices and stakeholder interactions. *Digital transformation* extends the impact further, representing a strategic reorientation in which organisations leverage digital technologies to innovate, redefine competitive positioning, and adapt to emerging societal, environmental, and economic demands (Vial, 2021). This transformation is not merely technological but also cultural and organisational, requiring leadership vision, workforce reskilling, and an openness to continuous change.

These changes are closely tied to the evolution of the Fourth Industrial Revolution (Industry 4.0), a term popularised by Schwab (2017) to describe the integration of cyber-physical systems, the Internet of Things (IoT), Artificial Intelligence (AI), and advanced analytics into production and service ecosystems. Industry 4.0 emphasises automation, connectivity, and real-time decision-making across value chains, with profound implications for productivity and innovation. As adoption matures, the conversation is increasingly shifting towards Industry 5.0, a concept driven by the European Commission that places human-centricity, sustainability, and resilience at the core of future industrial systems (Breque et al., 2021). While Industry 4.0 prioritised efficiency and technological integration, Industry 5.0 reintroduces the human element as a central design principle, emphasising ethical considerations, environmental stewardship, and collaborative innovation between humans and intelligent systems. Together, these paradigms set the stage for industries, including construction, to embrace digital capabilities not just for operational gains but also for societal and environmental value creation.

For the construction industry, this transformation marks a departure from historically fragmented and labour-intensive practices towards more integrated, technology-driven approaches. The sector is being reshaped by a range of emerging technologies: Building Information Modelling (BIM) provides a shared digital representation of physical and functional characteristics of built assets; Digital Twins (DTs) enable real-time simulation and monitoring across an asset's lifecycle; generative design algorithms optimise structures for cost, performance, and sustainability; and AI-assisted project management tools forecast risks, optimise scheduling, and improve resource allocation (Succar & Kassem, 2015; Sacks et al., 2018). Such technologies are no longer experimental; they are progressively becoming embedded in project delivery frameworks worldwide, with governments and industry leaders mandating their use in public sector projects (Jin et al., 2017; Whyte, 2019). This shift requires more than tool adoption; it necessitates rethinking procurement processes, contractual arrangements, data governance, and workforce development to ensure successful digital integration (Whyte, 2019).

Project managers (PMs) in the Architecture, Engineering, and Construction (AEC) sector sit at the nexus of this change. Traditionally, PM competencies have been grounded in frameworks developed by professional bodies such as the Project Management Institute (PMI) and the International Project Management Association (IPMA), emphasising areas such as scope, schedule, and budget management; quality assurance; stakeholder engagement; and risk mitigation (PMI, 2021a, IPMA, 2015b). These competencies have underpinned successful delivery in traditional contexts for decades, but the accelerating digitalisation of construction has introduced a new set of expectations. PMs are now expected to interpret complex data analytics, manage automation workflows, ensure cybersecurity compliance, coordinate virtual collaboration platforms, and integrate sustainability metrics into decision-making. The move towards integrated digital delivery models and lifecycle asset management has expanded the PM's role into strategic domains, where value is measured not only in terms of time and cost performance but also in innovation adoption, data interoperability, and alignment with broader societal outcomes (Wuni et al., 2024; Olanrewaju et al., 2021).

Despite the recognised need for digitally competent PMs, the industry continues to face significant barriers in developing and deploying such talent effectively. Empirical studies reveal persistent skills gaps, organisational inertia, and fragmented training pathways as key inhibitors of digital adoption (Jin et al., 2017; Eadie et al., 2013). While competency models exist for both traditional PM skills and general digital skills in other sectors, there is currently no empirically validated model that fully integrates traditional project management expertise with emerging digital competencies specifically for the construction sector (Owais et al., 2025c). The complexity of the AEC environment, its multi-stakeholder nature, project-based delivery, and long asset lifecycles, means that generic digital skills frameworks cannot simply be transplanted without adaptation.

This challenge is intensified by the evolving demands of digital transformation, which place equal emphasis on human–technology collaboration, sustainability, and resilience (Breque et al., 2021). PMs are now expected to address not only technical complexities but also the ethical, cultural, and environmental considerations inherent in technology-enabled projects. This shift highlights the urgent need for a Next-Gen Digital PM Competency Model that reflects the hybrid nature of the role, integrates both traditional and emerging digital competencies, and is validated for practical application in industry settings. Without such a model, professional development risks becoming reactive, inconsistent, and misaligned with long-term strategic goals, thereby limiting the construction sector's ability to harness digital transformation as a source of competitive advantage. Empirical evidence further reinforces this need, indicating that up to 47% of project success can be attributed to the competency of the PM, underscoring their pivotal role in enhancing performance and productivity in the construction sector (Hwang & Ng; 2013; Owais et al., 2025b).

Additional empirical research further reinforces the centrality of PMs' competencies to project success across diverse contexts. For example, a study in Indonesia demonstrated that PM competencies, encompassing knowledge, skills, attitudes, and management, accounted for 94.9% of construction project performance, with management emerging as the most dominant factor (Surya et al., 2024). Similarly, evidence from the United Kingdom (UK) construction sector revealed an extremely strong correlation between PM effectiveness and project success, underscoring the decisive influence of leadership, decision-making, and interpersonal skills (Ali and Chileshe, 2009). In Pakistan, a structural equation modelling study confirmed that PM competencies ($\beta = 0.321$, $p < 0.000$) exert a significant positive effect on project success, alongside project planning, with the two together explaining 56.6% of the variance in project success (Irfan et al., 2021).

Complementing these single-context studies, a recent Systematic Literature Review (SLR) of ten empirical investigations confirmed that personal and social competencies, particularly leadership, communication, and emotional intelligence, are consistently associated with higher project success across industries and geographies (Ochoa Pacheco et al., 2023). Collectively, these findings highlight that the PM's role is not only operational but also strategically determinative of project outcomes, as consistently evidenced across the reviewed empirical studies, amplifying the urgency of developing a validated competency model tailored to the demands of digital transformation in the construction sector.

To address this gap, the present research employs a five-phase mixed-methods design. It begins with an intensive review of traditional PM competencies (Chapter 3), followed by the identification of emerging digital competencies through a systematic review, thematic analysis, and Large Language Modelling (LLM) (Chapter 4). These are integrated into a taxonomy-based framework (Chapter 5) and empirically tested through Exploratory Factor Analysis (EFA) (Chapter 6) and Confirmatory Factor Analysis (CFA) (Chapter 7). This structured approach ensures that the proposed Next-Gen Digital PM Competency Model is both theoretically grounded and empirically validated, providing a robust foundation for workforce planning, curriculum development, and professional certification in the digital era of construction.

1.2 Problem Statement

The global construction industry is undergoing an unprecedented digital transformation, driven by the rapid integration of emerging technologies such as BIM, DTs, AI, IoT, and advanced data analytics (Dave et al., 2018; Deng et al., 2021). These innovations promise significant improvements in project efficiency, sustainability, and lifecycle value. Realising these benefits demands a project management workforce equipped with a highly specialised blend of traditional leadership skills and advanced digital competencies that address the unique challenges of digital construction advancement (Olawumi & Chan, 2019; Olanrewaju et al., 2021). While digital transformation in many sectors has been supported by clearly defined digital competency frameworks (Vuorikari et al., 2022), the construction sector still relies on fragmented, generic, or technology-specific skill sets that lack integration and alignment with the complex realities of managing projects in a digital ecosystem.

In this environment, the role of the construction PM is no longer confined to overseeing scope, cost, and schedule. Instead, PMs must act as strategic integrators of people, processes, and technologies, guiding multidisciplinary teams through data-driven, collaborative, and digitally mediated workflows (Rodrigues et al., 2023; Mandičák et al., 2020). These workflows exist within complex digital construction advancement environments, where human, organisational, and technological factors are deeply interdependent. While acknowledging this context is important, the central challenge lies in ensuring PMs possess the integrated technical (skills), cognitive (knowledge), and behavioural (core personality) traits necessary to navigate such environments effectively. Despite this expanded remit, no universally accepted and empirically validated digital competency model exists specifically for PMs in the AEC sector, as highlighted in existing studies (Olanrewaju et al., 2021). This absence undermines PMs' ability to lead successful digital adoption, limits organisational readiness, and constrains the industry's capacity to achieve its full digital potential.

A review of leading digital competency frameworks highlights a consistent gap: none fully integrate the cognitive, behavioural, and technical dimensions required of PMs in digital construction environments. Over the past decade, several digital competency frameworks have been developed to guide skill development in the digital economy. These models provide useful conceptual foundations but are predominantly designed for generic workforce digital literacy, Information and Communication Technology (ICT) professionals, or sector-specific needs outside construction. Consequently, they often lack the granularity, contextualisation, and integrated technical, cognitive, and behavioural domain focus required for construction PMs.

The European Digital Competence Framework (DigComp 2.2) was developed by the European Commission to establish a common understanding of digital literacy across the European Union (EU) (Vuorikari et al., 2022). It defines five key competence areas, including information and data literacy, communication and collaboration, digital content creation, safety, and problem solving, each with proficiency levels and examples of knowledge, skills, and attitudes. While DigComp has been widely adopted in education, training, and employment policy contexts, it is inherently generic, targeting broad societal digital inclusion rather than the high-stakes, sector-specific decision-making of construction PMs. As such, it provides insufficient guidance on competencies such as BIM-enabled risk management, DT integration, or AI-assisted project planning, capabilities that are increasingly central to digital construction leadership (Dave et al., 2018).

The Skills Framework for the Information Age (SFIA) offers a structured model of professional skills for ICT, software, and digital transformation roles, organised into categories such as strategy, change, development, and delivery (SFIA Foundation, 2021). It supports workforce planning, recruitment, and capability assessment in technology-intensive environments. However, SFIA is predominantly ICT-focused, with limited integration of competencies addressing construction's complexities, such as regulatory compliance in built environments, physical-digital coordination, or multidisciplinary stakeholder engagement. Its process- and system-oriented approach provides a valuable foundation but lacks explicit adaptation for the dynamic, fragmented, and risk-intensive context of construction projects.

The European e-Competence Framework (e-CF) (EN 16234-1:2019) is a standardised reference model developed by CEN, defining ICT professional competencies across five areas: plan, build, run, enable, and manage (CEN, 2019). Sometimes referred to as the e-Competency for ICT Professionals standard, it provides detailed descriptions of ICT-related skills and knowledge areas for technology-driven roles, including some project and service management elements. While it offers a structured, role-linked framework widely used in the ICT sector, its focus on ICT systems delivery and maintenance overlooks the hybrid physical–digital nature of construction projects, the integration of emerging technologies such as DTs, and the sector's regulatory, safety-critical, and sustainability imperatives. Consequently, competencies such as lifecycle sustainability integration, human-centric change management, and digitally mediated safety planning, critical in AEC contexts, are largely absent or only indirectly addressed.

The UNESCO Digital Literacy Global Framework consolidates existing digital literacy frameworks (including DigComp) into a global reference for foundational digital skills (Law et al., 2018). Its emphasis is on equitable access, basic digital participation, and employability in the digital economy. While valuable for promoting inclusive digital skills development, its orientation towards baseline digital literacy renders it insufficient for defining the advanced, hybridised competencies required of construction PMs managing high-value, technology-intensive projects.

The Skills Framework for the Built Environment (SFBE), developed in Singapore by the Building and Construction Authority in collaboration with SkillsFuture Singapore, provides detailed information on sector roles, career pathways, and the skills and competencies required for each job role, along with corresponding training programmes (Building and Construction Authority, 2020). It addresses selected digital competencies, including BIM use and digital facility management, primarily within the context of role-based capability mapping and workforce training. However, it does not present a cohesive taxonomy integrating strategic leadership, advanced technical proficiency, and human-centric change management specifically for project management roles. Furthermore, its Singapore-specific policy and delivery context limit its direct transferability to other regions and project delivery models.

The New Zealand Digital Skills Framework seeks to build a digitally capable workforce by mapping skills across levels of proficiency, from foundational digital literacy to advanced technical skills (Hindle & Muller, 2021). While it acknowledges sectoral needs, it is primarily designed for broad national workforce development and lacks detailed, construction-specific competency mappings. Its generalised structure does not account for the layered leadership, integration, and risk oversight responsibilities unique to PMs in digital construction.

A summary comparison of the reviewed digital competency frameworks and their limitations in addressing construction PM needs is presented in Table 1.1.

Table 1.1. Comparison of selected digital competency frameworks and their applicability to construction PM roles

Framework	**Origin / Developer**	**Primary Focus**	**Strengths**	**Key Limitations for Construction PMs**
DigComp	European Commission	General digital literacy	Widely adopted, comprehensive structure	Generic, lacks sector-specific integration for PM decision-making
SFIA	SFIA Foundation	ICT and digital transformation roles	Structured skill categories, supports workforce planning	ICT-centric, minimal construction context
e-CF	CEN (EU Standard)	ICT professional competencies	Standardised, role-linked	ICT service delivery focus, lacks integration of construction workflows
UNESCO DL Global Framework	UNESCO	Foundational digital skills	Inclusive, global perspective	Baseline literacy only, not advanced PM skills
SFBE	Building and Construction Authority (Singapore)	Built environment workforce skills	Includes BIM and facility management	Role-based, lacks integrated leadership-technical taxonomy
NZ Digital Skills Framework	Digital Skills Aotearoa	National workforce development	Recognises sectoral needs	Generalised, lacks detailed PM mapping

The absence of a dedicated, empirically validated digital competency model for construction PMs has several practical consequences. First, it leads to fragmented skill development, where PMs rely on ad hoc training in isolated technologies (e.g., BIM software courses) as highlighted by Olawumi and Chan (2019), whose BIM–Project Information Management Framework stresses the need for integrated leadership and technical competencies rather than piecemeal technology training. Second, it reduces organisational readiness for digital adoption, contributing to the underutilisation of investments in DTs, AI, and automation, a challenge reflected in Matarneh et al. (2019), who found that organisations often fail to leverage BIM and related digital tools effectively due to interoperability and process integration issues. Third, it weakens the strategic positioning of PMs as digital transformation leaders, limiting their ability to influence policy, procurement, and long-term sustainability outcomes, as discussed by Whyte (2019), who emphasises that without aligned competencies, digital information innovations cannot fully transform project delivery models.

In light of these limitations, the central research problem can be clearly articulated as follows:

Problem statement: *There is currently an absence of a sector-specific, empirically validated competency framework and model for construction project managers. Existing frameworks do not adequately unite traditional competencies with emerging digital demands or respond to the transformative pressures of digital transformation in the construction sector.*

Addressing this gap requires a holistic, taxonomy-based competency framework that unites traditional PM capabilities with the emerging digital skills demanded by technology-intensive construction environments. Such a framework must be empirically validated to ensure relevance, reliability, and adaptability across diverse project contexts. This thesis meets that need by developing and validating a Next-Gen Digital PM Competency Model explicitly tailored to the realities of digital construction advancement. In doing so, it provides a robust and transferable foundation for workforce planning, professional certification, and the cultivation of sustainable digital transformation leadership in the AEC sector.

1.3 Research Questions

The rapid digital transformation of the construction industry has created a pressing need to define and validate the competencies required for PMs to lead successfully in technology-enabled project delivery environments. Existing competency frameworks are either too generic or narrowly focused on isolated technical skills, lacking the integrated skills, knowledge, and core personality dimensions necessary for digital construction. This study addresses this gap through a multi-phase research design spanning the identification of traditional competencies, the development of digital competencies, taxonomy-based integration, and empirical validation using factor analysis techniques.

The research is guided by one Primary Research Question supported by five Supporting Research Questions (RQs); each aligned with a specific phase of the study and corresponding thesis chapters. This alignment ensures a logical progression from conceptualisation to validation and application of the proposed competency model.

Primary Research Question (PRQ): *How can traditional and emerging digital project manager competencies be identified, systematically integrated into a taxonomy, and empirically validated to create a robust competency model that supports construction project managers in leading digital transformation within the AEC sector?*

The PRQ provides an overarching inquiry that guides the study, while the five supporting RQs each address a distinct component of this overarching aim. Specifically, RQ1 and RQ2 focus on the identification of traditional and emerging digital PM competencies, RQ3 examines their systematic integration into a taxonomy, and RQ4 and RQ5 address the empirical synthesis and validation of the resulting framework. Together, these supporting questions collectively respond to the PRQ by sequentially covering the stages of identification, integration, and validation. This structured alignment ensures that each chapter contributes to part of the PRQ, and that the thesis as a whole delivers a comprehensive answer to the overarching research problem.

Supporting Research Questions (RQs):

- **RQ1. Traditional competency identification (Chapter 3):** *Which traditional project manager competencies are identified in literature and professional frameworks, and how can these be categorised into skills, knowledge, and core personality traits?*
- **RQ2. Digital competency identification (Chapter 4):** *What are the emerging digital competencies required for project managers to excel in the evolving construction sector?*
- **RQ3. Integration and taxonomy development (Chapter 5):** *How can traditional and emerging digital competencies be systematically integrated into a taxonomy-based classification that reflects construction's digital transformation needs?*
- **RQ4. Empirical synthesis (Chapter 6):** *How can the integrated taxonomy of traditional and digital competencies be empirically synthesised and modelled into an initial validated framework?*
- **RQ5. Confirmatory validation (Chapter 7):** *To what extent does the proposed framework demonstrate empirical validity and alignment with the competency demands of the digitally transformed construction industry?*

The supporting RQs are intentionally structured to mirror the study's multi-phase research methodology. RQ1 and RQ2 address the identification phases through an intensive round of literature review, thematic categorisation, SLR, NVivo-assisted thematic analysis, Large Language Model (LLM) synthesis, and expert validation, ensuring that both established traditional competencies and emerging digital competencies are systematically identified, refined, and categorised into skills, knowledge, and core personality traits from academic and industry sources. RQ3 aligns with the taxonomy-based classification stage combined with comparative analysis, producing the Next-Gen Digital PM Competency List that integrates traditional and digital competencies relevant to digital construction, while also serving as a pre-validation step of the categorised competencies from the previous phases.

RQ4 reflects the empirical synthesis stage, in which the integrated taxonomy is modelled through EFA to identify latent constructs and their associated competencies, thereby producing a statistically robust competency framework. RQ5 focuses on confirmatory validation, where the EFA-derived framework is tested using CFA to establish a validated competency model aligned with industry requirements and presenting the final Next-Gen Digital PM Competency Model tailored to the needs of construction's digital transformation. Collectively, these questions guide a research pathway that delivers a rigorously validated, context-specific competency model capable of supporting workforce planning, professional certification, and sustainable digital transformation leadership in the AEC sector.

1.4 Research Aim and Objectives

This research aims *to develop and validate a sector-specific digital PM competency model tailored to the needs of the AEC sector in the context of rapid digital transformation*. The study addresses the gap created by the absence of a comprehensive, empirically validated model that integrates traditional PM competencies with emerging digital competencies, thereby enabling PMs to lead high-performing, technology-enabled project delivery.

The specific Research Objectives (ROs) of this research are as follows:

- **RO1:** *To identify traditional project manager competencies from literature and professional frameworks, and to categorise them into skills, knowledge, and core personality traits.*
- **RO2:** *To identify the emerging digital competencies required for project managers to excel in the evolving construction sector.*
- **RO3:** *To systematically integrate traditional and emerging digital competencies into a taxonomy-based classification that reflects construction's digital transformation needs.*
- **RO4:** *To empirically synthesise and model the integrated taxonomy of traditional and digital competencies into an initial validated framework.*
- **RO5:** *To confirm the empirical validity of the proposed framework and assess its alignment with the competency demands of the digitally transformed construction industry.*

These objectives are deliberately aligned with the research questions outlined in Section 1.3 and follow a multi-phase methodological structure that ensures conceptual rigour, empirical validation, and practical relevance. The outcomes will support workforce planning, professional certification, and sustainable digital transformation leadership in the AEC sector.

1.5 Rationale and Significance

The construction industry is undergoing a profound digital transformation, driven by rapid advancements in tools such as BIM, DTs, AI, and automation. These technologies are fundamentally reshaping project delivery, stakeholder collaboration, and decision-making processes. As outlined in Section 1.2, while traditional project management competencies remain relevant, they are no longer sufficient on their own for managing high-value, digitally enabled construction projects.

Despite widespread recognition of the need for digitally competent PMs, there is no empirically validated competency framework or model that unites traditional PM skills with emerging digital capabilities specifically for the AEC sector. Existing frameworks tend to focus on either generic digital skills or narrow technical abilities, overlooking the critical leadership, behavioural, and technological capabilities required to navigate construction's digital transformation effectively. This gap constrains workforce development, reduces the return on digital investments, and limits the industry's capacity to achieve sustainable innovation.

This study addresses that gap through a rigorous, multi-stage research process:

1. Identification and categorisation of traditional PM competencies, alongside the identification of emerging digital competencies relevant to construction (RO1 & RO2, aligned with RQ1 & RQ2).
2. Integration of these competencies into a structured taxonomy encompassing skills, knowledge, and core personality dimensions tailored to digital construction contexts (RO3 / RQ3).
3. Empirical synthesis of the integrated taxonomy through EFA, thereby identifying latent constructs and their associated competencies (RO4 / RQ4).
4. Confirmatory validation of the latent constructs using CFA to test model fit, construct validity, and reliability, ensuring the competency framework's empirical robustness and alignment with industry requirements (RO5 / RQ5).

By directly linking the Research Questions, Objectives, and Methodology chain, this thesis produces a robust, context-specific Next-Gen Digital PM Competency Model that is both theoretically grounded and empirically validated. The model is designed to inform workforce planning, guide professional certification, and foster digital transformation leadership in the built environment sector.

These contributions position the study as both a practical and methodological bridge between academic theory and industry application, leading naturally to the following overview of the research methodology adopted in this thesis.

1.6 Research Methodology Overview

In construction management research, methodological diversity is increasingly recognised as essential for addressing complex, multi-dimensional problems (Fellows & Liu, 2021; Amaratunga et al., 2002). While quantitative methods enable statistical testing and generalisability, qualitative approaches provide rich contextual insights, particularly in emerging areas such as digital transformation. This study adopts a five-phase, sequential mixed-methods design, combining qualitative and quantitative techniques to strengthen validity and enhance analytical depth (Johnson et al., 2007; Tashakkori & Teddlie, 2010). The sequential structure builds cumulatively across exploratory, conceptual, and confirmatory stages, ensuring both theoretical rigour and empirical robustness in developing and validating the Next-Gen Digital PM Competency Model.

The methodology comprises five interconnected phases, as illustrated in Figure 1.1, each aligned with the research questions and objectives outlined in Sections 1.3 and 1.4.

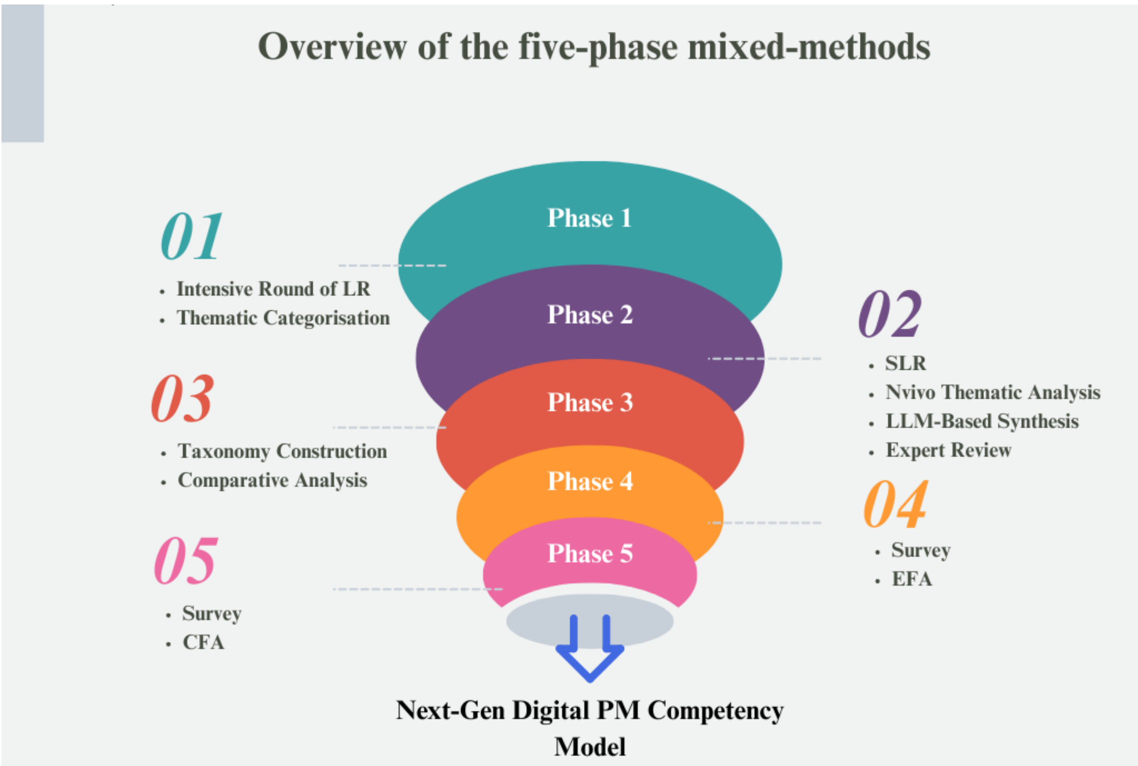

Figure 1.1: Overview of the five-phase mixed-methods research design for developing and validating the Next-Gen Digital PM Competency model.

As shown in Figure 1.1, the research progresses sequentially from the identification of competencies through qualitative methods (Phases 1 and 2), to their integration into a taxonomy (Phase 3), followed by quantitative validation using EFA and CFA (Phases 4 and 5). This structure ensures a logical flow from conceptual exploration to empirical testing, maintaining both theoretical depth and statistical robustness. The phases are as follows:

- **Phase 1. Identification of Traditional Competencies:** An intensive literature review and thematically categorise was conducted to identify and categorise traditional PM competencies recognised in the construction sector. This stage systematically sourced and synthesised peer-reviewed studies and industry reports, grouping the identified competencies into skills, knowledge, and core personality traits to establish a baseline for integration with emerging digital competencies, following best-practice guidelines for in-depth, domain-specific reviews (Snyder, 2019).
- **Phase 2. Identification of Emerging Digital Competencies:** A three-stage thematic analysis was employed, comprising a SLR, NVivo-assisted thematic analysis, and LLM-based synthesis, to identify and categorise digital competencies essential for PMs in digital construction environments (Braun & Clarke, 2006). These were organised into Skills, Knowledge, and Core Personality Traits. Draft definitions were reviewed by the research team and validated by two domain experts in construction project management and digital transformation, each with more than ten years of experience. This two-tier

validation ensured methodological transparency, thematic robustness, and professional alignment, thereby establishing the Next-Gen Digital PM Competency List.

- **Phase 3. Integration and Taxonomy Development:** Traditional and digital competencies were systematically integrated into a taxonomy-based classification following Nickerson et al. (2013), with comparative mapping techniques adapted from Hantrais (2009). This taxonomy provided a structured framework for integrating skills, knowledge, and core personality dimensions specific to digital construction, while also serving as a pre-validation step of the earlier stages.
- **Phase 4. Empirical Synthesis Using Exploratory Factor Analysis (EFA):** A survey instrument, developed from the integrated taxonomy, was administered to a purposive sample of experienced AEC professionals in New Zealand and Australia. Data was analysed using EFA to identify latent constructs underpinning digital PM competencies, thereby statistically grounding the taxonomy in empirical evidence and establishing the Next-Gen Digital PM Competency Framework (Hair Jr et al., 2010).
- **Phase 5. Model Validation Using Confirmatory Factor Analysis (CFA):** The latent constructs derived from EFA were tested using CFA to assess model fit, construct validity, and reliability (Brown, 2015; Kline, 2023). This ensured that the final Next-Gen Digital PM Competency Model was both empirically robust and practically aligned with the competency demands of the digitally transformed construction sector.

This phased approach ensured that the research progressed logically from conceptual exploration to empirical validation, producing a competency model that is both theoretically grounded and industry relevant. By combining qualitative depth with quantitative rigour, the methodology addressed the complexity of integrating traditional and emerging competencies in the context of construction's digital transformation. Each phase was directly aligned with the research questions and objectives, ensuring methodological coherence and traceability from problem identification to practical application.

The next section outlines the overall structure of the thesis, illustrating how the five methodological phases are distributed across subsequent chapters and how each contributes to addressing the primary and supporting research questions.

1.7 Scope of Study

This study focuses on the development and validation of a Next-Gen Digital PM Competency Model for the AEC industry. The study does not aim to represent the global AEC industry across all regions; rather, it is grounded in data collected from AEC professionals in New Zealand and Australia, providing a region-specific context for model development and validation. It addresses the sector's unique operational, regulatory, and cultural challenges while considering the transformative impact of technologies such as BIM, DTs, AI, and IoT. The research examines three core competency domains, Skills, Knowledge, and Core Personality Traits, emphasising their application to digital construction project management. While the scope acknowledges the importance of technical tool training, software-specific instructions, and highly specialised engineering competencies, these are only examined directly related to PM functions rather than technical execution.

PMs play a vital role in enhancing performance in the construction sector and are a key enabling element of digital transformation. In this study, the primary unit of analysis is the individual construction PM, reflecting the focus on personal competencies rather than organisational capabilities or project-level factors. The scope encompasses experienced AEC professionals, with empirical data drawn from participants in New Zealand and Australia, establishing the contextual basis for model development and validation. While participants may represent a variety of roles, sectors, and organisational sizes, these distinctions were not central to the analysis and were not used as formal sampling criteria. Instead, the emphasis is placed on identifying, integrating, and validating competencies that are broadly applicable to PMs operating in digitally enabled construction environments.

Methodologically, the study adopts a five-phase mixed-methods design, progressing from qualitative inquiry to quantitative validation. The qualitative phases involve an intensive round of literature review and thematic categorisation, SLR, NVivo-assisted thematic analysis, LLM–based synthesis, and taxonomy development supported by comparative analysis. The quantitative phases then proceed through expert validation of the competency definitions and domain assignments, followed by EFA to identify latent constructs and CFA to test model fit, construct validity, and reliability. This design ensures a logical progression from conceptual exploration to empirical testing, while explicitly excluding experimental designs and longitudinal case studies, which lie beyond the present scope.

The outcome of this research is a validated Next-Gen Digital PM Competency Model, intended to serve as both a theoretical foundation and a practical reference for the AEC industry. While the study does not directly produce a full training program, assessment tool, or certification scheme, the model provides a robust foundation on which such resources can be developed in the future by industry bodies, educators, and policymakers. By clearly defining the industry context, targeted competency domains, methodological boundaries, and intended outcomes, the study ensures a structured and transparent basis for advancing knowledge and capability in digital PM competency development.

The next section outlines the overall structure of the thesis, providing a chapter-by-chapter overview of how the study progresses from conceptual foundations to empirical validation and discussion of implications.

1.8 Thesis Structure

This thesis is organised into five main chapters, moving from conceptual exploration to empirical validation to develop and confirm the Next-Gen Digital PM Competency Model for the AEC industry.

Chapter 3 focuses on traditional PM competencies in the AEC sector. It employs an intensive round of literature review to identify and thematically categorise competencies reported in academic and industry sources, providing a baseline for subsequent phases of the study. While recognising their continued relevance, the chapter emphasises that traditional competencies alone are insufficient for digitally enabled project delivery.

Chapter 4 reviews and synthesises literature on emerging digital competencies relevant to PMs in the AEC sector. Using a SLR, NVivo-assisted coding, and LLM-based synthesis, it identifies and classifies digital competencies into three domains: Skills, Knowledge, and Core Personality Traits. Following generation, each definition was reviewed by the research team and validated through expert review by two domain specialists with more than ten years of professional experience, resulting in 55 standardised competency definitions that constitute the study's digital competency set.

Chapter 5 details the multiphase mixed-methods approach and serves as the methodological bridge between Chapters 3 and 4. It integrates the traditional and digital competency sets through taxonomy development and comparative analysis, producing a structured classification framework that aligns skills, knowledge, and core personality traits specific to digital construction. This integrated taxonomy provides the operational item pool and measurement structure for subsequent survey design and quantitative testing.

Chapter 6 presents the survey study based on the integrated taxonomy and reports the results of EFA. It explains instrument development, sampling, and data analysis, before detailing factor extraction, item retention, and interpretation. EFA reveals the underlying latent constructs that empirically organise the competency space and refines the framework in preparation for confirmatory testing.

Chapter 7 validates the EFA-derived structure using CFA, reporting model fit, reliability, and construct validity. It presents the final validated competency framework, discusses implications for practice and research, and outlines limitations and directions for future work.

The overall structure of the thesis is illustrated in Figure 1.2, which shows the sequential progression from conceptual exploration to empirical validation.

Figure 1.2: Structure of the Thesis: From conceptual foundations to empirical validation of the Next-Gen Digital PM Competency Model.

Chapter 2 Research Methodology

2.1 Introduction

This chapter presents the methodological foundations and research design adopted to achieve the aim and objectives outlined in Chapter 1. It systematically progresses from broader philosophical and paradigmatic assumptions to the specific strategies, choices, and procedures employed in this study. By addressing ontology, epistemology, and axiology before justifying the adopted stance, the chapter demonstrates an informed consideration of alternative research positions while clearly situating this study within its chosen framework.

The overarching aim of this research, as established in Chapter 1, is to develop and empirically validate a Next-Gen Digital Project Manager (PM) Competency Framework tailored to the Architecture, Engineering, and Construction (AEC) industry. This aim is operationalised through five interrelated objectives: (1) identifying traditional PM competencies, (2) identifying, categorising, and refining emerging digital competencies, (3) integrating both sets into a taxonomy, (4) empirically synthesising and validating the framework through Exploratory Factor Analysis (EFA), and (5) confirming its robustness via Confirmatory Factor Analysis (CFA). Together, these objectives chart a logical pathway from conceptual exploration to empirical validation, ensuring both theoretical grounding and practical relevance.

Given the complexity of this research problem, a multiphase mixed-methods design was adopted to integrate qualitative exploration with quantitative validation. Competency development in digital construction encompasses skills, knowledge, and core personality traits that cannot be adequately captured through a single approach. Mixed-methods research is widely recognised for its ability to combine qualitative depth with quantitative rigour, thereby enhancing both validity and insight (Johnson et al., 2007; Tashakkori & Teddlie, 2010). In this study, qualitative methods, including an intensive Literature Review (LR), Systematic Literature Review (SLR), NVivo-assisted Thematic Analysis, Large Language Model (LLM)-based synthesis, and taxonomy development, were employed to inductively identify, categorise, and structure PM competencies. This process was further validated by two domain experts in construction project management and digital transformation, ensuring that the resulting framework reflected both academic evidence and industry practice. These qualitative insights were subsequently complemented by quantitative methods, including survey-based data collection, EFA, and CFA, which tested and validated the framework. This sequential exploratory-to-confirmatory design ensured that inductively derived constructs were subjected to rigorous empirical evaluation.

The remainder of this chapter is organised according to Saunders'(2009, 2019) Research Onion, which provides a structured framework for methodological decision-making. Section 2.2 outlines the methodological framework and presents the adapted Research Onion diagram. Section 2.3 discusses the research philosophy and paradigm adopted. Section 2.4 addresses the research approach to theory development. Section 2.5 explains the methodological choice. Section 2.6 outlines the research strategy. Section 2.7 presents the study's time horizon. Section 2.8 describes the research methods, including qualitative and quantitative techniques. Finally, Section 2.9 summarises the adopted methodology and provides a transition to Chapter 3.

2.2 Methodological Framework

A methodological framework provides the conceptual and procedural structure that links a study's philosophical assumptions to its chosen research methods (Crotty, 1998; Creswell, 2009). It acts as a roadmap that ensures coherence and transparency by making explicit how ontological and epistemological positions inform paradigmatic choices, how these paradigms shape research approaches, and how approaches translate into practical designs and methods (Saunders et al., 2019). In applied fields such as construction management, a methodological framework is essential because it demonstrates not only the logical sequence of methodological decisions but also their alignment with the research objectives and the industry context (Morgan, 2007).

To structure this process, the study draws on Saunders' Research Onion (Saunders et al., 2009), a layered model that systematically guides researchers from broad philosophical foundations to specific techniques and procedures. Each layer of the onion illustrates how abstract assumptions about knowledge and reality are operationalised through methodological decisions, moving from philosophy, through approach, methodological choice, strategy, and time horizon, to techniques and procedures. This structure is particularly valuable in construction management research, where addressing socio-technical challenges requires both qualitative depth and quantitative rigour.

Figure 2.1 presents the Research Onion, which provides the overarching framework for this thesis. The subsequent sections (2.3–2.8) expand on each layer, explaining both the general methodological options and their relevance to the study's aim and objectives. The adopted decisions will then be synthesised and summarised in Section 2.9, providing a clear and transparent account of the methodological pathway followed.

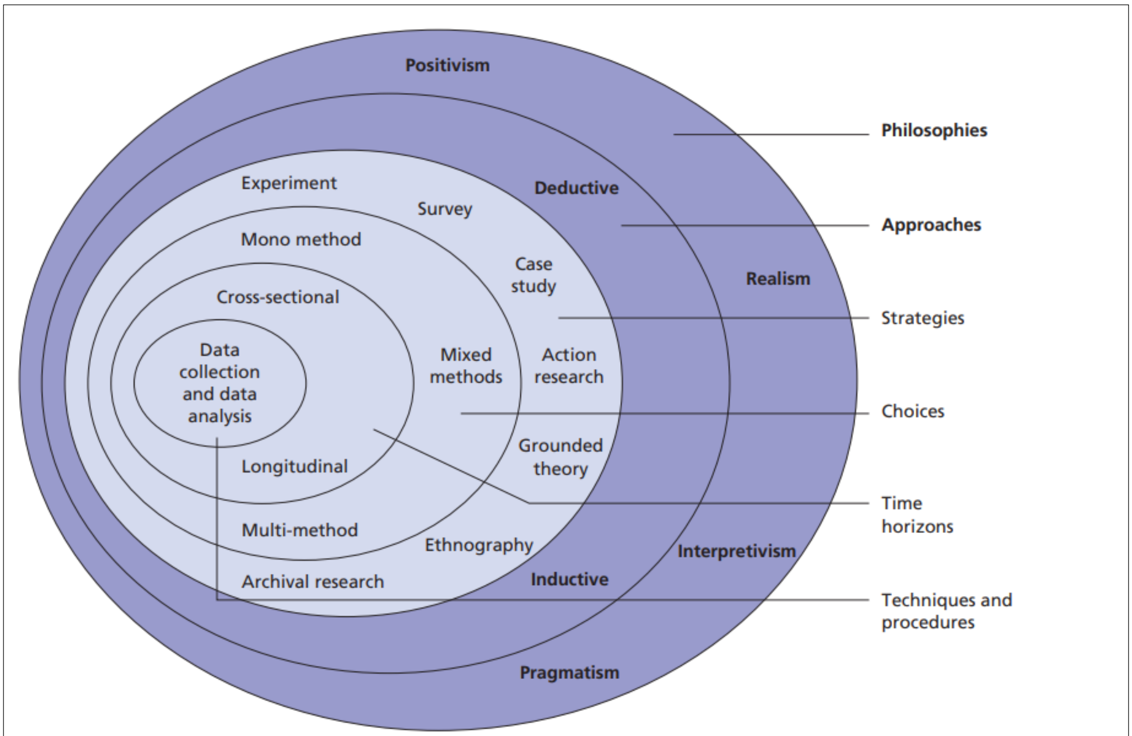

Figure 2.1: The Research Onion (adapted from Saunders et al. (2009)).

The following section (2.3) begins with research philosophy, which forms the outermost layer of the research onion. This layer establishes the foundational assumptions about reality (ontology), knowledge (epistemology), and values (axiology) that guide all subsequent methodological choices in the study.

2.3 Research Philosophy

Research philosophy refers to the underlying set of beliefs and assumptions about the nature of reality (ontology), knowledge (epistemology), and values (axiology), and how these assumptions shape the conduct of research (Crotty, 1998; Saunders et al., 2019). It underpins all methodological decisions, influencing how research questions are framed, which strategies are adopted, and how findings are interpreted. In applied fields such as project management and construction research, articulating a clear philosophical stance ensures methodological transparency and enables readers to assess the coherence between philosophical assumptions and research design (Lincoln et al., 2011; Creswell & Creswell, 2017).

Saunders et al. (2009), through the Research Onion, emphasise that philosophy is the outermost layer shaping all subsequent methodological choices. In this study, situating philosophy explicitly provides a defensible foundation for aligning abstract assumptions with concrete methodological decisions.

2.3.1 Purpose of Discussing Research Philosophy

The purpose of discussing research philosophy in this study is twofold. First, it clarifies the ontological and epistemological assumptions that frame the investigation. As Crotty (1998) explains, these assumptions form the foundation of methodological design by defining what constitutes reality and valid knowledge. Second, it enhances transparency in the chain of reasoning that links the study's abstract commitments to its practical methods. As Saunders et al. (2009) note in their Research Onion, explicitly stating philosophy ensures coherence across paradigm, approach, design, and method.

In construction management research, where complex socio-technical problems intersect with human and organisational dynamics, a clear philosophical stance strengthens credibility. For example, Creswell and Clark (2017) argue that mixed-methods research requires explicit philosophical justification to integrate qualitative and quantitative elements. Likewise, Morgan (2007) highlights that pragmatism provides a practical, problem-centred stance for bridging diverse traditions.

Accordingly, this section introduces four major philosophical traditions, positivism, interpretivism, realism, and pragmatism, followed by a discussion of the main research paradigms, and concludes with the justification for adopting pragmatism, situated within a post-positivist orientation, as the guiding stance for this thesis.

2.3.2 Types of Research Philosophies

Research philosophy provides the foundational worldview that guides inquiry, shaping what is regarded as knowledge and how it can be obtained. Four major traditions, positivism, interpretivism, realism, and pragmatism, are commonly discussed in the methodological literature, each offering distinct assumptions and implications for research design.

2.3.2.1 Positivism

Positivism assumes that reality is objective, singular, and independent of the researcher, and that valid knowledge can be generated through systematic observation and empirical testing (Creswell, 2009; Saunders et al., 2019). Positivist research emphasises hypothesis testing, causal explanation, and quantification, drawing from natural science approaches to study social phenomena (Cohen et al., 2017). Knowledge is viewed as arising from observable facts and generalisable regularities.

2.3.2.2 Interpretivism

Interpretivism rejects the notion of a single objective reality, instead positing that reality is socially constructed and understood through the meanings individuals assign to their experiences (Schwandt, 1994; Creswell & Poth, 2018). It values subjectivity, context, and the co-construction of knowledge between researcher and participant. Interpretivist approaches often employ qualitative methods such as interviews, ethnography, or focus groups, which seek to capture the richness and diversity of lived experience (Saunders et al., 2019).

2.3.2.3 Realism

Realism provides a middle ground between positivism and interpretivism. It acknowledges that reality exists independently of human thought but recognises that our understanding of it is mediated by cultural, social, and theoretical frameworks (Bhaskar, 2008; Maxwell, 2012). Critical realism, in particular, distinguishes between the real (underlying structures and mechanisms), the actual (events that occur), and the empirical (human experiences of those events) (Easton, 2010). Realism therefore enables the study of both objective structures and subjective perspectives.

2.3.2.4 Pragmatism

Pragmatism emphasises practical problem-solving, treating truth as provisional and judged by its usefulness in addressing specific research questions (Biesta, 2010; Morgan, 2007). It rejects rigid adherence to either objectivist or subjectivist traditions, instead supporting methodological pluralism (Tashakkori & Teddlie, 2010). Pragmatism allows researchers to employ both qualitative and quantitative methods as needed, aligning methodological choices with the demands of the research problem (Saunders et al., 2019).

2.3.3 Types of Research Paradigms

Research paradigms represent broad worldviews that link philosophical assumptions with methodological practices (Saunders et al., 2019; Guba & Lincoln, 1994). They provide coherence by connecting ontology (reality), epistemology (knowledge), and methodology (approach to inquiry). Four paradigms are especially influential in the social sciences: Post-positivism, Constructivism, Critical Theory, and Pragmatism.

To ensure conceptual clarity, Table 2.1 provides a structured comparison of these paradigms, highlighting their underlying assumptions and methodological implications.

Table 2.1: Comparison of Research Paradigms

Philosophy / ***Paradigm***	**Ontology (Reality)**	**Epistemology (Knowledge)**	**Methodology (Approach)**	**Key Focus / Critique**
Post-positivism	Reality exists but can only be imperfectly understood.	Knowledge is probabilistic and theory laden.	Quantitative and mixed methods; emphasis on objectivity and validity.	Useful for hypothesis testing but may understate social/contextual influences (Guba & Lincoln, 1994; Phillips & Burbules, 2000).
Constructivism	Reality is socially constructed and multiple.	Knowledge is co-created through shared meanings.	Qualitative methods (interviews, ethnography, thematic analysis).	Rich in context but criticised for lack of generalisability (Williams, 2007; Scotland, 2012).

Critical Theory	Reality shaped by power, culture, and ideology.	Knowledge influenced by ideology and power relations.	Participatory, emancipatory methods (e.g., action research).	Seeks transformation but may be overly normative (McGregor & Murnane, 2010; Kincheloe & McLaren, 2011).
Pragmatism	Reality is both singular and multiple, depending on context.	Knowledge judged by practical consequences ("what works").	Methodological pluralism; integration of qualitative & quantitative.	Well-suited to applied research but sometimes criticised for philosophical "lightness" (Morgan, 2007; Creswell & Clark, 2017).

2.3.3.1 Post-positivism

Post-positivism emerged as a refinement of classical positivism, recognising that absolute objectivity is unattainable. While reality exists independently, knowledge of it is fallible, theory-laden, and probabilistic (Phillips & Burbules, 2000; Creswell, 2009). Post-positivism typically employs quantitative methods such as surveys or experiments but also supports triangulation to improve validity (Williams, 2007).

2.3.3.2 Constructivism

Constructivism, also referred to as interpretivism, assumes that reality is socially constructed and that knowledge emerges through interaction and shared meanings (Lincoln & Guba, 1985; Schwandt, 1994). Constructivist approaches prioritise qualitative methods such as interviews, case studies, and ethnography, focusing on participants lived experiences and multiple perspectives (Creswell & Creswell, 2017).

2.3.3.3 Critical Theory

Critical theory highlights the influence of power, ideology, and inequality in shaping reality and knowledge (Fay, 1987; Habermas, 2015). It argues that research should not only interpret the world but also transform it by addressing structural inequalities (Kincheloe & McLaren, 2011). Methods are often participatory and action-oriented, such as action research or critical discourse analysis (Morrow & Brown, 1994).

2.3.3.4 Pragmatism

As a paradigm, pragmatism prioritises practical consequences and methodological flexibility. It treats truth as contextual, with knowledge judged by its usefulness in solving problems (Morgan, 2007; Saunders et al., 2019). Pragmatism encourages methodological pluralism, legitimising both exploratory qualitative techniques (e.g., thematic analysis, taxonomy development) and confirmatory quantitative approaches (e.g., survey-based EFA and CFA).

2.3.4 Justification of Adopted Philosophy and Paradigm

Having reviewed alternative philosophies and paradigms, this study adopts pragmatism, situated within a post-positivist orientation, as the guiding stance. Pragmatism was chosen because of its pluralistic stance, problem-driven orientation, and emphasis on practical consequences, making it particularly suitable for applied research in construction management (Saunders et al., 2009; Biesta, 2010; Morgan, 2007).

Ontologically, pragmatism avoids rigid commitments to either objectivism or subjectivism, treating truth as contextual and judged by its practical consequences. Epistemologically, it legitimises drawing upon multiple forms of evidence, whether qualitative or quantitative, provided they contribute to addressing the central research question. Axiologically, pragmatism recognises the value-laden nature of applied research, where the worth of knowledge lies in its utility for solving real-world problems.

From an ontological perspective, this study recognises that digital project management competencies exist as structured capabilities within the construction domain, while also being shaped by organisational context, technological maturity, and professional practice. Epistemologically, the study adopts a post-positivist position that supports the systematic measurement of these competencies through quantitative methods, while acknowledging the role of prior qualitative and conceptual synthesis in informing their development. This combined stance directly underpins the multi-phase methodological design of the study, integrating qualitative and conceptual approaches (intensive LR, thematic categorisation, SLR, NVivo-based thematic analysis, LLM-assisted synthesis, expert review, and taxonomy construction with comparative analysis) with quantitative validation techniques (survey-based EFA and CFA) to ensure both conceptual depth and empirical rigour.

By adopting pragmatism within a post-positivist orientation, this thesis ensures methodological flexibility, coherence, and relevance. This stance provides a defensible foundation for later methodological choices, supporting the central aim of the study: to develop and empirically validate a Next-Gen Digital PM Competency Model that is both conceptually robust and practically applicable to the digital transformation of the construction industry.

2.4 **Research Approach**

A research approach represents the logic of reasoning that links theory with empirical data and guides how researchers move between conceptual frameworks and observed realities. In other words, it establishes the pathway through which knowledge claims are generated, tested, and refined (Saunders et al., 2009; Creswell & Creswell, 2017) . Research approaches serve as an intermediate layer between broader philosophical assumptions and specific methodological choices, ensuring coherence across the research design. Within the social sciences, three dominant approaches are recognised: deductive, inductive, and abductive reasoning. Each provides a distinctive lens for structuring the research process and determining the relationship between theory development and empirical evidence.

2.4.1 Purpose of Discussing Research Approach

A research approach refers to the reasoning strategy that bridges abstract philosophical assumptions with the practicalities of research design (Creswell & Creswell, 2017; Blaikie & Priest, 2018). It determines whether a study begins with theory and seeks to test it (deduction), builds theory from data (induction), or iteratively moves between the two (abduction). Discussing the research approach is therefore essential for clarifying the logical basis of inquiry, ensuring internal coherence across the research philosophy, design, and methods, and providing transparency in how knowledge claims are developed and validated (Saunders et al., 2009).

2.4.2 Types of Research Approaches

At the core of methodological reasoning lie three dominant approaches: deductive, inductive, and abductive logics (Blaikie & Priest, 2018; Saunders et al., 2009). Deduction begins with existing theory and tests it against data; induction develops theory from observations; while abduction moves iteratively between the two, generating new insights through a cycle of inference and validation. These approaches are not synonymous with methodological choices such as quantitative, qualitative, or mixed methods; rather, they underpin those choices as reasoning strategies (Creswell & Creswell, 2017). By selecting an appropriate approach, researchers ensure that their study design remains logically consistent with both their philosophical stance and the nature of the research problem.

2.4.2.1 ***Deductive***

The deductive approach is characterised by reasoning that moves from the general to the specific, beginning with established theory and hypotheses that are then tested against empirical evidence (Bryman, 2016; Saunders et al., 2009). Deduction emphasises the primacy of theory, with research designed to either confirm or refute predefined propositions. This approach is closely associated with quantitative research, where structured instruments such as surveys or experiments are used to generate measurable data that can be subjected to statistical testing (Creswell & Creswell, 2017). Its strengths lie in the ability to produce replicable and generalisable findings, provided that the initial theoretical framework is robust. However, critics argue that deduction can restrict discovery, as the research process may be overly confined by predetermined variables and assumptions, leaving limited room for emergent insights (Blaikie & Priest, 2018). Despite these limitations, deduction remains a cornerstone in fields where testing existing theories against new contexts is central to advancing knowledge.

2.4.2.2 ***Inductive***

In contrast, the inductive approach moves from the specific to the general, building theoretical insights from patterns observed in empirical data (Thomas, 2006; Saunders et al., 2009). Rather than starting with hypotheses, inductive research allows themes, concepts, and theories to emerge organically from the data, making it particularly suited to qualitative methodologies such as interviews, ethnography, and thematic analysis. This approach is highly valued for its capacity to capture complexity, context, and the lived experiences of participants, thereby generating rich and nuanced understanding (Creswell & Clark, 2017). Its strength lies in flexibility and openness, yet it has been critiqued for potential subjectivity, as the researcher's interpretations play a central role in shaping outcomes (Blaikie & Priest, 2018). Nonetheless, induction is essential for exploring novel or under-researched phenomena where existing theory is insufficient or fragmented, offering a powerful means to develop grounded explanations of social realities.

2.4.2.3 ***Abductive***

The abductive approach occupies a middle ground, combining elements of both deduction and induction through a cyclical and iterative reasoning process (Timmermans & Tavory, 2012; Saunders et al., 2009). Abduction begins with surprising or puzzling empirical observations that cannot be adequately explained by existing theory. Researchers then propose tentative explanations, which are iteratively tested and refined through further data collection and theoretical reflection. This makes abduction particularly valuable for addressing complex, dynamic research contexts where neither purely deductive nor purely inductive reasoning is sufficient (Blaikie & Priest, 2018). Abduction aligns well with mixed-methods research, as it allows for the integration of qualitative insights and quantitative validation within a coherent framework (Creswell & Clark, 2017). Its strength lies in creativity and flexibility, fostering theoretical innovation while remaining empirically grounded. However, it also requires careful management to avoid drift or incoherence, as the iterative movement between data and theory can complicate methodological transparency. Despite these challenges, abduction has gained prominence in contemporary social science research for its capacity to generate fresh insights and bridge the gap between theory and practice.

2.4.3 Justification of Adapted Approach

The present study adopts an abductive approach as the most appropriate reasoning logic to address the research problem. Abduction is particularly suited to contexts where research seeks both to develop novel theoretical insights and to validate them empirically through iterative cycles of inference (Timmermans & Tavory, 2012; Blaikie & Priest, 2018). In line with the pragmatic philosophical stance outlined earlier, abduction enables a flexible interplay between inductive exploration and deductive testing, ensuring that emerging insights remain grounded in real-world practice while still being subject to systematic validation.

This abductive orientation is evident in the study's multi-phase design. In the early stages, inductive reasoning is employed through qualitative techniques such as the targeted LR, SLR, NVivo-assisted thematic analysis, and LLM-based synthesis, allowing new competency dimensions to emerge from the data (Creswell & Poth, 2018; Thomas, 2006). Subsequently, deductive reasoning is incorporated in the quantitative phases, where the hypothesised competency framework is first refined through domain expert validation and then subjected to statistical testing via EFA and CFA (Creswell & Creswell, 2017; Hair et al., 2010). By combining inductive generation with deductive validation, the abductive approach ensures both the novelty and robustness of the proposed framework.

Adopting abduction also reflects the practical realities of digital transformation in the AEC sector. As the field evolves rapidly, no single deductive model can fully capture emerging competencies, nor can purely inductive inquiry provide the validation necessary for widespread acceptance. Instead, an abductive approach allows the study to remain open to emergent findings while subjecting them to rigorous empirical testing. This reasoning pathway therefore aligns with the overarching pragmatic philosophy, ensuring that theoretical advancement remains closely tied to practical application and industry relevance (Creswell & Poth, 2018; Saunders et al., 2009).

2.5 **Research Strategy**

Research strategy constitutes the overarching framework that connects philosophical assumptions and research approaches with specific methods of data collection, analysis, and interpretation. It functions as the strategic plan that ensures coherence between a study's objectives, the logic of reasoning, and the techniques applied in practice (Creswell & Poth, 2018; Saunders et al., 2009). By providing a structured pathway, research strategy enables researchers to operationalise abstract methodological considerations into concrete procedures capable of addressing the research problem with rigour and validity.

2.5.1 Purpose of Discussing Research Strategy

The purpose of discussing research strategy is to clarify the strategic decisions underpinning the conduct of a study. Strategy choices articulate how the research philosophy and approach are translated into a workable plan, linking theoretical propositions with empirical procedures (Bryman, 2016; Creswell & Creswell, 2017). In this sense, research strategy serves not only as a procedural roadmap but also as a safeguard for internal consistency, ensuring that philosophical assumptions, reasoning strategies, and methodological tools align coherently.

2.5.2 Types of Research Strategies

Research strategies can be classified into several types, each providing a distinctive pathway for linking research questions to empirical evidence. Common strategies in the social sciences include case study, survey, ethnography, grounded theory, action research, and experimental designs. Each reflects differing assumptions about the nature of social reality, the role of the researcher, and the type of knowledge that can be generated (Blaikie & Priest, 2018; Saunders et al., 2009).

2.5.2.1 Case Study

The case study design involves an in-depth exploration of a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly defined (Yin, 2018). Case studies are particularly valuable when the research seeks to understand complex processes, organisational practices, or emerging phenomena that cannot be easily separated from their settings. They allow the use of multiple data sources, such as interviews, documents, and observations, enabling a holistic understanding of the subject (Creswell & Poth, 2018). In construction management research, case studies are often employed to capture the nuanced realities of project environments, digital technology adoption, or stakeholder interactions.

2.5.2.2 Survey

Survey design is characterised by the systematic collection of data from a defined population, often using structured questionnaires or interviews to capture attitudes, perceptions, and behaviours (Saunders et al., 2019). Surveys are typically associated with quantitative analysis but can also include open-ended elements to enrich contextual understanding. Their strength lies in their ability to gather data from large samples, thereby enhancing generalisability and supporting statistical validation of relationships between variables (Creswell & Creswell, 2017). Within the AEC sector, surveys are particularly effective for assessing competencies, adoption barriers, and organisational readiness for digital transformation.

2.5.2.3 Ethnography

Ethnographic design originates from anthropology and focuses on the immersive study of cultures, practices, and meanings within natural settings (Saunders et al., 2019). It typically involves prolonged engagement, participant observation, and the collection of narratives to generate deep insights into social practices. Ethnography is well-suited for research questions that demand understanding of lived experiences, tacit knowledge, and cultural dimensions of organisational life (Hammersley & Atkinson, 2019). In construction studies, ethnography is less common but can be applied to explore collaborative practices, cultural challenges in project teams, or the integration of new digital tools in workplace routines.

2.5.2.4 Grounded Theory

Grounded theory design seeks to develop theory inductively from systematically collected and analysed data, rather than testing pre-existing hypotheses (Charmaz, 2014). It is iterative in nature, relying on cycles of data collection and coding until theoretical saturation is reached. The strength of grounded theory lies in its capacity to generate explanatory frameworks that are closely aligned with participants' experiences and empirical realities. While demanding in terms of time and analytic rigour, it is particularly valuable in underexplored areas, such as identifying new digital competencies or uncovering hidden barriers to innovation in construction projects (Birks & Mills, 2015).

2.5.2.5 Action Research

Action research design is collaborative and interventionist, involving cycles of planning, acting, observing, and reflecting in partnership with stakeholders (Reason & Bradbury, 2008). Its primary aim is not only to generate knowledge but also to drive practical change within the research context. Action research is especially relevant in organisational settings where researchers and practitioners co-develop solutions to pressing challenges. In the AEC industry, it can be applied to improve project delivery processes, trial digital solutions, or foster cultural change towards more collaborative and sustainable practices.

2.5.2.6 Experimental Design

Experimental design is characterised by the manipulation of variables under controlled conditions to establish causal relationships (Creswell & Creswell, 2017). Experiments can be conducted in laboratories or field settings and typically involve random assignment of participants to treatment and control groups. While highly rigorous in terms of internal validity, experimental designs are less commonly used in construction management research due to practical constraints. However, they may be useful in testing the effectiveness of training interventions, decision-support tools, or digital simulation environments in controlled settings. In broader methodological literature, experimental designs are regarded as the "gold standard" for establishing causality, as they allow researchers to control confounding variables and directly test the effects of interventions (Shadish et al., 2002; Bryman, 2016).

2.5.3 Justification of Adopted Strategy

The present study adopts a survey-based research strategy as the most appropriate means of addressing its research objectives. This choice aligns with the study's pragmatic philosophical foundation and its abductive reasoning approach, which emphasises the iterative integration of theory and empirical evidence (Saunders et al., 2009; Creswell & Creswell, 2017). By using a survey as the primary strategy, the research enables the systematic collection of data from a broad sample of construction professionals, thereby capturing diverse perspectives on digital PM competencies and their role in digitally enabled environments.

Furthermore, the survey strategy was complemented by a multiphase mixed-methods design, in which survey findings were integrated with a targeted LR, SLR, thematic analysis, and LLM–based synthesis to establish a comprehensive competency list. This framework was further validated through domain expert review to ensure clarity and industry alignment and subsequently tested empirically through EFA and CFA. Such integration of qualitative exploration with quantitative validation ensured both conceptual richness and empirical robustness. This multiphase design was particularly suited to the study's aim of developing and validating a Next-Gen Digital PM Competency Model, as it enabled triangulation across multiple phases of inquiry, thereby strengthening the credibility and practical relevance of the findings (Tashakkori & Teddlie, 2010; Creswell & Poth, 2018).

2.6 **Methodological Choice**

Methodological choice refers to the decision regarding how many methods, and of what type, are employed within a study. As Saunders et al. (2009) highlight in their Research Onion, this layer distinguishes between the adoption of a single method, multiple methods of the same type, or a combination of qualitative and quantitative methods. Clarifying this choice ensures transparency in how evidence is generated and how the logic of inquiry is operationalised.

Research methods represent the specific procedures and techniques employed to collect, analyse, and interpret data in pursuit of addressing the research questions. While research philosophy, paradigms, and approaches provide the broader ontological and epistemological orientation of a study, methods operationalise these orientations into concrete practices (Creswell & Creswell, 2017; Saunders et al., 2009). Methods are therefore the most practical layer of the methodological framework, translating abstract reasoning strategies into observable and replicable actions.

Research Methods

- **Quantitative methods** are characterised by reliance on numerical data, statistical analysis, and structured instruments such as surveys, experiments, or secondary datasets. They are most often associated with a deductive logic of reasoning, where existing theories are tested against empirical observations to confirm or refute hypotheses (Saunders et al., 2009; Creswell & Creswell, 2017). These methods prioritise measurement, objectivity, and generalisability, seeking patterns that can be extrapolated to larger populations (Bryman, 2016). Strengths of quantitative approaches include their ability to establish causal relationships, generate replicable results, and provide statistical confidence in findings. However, they may risk oversimplifying complex social phenomena by reducing them to numerical indicators, potentially neglecting context or meaning (Tashakkori & Teddlie, 2010).
- **Qualitative methods** focus on exploring meanings, experiences, and processes, typically through interviews, observations, focus groups, or document analysis. They are generally aligned with an inductive logic of reasoning, where theory is developed from data through thematic exploration rather than pre-determined hypotheses (Bryman, 2016; Creswell & Creswell, 2017). These methods are particularly valuable for investigating complex, context-dependent phenomena and uncovering insights that are not easily measurable. Their strengths lie in providing depth, flexibility, and rich descriptions of human behaviour and organisational processes (Saunders et al., 2009). However, qualitative research is often critiqued for its limited generalisability and potential researcher subjectivity, which necessitates careful attention to reflexivity, credibility, and transparency in interpretation (Creswell, 2009).
- **Mixed methods** integrate both quantitative and qualitative approaches within a single study, either sequentially, concurrently, or in embedded designs (Creswell & Clark, 2017). This approach is commonly associated with pragmatism, as it emphasises methodological flexibility and the use of "what works" to address the research question (Saunders et al., 2009; Tashakkori & Teddlie, 2010). The primary strength of mixed methods lies in their ability to combine the statistical generalisability of quantitative approaches with the contextual depth of qualitative insights, thereby achieving triangulation and complementarity (Bryman, 2016). Mixed methods are particularly valuable when exploring emerging or complex research areas where a single method would provide only a partial perspective. Nevertheless, this approach requires careful integration of findings and greater resources in terms of time, skills, and data management (Creswell & Clark, 2017).

The discussion of research methods is critical because it provides transparency in how evidence is generated and evaluated. By clarifying the methods adopted, researchers demonstrate alignment between their research questions, philosophical stance, and design strategy, thereby strengthening validity and replicability (Creswell & Clark, 2017; Saunders et al., 2009). Explicitly defining the chosen method also allows the audience to critically assess the appropriateness of the techniques in addressing the stated objectives.

2.6.1 Purpose of Discussing Methodological Choice

The purpose of discussing methodological choice is to demonstrate how the study translates its philosophical stance and reasoning approach into a coherent design for data collection and analysis. By specifying the type of methodological choice, researchers provide clarity on whether the inquiry is oriented towards breadth, depth, or integration of perspectives (Creswell & Clark, 2017). This discussion also highlights the rationale for aligning methodological choice with the pragmatic philosophy and abductive reasoning adopted in this thesis, ensuring that the design remains both theoretically coherent and practically feasible.

2.6.2 Types of Methodological Choices

Methodological choices can be categorised according to whether a study employs a single method (mano method), multiple methods within the same tradition (multi method), or a combination of qualitative and quantitative methods (mixed method). Each type reflects different priorities in terms of breadth, depth, and integration of perspectives, and selecting among them depends on the research aims, complexity of the problem, and philosophical stance guiding the inquiry (Creswell & Clark, 2017; Saunders et al., 2009).

2.6.2.1 ***Mono-method***

A mono-method design refers to the use of a single data collection technique and its associated analysis procedure, which can be either quantitative (e.g., a structured survey analysed statistically) or qualitative (e.g., in-depth interviews analysed thematically). This choice is often suitable for studies with a focused scope, where one type of data is sufficient to address the research objectives. Its strength lies in methodological simplicity and coherence, but it may limit the breadth of insights when dealing with complex, multi-dimensional phenomena (Saunders et al., 2009).

2.6.2.2 ***Multi-method***

A multi-method design involves employing more than one technique of data collection and analysis but restricted within the same methodological tradition. For example, a researcher may use multiple qualitative methods such as interviews, focus groups, and document analysis, or multiple quantitative methods such as survey data combined with secondary statistical datasets. The value of multi-method lies in triangulation within one tradition, strengthening the credibility and robustness of findings. However, since it remains within a single tradition, it cannot capture both statistical generalisability and contextual richness at the same time (Saunders et al., 2009; Bryman, 2016).

2.6.2.3 ***Mixed methods***

A mixed-methods design combines both quantitative and qualitative approaches in a single study, either sequentially (e.g., qualitative exploration followed by quantitative testing) or concurrently (collecting both types of data in parallel). This design is particularly valuable in complex fields such as construction management, where numerical evidence alone cannot capture socio-technical dynamics, and qualitative insights alone may lack generalisability. Mixed-methods research provides complementary perspectives, enabling triangulation, elaboration, and integration of findings. Its strength lies in producing a more comprehensive and nuanced understanding of the research problem, though it requires careful design, integration, and greater resources in terms of time and expertise (Creswell & Clark, 2017; Saunders et al., 2009).

2.6.3 Justification of Adopted Choice

This study adopts a mixed-methods, sequential multiphase design, consistent with the pragmatic stance outlined earlier. The integration of qualitative exploration and quantitative validation ensures that both conceptual richness and empirical rigour are achieved. The qualitative phases (intensive LR, SLR, NVivo-assisted thematic analysis, LLM synthesis, and expert validation) provide exploratory depth, while the quantitative phases (survey, EFA, CFA) enable statistical validation. This sequential design allows inductive insights to be refined and confirmed through deductive testing, exemplifying abductive reasoning in practice.

2.7 **Time Horizon**

Research can also be classified by its time horizon. Cross-sectional designs capture data at a single point in time, offering a snapshot of relationships or perceptions, while longitudinal designs track changes over extended periods, allowing for the study of trends, development, and causality (Saunders et al., 2009).

In this study, a cross-sectional orientation was adopted because the aim was to provide a comprehensive snapshot of competency requirements within the AEC industry at a single point in time. Given the rapidly evolving nature of digital technologies, a cross-sectional design provided an efficient means of identifying current competency structures and aligning them with ongoing industry transformation efforts (Bryman, 2016). While longitudinal designs could capture trends over time, they were not feasible within the time and resource constraints of this thesis. Nevertheless, this study establishes a validated baseline framework that can serve as a reference point for future longitudinal investigations, enabling subsequent research to track the evolution of digital PM competencies as technologies and industry practices continue to develop.

2.8 **Research Techniques and Procedures**

Research techniques and procedures represent the innermost layer of Saunders et al. (2009) Research Onion. While the preceding sections established the study's philosophical orientation, paradigmatic stance, reasoning approach, methodological choice, strategy, and time horizon, this section focuses on the practical implementation of those decisions. Techniques and procedures detail how data were collected, analysed, and validated, ensuring transparency and replicability in addressing the research objectives (Saunders et al., 2019; Creswell & Clark, 2017). In this study, these procedures were structured to investigate, refine, and validate digital PM competencies in the AEC industry, integrating qualitative synthesis, expert validation, and quantitative survey-based analysis.

2.8.1 Data Collection

Data collection was conducted through a structured questionnaire survey, which served as the primary tool for empirically validating the competency framework. The survey instrument was developed in line with best practices in scale development and psychometric research (Boateng et al., 2018; DeVellis & Thorpe, 2021). Items were derived from the intensive LR, SLR, NVivo-assisted thematic analysis, LLM–based synthesis, and expert validation conducted in earlier phases of the study, as illustrated in Chapter 4. This process ensured content validity and alignment with the conceptual taxonomy of 55 digital PM competencies, categorised under Skills, Knowledge, and Core Personality Traits.

The questionnaire employed a five-point Likert scale (1 = Strongly Agree to 5 = Strongly Disagree) to capture participants' evaluations of the importance and relevance of each competency. This scale is widely recognised for its reliability in measuring perceptions and attitudes (Joshi et al., 2015). Alternative Likert formats, including seven-point and higher-point scales, were considered; however, the five-point scale was selected because it provides an appropriate balance between response discrimination, practical usability, and data quality in applied survey settings. While scales with more response categories may offer finer gradation, evidence suggests that they do not necessarily improve reliability or validity and, in the case of agree or disagree formats, may yield lower-quality data and place greater burden on respondents. A limitation of the five-point Likert scale is its lower granularity, which may restrict the detection of subtle differences in perception; however, it remains appropriate for exploratory and validation-oriented research where clarity, usability, and response reliability are prioritised (Dawes, 2008; Revilla et al., 2014).

The survey was pilot tested with a small group of industry professionals to ensure clarity and usability, and refinements were made accordingly. To improve content validity and ensure item clarity, the survey underwent pilot testing with three domain experts based in New Zealand, comprising two senior academics and one industry-based digital PM, who provided feedback on item phrasing, relevance, and terminology. Based on their input, minor wording refinements were made to enhance clarity and ensure consistent interpretation across diverse professional backgrounds.

Administration was undertaken electronically via Qualtrics, which enabled secure data collection, efficient data management, and broad geographic reach. Participation was voluntary, with informed consent obtained in accordance with Auckland University of Technology Ethics Committee (AUTEC) approval [Approval No. 23/257], Appendix A1: Ethics Approval and Documentation. Recruitment was conducted through professional networks, industry associations, and direct invitations, ensuring participation by individuals with substantial project management experience in the AEC sector.

For transparency and replicability, the full survey instrument is included in Appendix A2: Qualtrics Survey Instrument. The data collected provided the empirical basis for subsequent statistical analyses, including EFA and CFA.

2.8.2 Sampling

Sampling is a critical determinant of representativeness and generalisability (Saunders et al., 2019; Creswell & Creswell, 2017). This study employed purposive sampling, targeting professionals in the AEC industry with a minimum of five years' project management experience and prior involvement in digital technology. These criteria ensured participants were sufficiently experienced in both traditional and digital practices, enabling them to provide informed perspectives on the competencies under investigation.

The target population comprised project managers, senior engineers, architects, and construction professionals across New Zealand and Australia, reflecting a digitally engaged yet diverse regional context. Recruitment leveraged the principal researcher's professional networks, industry associations, and direct contacts. In addition, snowball sampling was used, with initial respondents encouraged to share the survey with eligible peers (Etikan et al., 2016), thereby extending reach while retaining relevance.

To further enhance outreach, the research was presented at AUT engagement conferences, creating an additional channel for engaging practitioners involved in digital innovation and project delivery. In addition, the study was featured in the national industry publication Master Builder Magazine, which extended its visibility within the construction sector and encouraged wider participation. This combined purposive and snowball approach ensured that the sample captured a broad range of professional perspectives while remaining tightly aligned with the study's focus on digital PM competencies.

While purposive sampling is appropriate for targeting knowledgeable and experienced participants, it is subject to certain limitations in quantitative research. Specifically, it may introduce selection bias, as participants are not randomly selected, which can limit the statistical representativeness of the sample. Additionally, the findings may not be fully generalisable to the wider population beyond the sampled group (Saunders et al., 2019; Etikan et al., 2016). However, these limitations are mitigated in this study through clearly defined inclusion criteria, a diverse professional sample across two countries, and the use of subsequent statistical validation techniques, including EFA and CFA, to strengthen the robustness and credibility of the results.

2.9 Research Approach Adopted Summary for this Study

This section consolidates the methodological framework outlined in the preceding subsections, providing an integrated account of the philosophical stance, paradigmatic orientation, reasoning logic, design, and methods adopted. The purpose is to demonstrate how these decisions form a coherent pathway for achieving the overarching aim: the development and empirical validation of a Next-Gen Digital PM Competency Model for the AEC industry.

Building on a pragmatic philosophy situated within a post-positivist orientation (Section 2.3.4), the study adopts an abductive approach (Section 2.4.3), which enables iterative movement between inductive exploration and deductive validation. This stance is operationalised through a mixed-methods, sequential multiphase design (Section 2.5.3) that integrates qualitative richness with quantitative rigour.

The research strategy was anchored in a survey-based orientation (Section 2.6.3), complemented by qualitative strategies including an intensive LR, a SLR, NVivo-assisted thematic analysis, LLM-based synthesis, and expert validation, which together provided conceptual depth and ensured the credibility of extracted competencies. This qualitative foundation was further extended through taxonomy development, in which competencies were classified into Skills, Knowledge, and Core Personality Traits, ensuring structural clarity and preparing them for quantitative testing. The quantitative phases then included survey instrument development and administration, EFA and CFA, which enabled statistical validation and empirical robustness of the proposed competency framework. This multiphase strategy ensured both conceptual richness and empirical reliability, supporting triangulation across data sources and methods.

The research methods (Section 2.6.1) operationalised this design through the combination of qualitative and quantitative procedures. The qualitative phases (intensive LR, SLR, NVivo-based thematic analysis, LLM synthesis, expert validation, and taxonomy construction) provided exploratory insights, conceptual coherence, and theoretical grounding. The quantitative phases (survey, EFA, and CFA) enabled statistical testing, validation of latent structures, and confirmation of the framework's internal consistency. Together, these phases exemplify an exploratory sequential mixed methods design in which qualitative findings guided the development of quantitative instruments, and quantitative validation strengthened the credibility of qualitative insights.

Figure 2.2 illustrates this integrated pathway, mapping the sequential alignment of the research framework across six methodological layers adapted from Saunders' Research Onion (2009). Beginning with ontological and epistemological foundations, the framework progresses through research philosophy, research approach, methodological choice, research strategy, and time horizon, before being operationalised through methods and procedures. This layered representation ensures methodological coherence and demonstrates how each decision is anchored in the overall objective of developing and validating the Next-Gen Digital PM Competency Model.

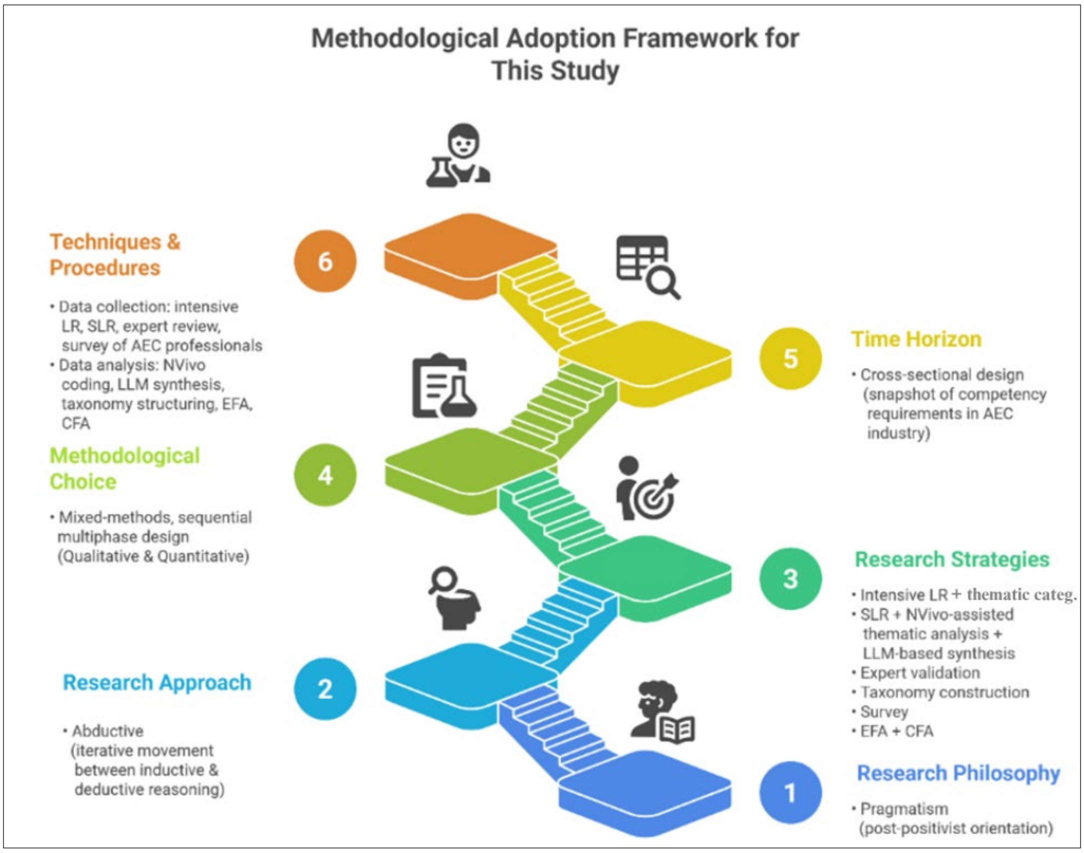

Figure 2.2: Summary of the Adopted Research Framework

This integrated approach ensures that methodological decisions are not fragmented but anchored in a consistent framework (Creswell & Clark, 2017; Bryman, 2016). By combining qualitative depth with quantitative validation, the adopted strategy addresses the dual objectives of developing a theoretically grounded model and producing empirically tested findings. This pathway not only enhances academic rigour but also ensures the model's practical applicability for PMs navigating digital transformation in the construction industry (Tashakkori & Teddlie, 2010; Kaushik & Walsh, 2019).

2.10 Conclusion

This chapter has outlined the methodological framework adopted to address the central aim of this thesis: the development and empirical validation of a Next-Gen Digital Project Manager (PM) Competency Model for the AEC industry. Guided by Saunders et al. (2009) Research

Onion, the chapter has progressively unpacked the methodological layers, from philosophical assumptions to specific techniques and procedures.

The study is grounded in a pragmatic philosophy situated within a post-positivist orientation, which provides methodological flexibility and ensures that knowledge generation remains both theoretically robust and practically relevant. Within this philosophical stance, an abductive research approach was adopted, enabling iterative movement between inductive exploration and deductive testing. This approach was essential given the complexity and evolving nature of digital transformation in construction management.

A sequential mixed-methods design was chosen, reflecting the need to combine qualitative depth with quantitative validation. At the strategy level, the study employed multiple interlinked approaches: an Intensive Literature Review (LR) and Systematic Literature Review (SLR), NVivo-assisted thematic analysis, Large Language Model (LLM)-based synthesis, expert validation, taxonomy development, and finally survey-based statistical validation through Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). These were operationalised within a cross-sectional time horizon, offering a comprehensive snapshot of digital competency requirements in the AEC sector.

Techniques and procedures were structured across two domains: data collection (LR, SLR, expert validation, and survey administration) and data analysis (NVivo coding, LLM synthesis, taxonomy structuring, EFA, and CFA). Together, these provided methodological transparency, triangulation, and credibility, ensuring that findings were both empirically reliable and practically grounded.

In summary, this methodology chapter demonstrates how philosophical foundations, research approach, strategic design, and analytical techniques were integrated into a coherent framework capable of addressing the research objectives. The layered adoption of pragmatism, abduction, mixed methods, and rigorous procedures ensures alignment between theory and practice, thereby providing a defensible basis for the empirical investigations that follow. The next chapters present the results of this multi-phase research process, beginning with the identification of both traditional and digital PM competencies and progressing through their integration, taxonomy development, and empirical validation.

Chapter 3 Establishing the Foundations: Positioning Traditional Project Manager Competencies for Construction's Digital Transformation

This chapter is extended from:

- Owais, O. A., Poshdar, M., Ying, F., Ghaffarian Hoseini, A., & Jaafar, K. (2025b). *Evolving project manager competencies in the dynamic construction industry: A comprehensive framework for success*. In M. Sutrisna et al. (Eds.), *Creating Capacity and Capability: Embracing Advanced Technologies and Innovations for Sustainable Future in Building Education and Practice* (Lecture Notes in Civil Engineering, Vol. 562, pp. 171–182). Springer Nature Singapore. https://doi.org/10.1007/978-981-96-1181-2_14.

3.1 Abstract

This chapter addresses the fragmented landscape of traditional project manager (PM) competencies by consolidating them into a coherent framework for the Architecture, Engineering, and Construction (AEC) sector. Although numerous conceptual models and institutional standards exist, they differ considerably in terminology, scope, and categorisation, creating inconsistencies that hinder both academic analysis and professional application. To address this, the study employed an intensive literature review combined with thematic categorisation to extract and synthesise competencies from leading sources.

The review identified three recurring domains, Skills, Knowledge, and Core Personality Traits, that provide a structured foundation for understanding PM effectiveness. Within each domain, comprehensive definitions were developed by clustering overlapping elements and aligning recurring patterns across frameworks, offering both conceptual clarity and practical relevance for the construction sector.

At the same time, the analysis reveals key limitations. Traditional frameworks often lack consistency, remain context dependent, and are slow to adapt to the challenges introduced by digital transformation. While they provide indispensable foundations, they are insufficient on their own for the evolving digital construction era. This underscores the need for a unified taxonomy that integrates traditional and digital competencies, providing the basis for empirical validation through a Next-Gen digital PM competency model in later chapters.

3.2 Introduction

The construction industry is essential to global economic growth (Alaloul et al., 2021). It acts as a country's economic engine and provides a foundation for development (Rafiq et al., 2021). Construction-related expenditure contributes to approximately 13 % of global GDP, even though sector productivity has increased by barely 1 % annually over the last two decades (Barbosa et al., 2017). Major markets such as Indonesia, the United States, India, and China account for about 58 % of global construction growth (Marsh, 2021), and the industry is predicted to reach 15.2 trillion US dollars by 2030 with an average growth rate of 3.5 % per annum. Within this context, project management has been recognised as a primary driver for enhancing the sector (Khamaksorn, 2016).

The administration of design, planning, and construction is conducted professionally using project management techniques that control quality, cost, and time, critical factors in project success, with the project manager (PM) playing a pivotal role (Munns & Bjeirmi, 1996; PMI, 2013). Numerous studies confirm that PM competencies are a decisive factor in successful project delivery (Crawford, 2000; Pretorius et al., 2022). Empirical evidence indicates that up to 47 % of project success can be attributed to the competency of the PM (Hwang & Ng, 2013). Scholars also emphasise that PM competencies enhance outcomes, foster stakeholder satisfaction, and mitigate risks in increasingly complex environments (Turner & Müller, 2005; Stevenson & Starkweather, 2010). The sector is therefore becoming increasingly aware of the strong link between PM competencies and project success.

A critical question, however, is whether current PM competencies remain adequate, particularly given the limited updates to many frameworks. In addition, the coexistence of various international guidelines has created inconsistencies in competency assessment and development. Addressing this issue requires a consolidated understanding of traditional PM competencies that can provide a structured foundation for workforce education and professional training in the Architecture, Engineering, and Construction (AEC) sector.

This chapter therefore responds to the following research question:

RQ1: *Which traditional project manager competencies are identified in literature and professional frameworks, and how can these be categorised into skills, knowledge, and core personality traits?*

To address this, the chapter applies a two-stage approach. First, an intensive literature review (LR) is conducted, drawing on international guidelines, models, and academic contributions to extract competency elements relevant to PM practice. Second, these elements are subjected to thematic categorisation, resulting in a consolidated framework structured around three overarching domains: Skills, Knowledge, and Core Personality.

3.3 Method

The development of a consolidated framework of traditional PM competencies in construction required a structured methodological approach, given the fragmented and inconsistently updated nature of existing guidelines and models. This chapter therefore applying a two-stage process to identify, extract, and categorise competencies specifically relevant to the AEC sector. The aim is to establish an updated baseline that reflects the foundations of professional PM practice in construction.

Stage 1 consisted of an intensive round of LR to identify competency elements across international standards, industry guidelines, and academic publications, with a focus on studies explicitly addressing PMs in construction. *Stage 2* involved thematic categorisation, synthesising these elements into a unified framework structured around three overarching domains: Skills, Knowledge, and Core Personality. The overall sequence is shown in Figure 3.1.

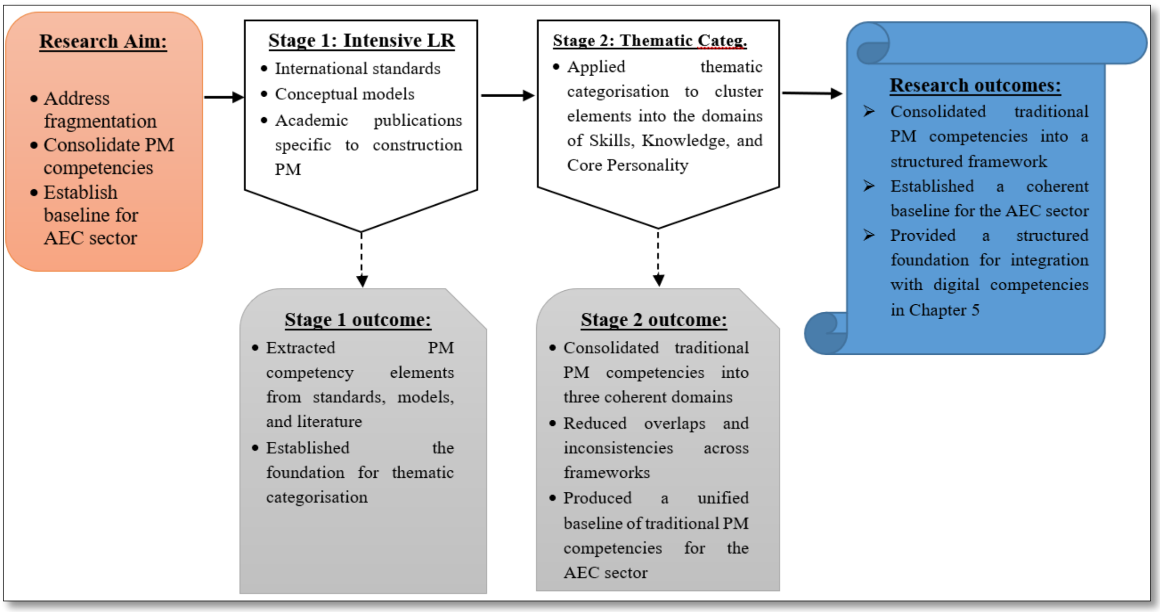

Figure 3.1: Two-stage methodological approach for consolidating traditional project manager competencies

In *Stage 1*, LR is defined as a systematic process of identifying, evaluating, and synthesising prior knowledge to establish a foundation for further study (Snyder, 2019). The review extracted competency elements from academic studies and professional standards widely recognised in project management. Searches were conducted in Scopus and supplemented by official publications from leading project management associations. A structured Boolean strategy combined project management and competency terms with construction-specific filters, for example ("project manager" OR "project management" OR PM) AND ("competenc*" OR "skill" OR "capabilit*") AND ("framework" OR "baseline" OR "standard") AND ("construction" OR "AEC"). This ensured systematic coverage of academic and professional sources, while excluding unrelated studies. The extracted elements are presented in Section 3.6.

To ensure rigour, inclusion and exclusion criteria guided the selection of sources, as shown in Table 3.1.

Table 3.1: Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• Explicit definition, categorisation, or discussion of PM competencies.	• Focus solely on technical or engineering skills without a competency perspective.
• Relevant to project management generally or specifically to the AEC sector.	• Mentions competencies only superficially without categorisation.
• Published in English in peer-reviewed journals, conferences, or by recognised professional associations.	• Non-English publications.

In *Stage 2*, thematic categorisation is defined as a qualitative method used to identify, analyse, and report recurring patterns within data (Braun & Clarke, 2006). Here, it was applied to synthesise the competency elements identified in *Stage 1* into a structured framework. Following established competency research traditions (Boyatzis, 1982; Spencer & Spencer, 1993), the extracted elements were clustered into three overarching domains:

- **Skills**: Practical and technical abilities enabling construction PMs to plan, organise, and execute project activities.
- **Knowledge**: Theoretical and cognitive understanding of tools, processes, and organisational contexts.
- **Core Personality**: Enduring traits, values, and behavioural attributes that shape the effectiveness of PMs in complex construction environments.

This stage aimed to consolidate fragmented definitions into a single structure, reducing inconsistencies and clarifying competency expectations in the AEC sector.

3.4 Historical Evolution of Competency Thinking

The term competency has deep linguistic and conceptual roots, deriving from the Latin competentia, meaning "has the right to speak" or "is authorised to judge" (Caupin et al., 2006; Misra & Sharma, 2016; Ogbu et al., 2019; Wong, 2020). Its first formal use in academic literature appeared in 1959 when Robert W. White described competence as an individual's effective interaction with the environment, distinguishing between competence as an achieved ability and as a motivational drive influencing performance (Wong, 2020; Le Deist & Winterton, 2005). This broadened the definition beyond technical proficiency to include skills, attitudes, and knowledge (Caupin et al., 2006).

The 1970s marked a turning point with David McClelland's seminal article Testing for Competency Rather Than for Intelligence, which argued that intelligence tests were poor predictors of workplace success. McClelland instead highlighted interpersonal skills, leadership, communication, patience, and self-regulation as stronger indicators of performance (Wong, 2020; Vazirani, 2010). His work initiated the first wave of competency modelling, later institutionalised through Hay McBer and Company in the mid-1970s (Le Deist & Winterton, 2005).

Building on this, Boyatzis (1982) developed the Job Competence Assessment (JCA) Technique, identifying characteristics that differentiate high-performing from average-performing managers. Boyatzis defined job competency as "an underlying feature of a person that leads to or produces outstanding or successful performance" (Yeung, 1996), emphasising the alignment of individual attributes with job demands and organisational context (Wong, 2020; Omran & Suleiman, 2017; Vathanophas, 2007). Tools such as Flanagan (1954) Critical Incident Technique also laid the groundwork for behavioural-event interviewing and systematic competency mapping (Rothwell & Lindholm, 1999).

Large-scale applications soon followed. The American Management Association (AMA), in collaboration with McBer, conducted one of the earliest broad competency programs with 1,800 managers. Their findings identified five maturity-related competencies, on-the-job, interpersonal, entrepreneurial, intellectual maturity, and specialised knowledge, as critical for superior managerial performance (Rothwell & Lindholm, 1999; Hayes, 1979; Mani, 2013). In parallel, McLagan (1983), McLagan (1989) embedded competencies into Human Resource Development (HRD) practices, positioning them as central tools for training, workforce planning, and succession management (Moy, 1992).

The field advanced further with Spencer and Spencer (1993) influential Competence at Work, which formalised the iceberg model, distinguishing visible competencies (knowledge and skills) from deeper attributes (motives, values, and self-concept). Their framework demonstrated how to construct competency dictionaries and models for organisational application, cementing competencies as a methodology in HR and management practice (Rothwell & Lindholm, 1999).

By the 1990s, competency had evolved into a strategic organisational concept. Prahalad and Hamel (1990), Hamel and Prahalad (1994) introduced core competencies as collective organisational strengths providing market access, customer value, and sustained competitive advantage. Ulrich (1997) extended this view by linking competencies to organisational capabilities, the collective expertise and adaptability that allow firms to respond to changing environments.

Taken together, these milestones chart the evolution of competency thinking from its psychological origins (White, 1959; McClelland, 1973), through its managerial and HR applications (Spencer & Spencer, 1993; Boyatzis, 1982), to its strategic integration at the organisational level (Prahalad & Hamel, 1990; Ulrich, 1997). This trajectory provides the conceptual foundation upon which competency frameworks in project management were later developed, bridging individual effectiveness with organisational strategy.

Throughout this development, the terms "competence" and "competency" were often used interchangeably in psychology and management literature (Le Deist & Winterton, 2005; Crawford, 2005). Early studies emphasised observable competence in relation to tasks or performance standards, while later works increasingly employed competency to describe the underlying behavioural attributes that drive performance. This lack of terminological consistency has fuelled ongoing debates in the field and is addressed further in Section 3.4.1.

3.4.1 Competence vs. Competency

A longstanding debate in the literature concerns the distinction between competence and competency. Although often used interchangeably, several scholars emphasise subtle but important differences. Competence is generally linked to the ability to perform tasks or functions to an accepted standard, usually aligned with job requirements and professional benchmarks (Le Deist & Winterton, 2005; Crawford, 2005). It represents the threshold of ability needed to achieve satisfactory performance within a defined context.

In contrast, competency is defined as the underlying set of characteristics, knowledge, skills, and behavioural traits that enable effective performance (Wong, 2020; Crawford, 2005). It captures not only what an individual can do but also how they apply their capabilities in practice. This includes attributes such as motivation, interpersonal style, values, and problem-solving orientation, which may not be directly observable but strongly influence outcomes.

For example, while competence may describe the technical ability of a PM to apply scheduling techniques or risk analysis methods, competency extends to behavioural attributes such as leadership, communication, and resilience, which determine how effectively these technical skills are applied in dynamic environments.

The debate has also been shaped by the diversity of definitions across psychology, management, human resources, and education. Table 3.2 summarises how different scholars have defined competence and competency, reflecting their evolution across disciplines.

Table 3.2: Evolution of Competency Definitions from Various Scholars

Author	**Definition**
Gaddis (1959)	"ability to have different approach towards classic management functions, ability to finish tasks within the time with no specific information at the early stages of the project and that is related to the ability of taking risks, shall have power in the organization to delegate responsibility to subordinates, 'trouble shooting' skills, planning skills, avoid crises

	'selling and reselling the project' abilities, to be able to act as a front man and a man in between with communication skills, 'ability to generate necessary drive and momentum to spark the project to success'."
McClelland (1973)	Knowledge and skills are "threshold competencies" that are needed by all employees in order to be able to perform their jobs. Motive, traits, self-image, and social role are "differentiate competencies" which superior performers have but average performers do not.
Hayes (1979)	Competences generally include knowledge, motivation, social characteristic and roles, or skills of one person in accordance with the demands of organizations of their clerks.
Boyatzis (1982)	"An underlying characteristic of an individual which is causally related to superior performance in a job."
Mirabile (1985)	"Knowledge, skills, abilities and behaviours required for successful performance of job duties."
Albanese (1989)	Competences are individual's characteristics which are used to effect on the organization's management.
Woodruffe (1993)	Competence is a combination of two topics of personal competence and merit at work. Personal merit is a concept which refers to the dimensions of artificial behavior in order to show the competence performance and merit at work depends on the competences of the person in his field.
Spencer and Spencer (1993)	"An underlying characteristic of an individual that is causally related to criterion-referenced effective and/or superior performance in a job or situation."
Dubois (1993)	"Those characteristics—knowledge, skills, mindsets, thought patterns, and the like—that, when used singularly or in various combinations, result in successful performance."
Hartle (1995)	"A characteristic of an individual that has been shown to drive superior job performance. It includes both visible competencies of knowledge and skills and underlying elements of competencies like traits and motives."
Blancero et al. (1996)	"Knowledge, skills, abilities, and other attributes required to perform desired future behaviour."
Mansfield (1996)	"Skills and traits that are needed by employees to be effective in a job."
McLagan (1996)	"Knowledge and skills that underlie effective performance."
Marrelli (1998)	"Measurable human capabilities that are required for effective work performance demands."
Weinert (2001)	"Those intellectual abilities, content-specific knowledge, cognitive skills, domain-specific strategies, routines and subroutines, motivational tendencies, volitional control systems, personal value orientations, and social behaviours [combined] into a complex system."
Kurz and Bartram (2002)	"Repertoires of capabilities, activities processes and responses available that enable a range of work demands to be met more effectively by some people than by others, and not as the behaviour or performance itself."
Jackson and Schuler (2003)	"A measurable pattern of skills, knowledge, abilities, behaviours, and other characteristics that an individual needs to perform work roles or occupational functions successfully."
Shermon (2004)	"An underlying characteristic of a person, which enables him to deliver superior performance in a given job, role or situation."
Bartram (2005)	Competencies as sets of behaviours that are instrumental in the delivery of desired results or outcomes.
Draganidis and Mentzas (2006)	"A combination of tacit and explicit knowledge, behaviour and skills that gives someone the potential for effectiveness in task performance."
Boyatzis (2008)	"A capability or ability. It is a set of related but different sets of behaviours organized around an underlying construct, which we call the 'intent'. The behaviours are alternate manifestations of the intent, as appropriate in various situations or times."
Koeppen et al. (2008)	"Competencies are conceptualized as complex ability constructs that are context-specific, trainable, and closely related to real life."
Tripathi and Ranjan (2009)	"Competencies are not simply concrete actions that are easily imitated. Instead, competencies can be manifestations of some underlying intent driven by a person's basic personality, ability, knowledge and skills."
Blömeke et al. (2015)	Competence is viewed as a horizontal continuum, where different aspects of competence interact and lead to observable behaviour in specific situations.

Maaleki (2018)	"Competency is a series of knowledge, abilities, skills, experiences and behaviors, which leads to the effective performance of individual's activities. Competency is measurable and could be developed through training. It is also breakable into the smaller criteria."
European Commission (2019)	"Digital competence involves the confident, critical and responsible use of, and engagement with, digital technologies for learning, at work, and for par-ticipation in society. It includes information and data literacy, communica-tion and collaboration, media literacy, digital content creation (including pro-gramming), safety (including digital well-being and competences related to cybersecurity), intellectual property related questions, problem solving and critical thinking."
Guitert et al. (2020)	"Digital competence clearly involves more than knowing how to use devices and applications. It consists of (a) technical digital technologies skills, (b) the ability to use digital technologies in a meaningful way for working, studying and other everyday activities, and (c) the ability to critically evaluate digital technologies."
Oberländer et al. (2020)	Digital competencies at work are a set of knowledge, skills, abilities, and other characteristics that enable individuals to effectively and successfully perform job tasks in digital work environments
Quintero (2022)	"The ability to adopt and use new or existing information technology to critically analyze, select and evaluate digital information to investigate and solve work-related problems and develop a collaborative body of knowledge"
Sánchez-Canut et al. (2023)	"Professional digital competence could, thus, be defined as the set of knowledge, skills, and attitudes that enable the effective and responsible use of digital technologies to perform tasks and solve problems in increasingly digitized working environments; build meaningful professional relationships through digital collaboration; foster innovation in the workplace; facilitate lifelong continuous professional development; and enhance individuals' employability."
Chiu et al. (2024)	"Clearly, digital competency encompasses more than just proficiency in operating devices and programs; it is also closely intertwined with the ability to communicate using technologies and digital skills. It should include a balanced view of technology for responsible and healthy use of digital technology. Knowledge and attitudes about privacy and security, legal and ethical considerations, and the role of digital technologies in society should be included."
Cosgrove and Cachia (2025)	"Digital competence – knowledge, skills and attitudes for the confident, critical and responsible use of, and engagement with, digital technologies for learning, at work, and for participation in society."

These definitions show that competence is often associated with baseline ability, while competency emphasises the behavioural and motivational attributes that distinguish superior performance.

For this thesis, competency is defined as an integrated set of knowledge, skills, abilities, experiences, behaviours, and personal attributes that enable PMs to achieve superior performance in complex project environments. It encompasses both visible elements, such as technical knowledge and practical skills, and underlying traits, including motivation, attitudes, and personality.

Competency is regarded here as measurable and trainable, developed progressively through education and experience, and evaluated against professional standards. It can be grouped into three overarching domains:

- **Skills**: Functional, technical, and methodological abilities that enable PMs to plan, organise, and deliver projects effectively. This includes proficiency in tools, techniques, and approaches (e.g., scheduling, risk management, digital platforms).
- **Knowledge**: Theoretical understanding, cognitive skills, and contextual awareness that allow PMs to interpret industry trends, organisational strategies, and project processes.

- **Core Personality Traits**: Enduring behavioural and interpersonal attributes that shape how PMs apply skills and knowledge. These include leadership, communication, ethical responsibility, resilience, and adaptability.

This working definition provides conceptual clarity and establishes the basis for thematic categorisation in later sections of this chapter and for the taxonomy integration in Chapter 5.

3.5 Project Management Context

Understanding PM competencies requires situating them within the broader historical and professional evolution of the role. This section therefore traces how PMs became recognised as professionals, outlines the frameworks and standards that shaped their responsibilities, and considers how these developments influence competency expectations. By establishing this context, the section provides a clearer basis for evaluating the traditional competencies relevant to construction.

3.5.1 The Evolution of Project Management as a Profession

Although the practice of managing complex undertakings dates back millennia, most notably in the construction of the Egyptian pyramids (c. 2570 BC) and the Great Wall of China (208 BC), project management as a formalised discipline only began to take shape in the mid-20th century (Carayannis et al., 2005; Conrad, 2017; Haughey, 2010). These early endeavours demonstrate that even ancient societies applied rudimentary forms of planning, coordination, and control, often assigning distinct managerial roles to oversee execution.

Modern project management methodology emerged during the 1950s with the institutionalisation of systematic planning and control techniques. The American Association of Cost Engineers (AACE) was founded in 1956 to standardise practices in cost engineering and project control, later publishing the Total Cost Management Framework in 2006. In parallel, major innovations in scheduling tools were introduced: Critical Path Method (CPM) by DuPont in 1957, and the Program Evaluation Review Technique (PERT) by the United States Navy in 1958 during the Polaris missile project (Conrad, 2017; Haughey, 2010). These developments established the scientific and engineering foundations of project management, marking its recognition as a distinct field of professional practice (Carr , n.d.).

Prior to the 1940s, the role of the PM was not formally acknowledged, with project delivery largely embedded within engineering or administrative functions (Bourne, 2010). By the 1960s and 1970s, however, PMs increasingly appeared in organisations, often entering the role unintentionally and with diverse backgrounds, as industries began adopting the concept of projects as discrete organisational undertakings. From the 1980s onward, project management became progressively codified, supported by professionalisation, certification schemes, and the recognition of project delivery within defined parameters of time, cost, and scope.

This period also reflected growing interest in leadership and governance, with effective PM practice linked to higher-order leadership qualities, what Collins (2001) termed “Level 5 Leadership,” that emphasised both team needs and organisational structures. Project Management Offices (PMOs) emerged in parallel, formalising support for programme and portfolio management within governance frameworks. Project success also evolved: while traditionally judged against the “iron triangle” of cost, time, and scope, success became increasingly associated with stakeholder satisfaction and strategic value delivery (Bourne, 2010).

Historical developments in management reinforced these trends. Procter & Gamble's introduction of "brand managers" in the 1920s is often regarded as one of the earliest managerial structures resembling modern PM, while the U.S. Air Force adopted project offices in the 1930s to oversee aviation programmes (Morris , 1994). In construction, Bechtel was among the first firms to designate PMs formally, with the Trans Mountain Oil Pipeline in Canada (1951–1953) representing an early milestone (Stretton, 1994). By the late 1950s, Civil & Civic Pty Ltd in Australia promoted project management as a professional service, further institutionalising the role.

The late 1950s and 1960s also saw methodological innovations such as CPM and the introduction of the "iron triangle" of cost, time, and quality (Barnes, 2006), which provided a foundation for defining PM responsibilities (Weaver, 2007). At the same time, the broader general management movement and principles of scientific management influenced structured approaches to project delivery.

By the mid-1990s, project management was sufficiently mature to warrant codification as a recognised profession, with international bodies developing competency standards and knowledge frameworks. Three foundational standards remain widely acknowledged: the PMBOK Guide by the Project Management Institute (PMI, 1996) in the United States, the ICB Competence Baseline by the International Project Management Association (International Project Management Association (IPMA), 1999) in Europe, and the BoK/CRMP BoK by the Association for Project Management (Association for Project Management (APM), 1996) in the United Kingdom (Crawford, 2000). Performance-based competency standards were also pioneered in Australia through the Australian National Competency Standards for Project Management (1996), and in the United Kingdom through the Occupational Standards Council for Engineering initiatives (OSCEng, 1996, as cited in Crawford, 2000; OSCEng, 1997, as cited in Crawford, 2000). These standards extended project management from a technical discipline into a performance-based profession, explicitly linking competencies with measurable workplace outcomes (Crawford, 2000).

In this thesis, a PM is defined as the individual formally entrusted with overall responsibility for planning, coordinating, and delivering projects within defined parameters of scope, time, cost, and quality. Beyond managing these operational constraints, the PM functions as a strategic leader and integrator of people, processes, and technologies, ensuring that project outcomes align with organisational goals and stakeholder expectations. Modern PMs require not only technical and methodological expertise but also contextual awareness, interpersonal effectiveness, and adaptive leadership capabilities.

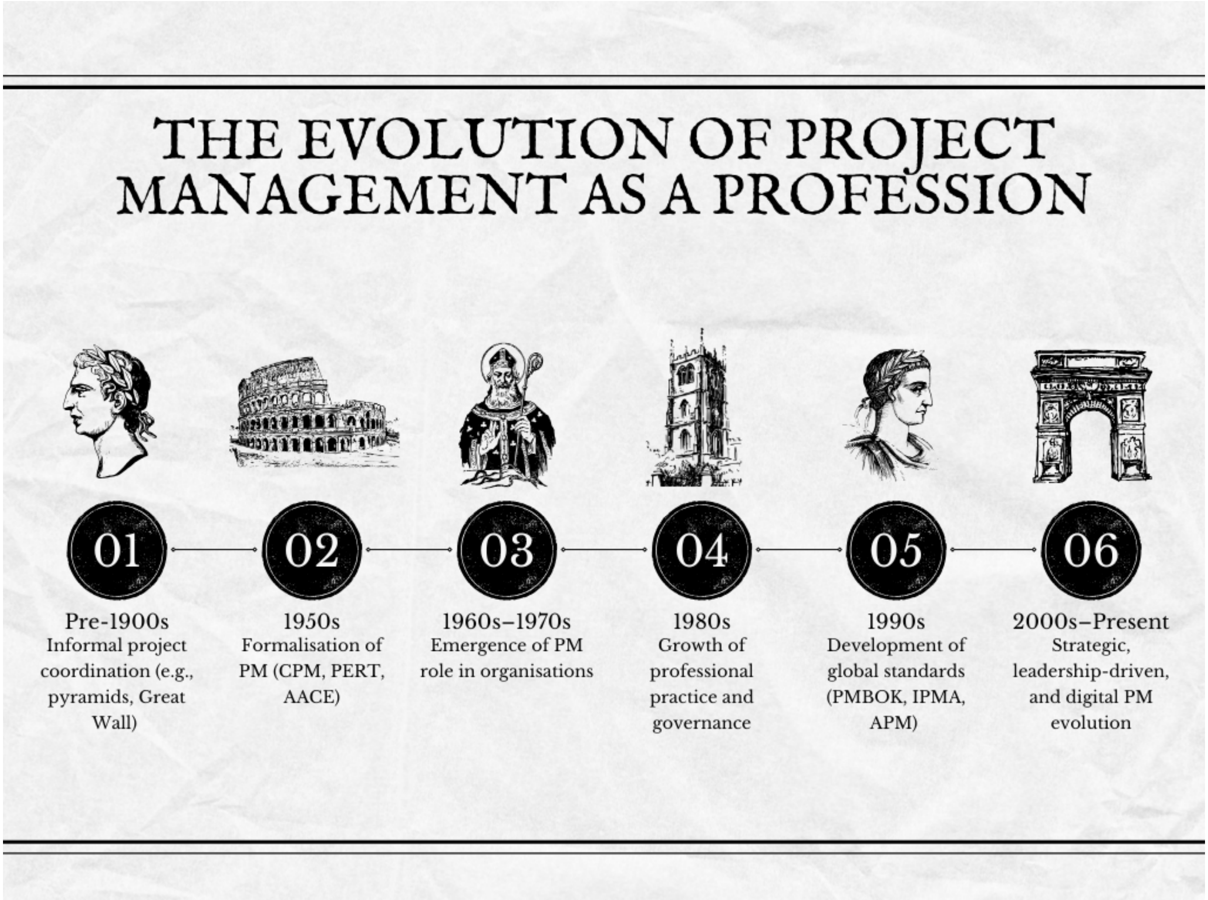

Figure 3.2A: Timeline illustrating the evolution of project management as a profession

Taken together, these developments illustrate how the role of PMs evolved from an incidental appointment to a formally defined profession underpinned by standards and competencies as summarised in Figure 3.2A. This professionalisation sets the stage for the next section, which examines the relationship between project manager competency and project success.

3.5.2 Project Manager Competency and Project Success

A recurring theme in the literature is the link between PM competencies and project success. Scholars distinguish between success criteria, which are the benchmarks used to judge outcomes, and success factors, which are the behaviours, processes, and contextual enablers that drive achievement (Crawford, 2000; Prabhakar, 2008).

Research shows that PM competencies influence both dimensions. Competency is recognised as a critical determinant of delivery, with the skills and knowledge applied by PMs directly shaping results. At the same time, the professionalisation of project management has led to standards and certification processes designed to define, recognise, and evaluate these competencies. Frameworks such as the APM BoK (1996), IPMA Competence Baseline (1999), and PMBOK Guide (PMI, 1996) embed expectations aligned with attribute and performance based competency models.

Competency is considered an intangible asset, inferred from observable evidence such as behaviours and outcomes (Heywood et al., 1992). Three main approaches are recognised:

- **Attribute-Based Approach:** Defines competency in terms of traits, attitudes, skills, and knowledge. It assumes these attributes naturally translate into workplace performance but lacks consistent evidence of effectiveness (Heywood et al., 1992).
- **Performance-Based Approach:** Focuses on observable behaviours and outcomes in workplace settings. Applied widely in South Africa, New Zealand, Australia, and the U.K., it is results-focused but may overlook attributes such as motivation and judgement (Heywood et al., 1992).
- **Integrated Approach:** Combines attributes with demonstrated workplace outcomes, providing a holistic view of competency that reflects both what PMs possess and how they apply it (Crawford, 2005; Heywood et al., 1992; Bredillet et al., 2015).

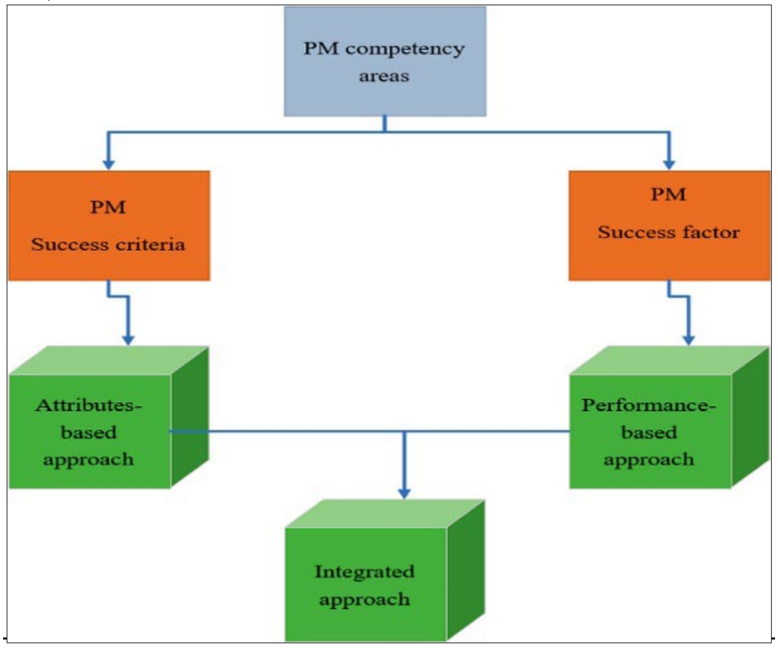

Figure 3.2B: Hierarchy of project manager competency approaches and their relationship to success criteria and success factors

As illustrated in Figure 3.2B, PM competency areas influence both success criteria and success factors through attribute-based, performance-based, and integrated approaches. Considerable research has explored how this interplay shapes project outcomes. Success criteria are no longer limited to the iron triangle of cost, time, and scope, but now include quality, stakeholder satisfaction, and strategic alignment (Baccarini, 1999; Freeman & Beale, 1992; Pinto & Slevin, 1988). Success factors include behaviours such as leadership, planning, stakeholder consultation, and communication, which empirical studies consistently rank as decisive (Crawford, 2000; Pinto & Slevin, 1987; Baker et al., 1988).

In the context of the AEC sector, these distinctions can be illustrated through practical examples. PM success criteria refer to the measurable outcomes used to evaluate project performance, such as delivering a construction project within budget, on schedule, and to the required quality standards, while also achieving stakeholder satisfaction and regulatory compliance. In contrast, PM success factors relate to the behaviours and processes that enable these outcomes, including effective coordination of multidisciplinary teams, proactive risk management, stakeholder engagement, and the use of digital tools such as BIM for planning and monitoring. For example, a project may meet its cost and time targets (success criteria) due to strong leadership, structured planning, and real-time data-driven decision-making (success factors). This highlights the role of PM competencies as the mechanism linking capability to project outcomes in AEC environments.

Research linking PM competencies to project success dates back to Gaddis (1959) and McClelland (1973), who emphasised that interpersonal skills and motivation often predict performance more strongly than intellectual ability. Later contributions by Frame (1999), Kerzner (2009), and Turner (2009) reinforced that leadership, planning, communication, and stakeholder engagement are consistently associated with higher project performance. Empirical studies by Posner (1987), Ford and McLaughlin (1992), Wateridge (1996), and Zimmerer and Yasin (1998) further demonstrated that planning, integrative control, and team development rank among the most significant differentiators of success.

As Crawford (2000) notes, PM competency factors often outperform general success factors in explaining performance. Leadership consistently ranks among the most critical PM competencies, while planning and control dominate both competency and success research, underscoring their integrative role. This convergence indicates that PM competency is not merely supportive of project success but the primary mechanism through which both success criteria and success factors are realised in practice. Building on this foundation, the next section examines the competency frameworks in project management that formalise and institutionalise these competencies across professional standards.

3.6 Competency Frameworks in Project Management

The professionalisation of project management has been closely tied to the development of structured competency frameworks, which define the knowledge, skills, and behavioural attributes expected of practitioners. These frameworks provide reference points for certification, education, and workforce development, offering benchmarks for both individual assessment and organisational capability building (Crawford, 2005; Bredillet et al., 2015).

Over the past decades, two broad traditions of competency modelling have shaped the field. The first tradition comprises conceptual models rooted in psychology and management education, including Bloom's Taxonomy (1964), El-Sabaa's skills model (2001), and Crawford's integrated framework (2005). These established theoretical foundations by classifying competencies into domains of knowledge, skills, and personal attributes, bridging the attribute- and performance-based approaches.

The second tradition encompasses professional standards and guidelines developed by international bodies such as the IPMA and PMI. These frameworks embed competencies into certification systems and role delineation studies, ensuring alignment with practice. Recent versions, including IPMA's ICB v4 (2015), PMI's PMBOK® Guide and Talent Triangle (PMI, 2022c), and the Project Manager Competency Development (PMCD) Framework (PMI, 2002), represent the most up-to-date references, capturing technical, behavioural, and contextual competencies required in today's project environments.

A persistent challenge lies in the irregular update cycles of these frameworks. While industries such as construction undergo rapid technological and organisational change, revisions are often sporadic, creating risks of misalignment. For example, IPMA's ICB had a nine-year gap between its third (2006) and fourth edition (2015) (International Project Management Association (IPMA), 2006; International Project Management Association (IPMA), 2015). Similarly, PMI's Talent Triangle was not revised until 2022, despite significant changes in global project management practice between 2017 and 2022 (PMI, 2017a, PMI, 2022b, PMI, 2022a). Such delays underscore the need for continual revision to keep frameworks responsive to evolving demands.

To enable consistency in later analysis, competency components from both conceptual models (Bloom's Taxonomy, El-Sabaa's model, Crawford's integrated framework) and professional standards (IPMA ICB v4, PMI's PMBOK® Guide and Talent Triangle, and the Project Manager Competency Development (PMCD) Framework) are categorised under the three overarching domains of Skills, Knowledge, and Core Personality. While earlier models established the theoretical underpinnings of competency thinking, international standards remain the most influential for education, certification, and practice. The following sub-sections therefore review these frameworks in detail, beginning with conceptual models before turning to professional standards.

3.6.1 Bloom's Taxonomy Model

One of the earliest and most influential frameworks relevant to competency thinking is Bloom's Taxonomy, first developed in 1964. It remains a cornerstone in educational design and professional training, often forming the basis for the Knowledge, Skill, and Attitude (KSA) framework used across multiple domains (Winterton et al., 2006). The taxonomy distinguishes three domains:

1. **Cognitive (Knowledge) Domain**: Mental skills, including the ability to acquire, process, and apply information.
2. **Psychomotor (Skill) Domain**: Physical or manual skills, involving coordination and technical execution.
3. **Affective (Attitude) Domain:** Values, emotions, and attitudes shaping behaviour and performance.

These domains were further categorised into levels of learning outcomes, as illustrated in Table 3.3, providing a structured means of distinguishing competency attributes across contexts such as information technology, healthcare, engineering, and project.

Table 3.3: Bloom's taxonomy domains and categories (Winterton et al., 2006)

Domain	Category
Cognitive (KNOWLEDGE) *"knowledge and the development of intellectual skills"* (Winterton et al., 2006, p. 18)	1. knowledge (recall of data); 2. comprehension (understand meaning, interpret); 3. application (use a concept in a new situation); 4. analysis (separate material into component parts); 5. synthesis (build a structure or pattern); 6. evaluation (make judgments) (Winterton et al., 2006, p. 18)
Psychomotor (SKILL) *"physical movement, coordination, and use of the motor-skill areas"* (Winterton et al., 2006, p. 18)	1. perception (using sensory cues to guide motor activity); 2. set (readiness to act); guided response (imitation, trial and error); 3. mechanism (intermediate stage in learning a complex skill); 4. complex overt response (skilful performance of motor acts that involve complex movement patterns); 5. adaptation (modify movement patterns to meet special requirements); 6. origination (developing new movement patterns to fit specific problem) (Winterton et al., 2006, p. 19)
Affective (ATTITUDE) *"the manner in which we deal with things emotionally, such as feelings, values, appreciation, enthusiasms, motivations, and attitudes"* (Winterton et al., 2006, p. 18)	1. receiving phenomena (awareness and attention); 2. responding to phenomena (active participation); 3. valuing (acceptance and commitment); 4. organization (organizing values into priorities); 5. internalising values (having a value system that controls behaviour) (Winterton et al., 2006, p. 18)

Despite its significance, Bloom's Taxonomy has been criticised for limited revision and adaptation. Since its introduction, the model has undergone only one major update (Anderson and Krathwohl, 2001), which refined categories but preserved its original three-domain structure. As Adams (2015) observes, the taxonomy continues to be widely applied in education and professional training, yet its static design raises concerns about its ability to reflect contemporary learning demands.

In the context of construction project management, where digitalisation, stakeholder complexity, and sustainability introduce new competency requirements, Bloom's framework is increasingly viewed as insufficient. It offers a strong conceptual foundation but lacks the flexibility to capture the dynamic, multi-dimensional competencies needed in modern project environments. This limitation highlights the need for later models, such as El-Sabaa's skills framework, which extended competency thinking beyond Bloom's original domains and is discussed in Section 3.6.2.

3.6.2 El-Sabaa's Competency Model

The conceptualisation of projects as temporary organisations gained prominence in the 1980s, attracting significant attention from researchers across disciplines (Lundin & Söderholm, 1995). Within this perspective, El-Sabaa (2001) highlighted three categories of PM skills. Technical or hard skills were regarded as essential, providing the methodological and analytical foundation for effective planning, monitoring, and execution. At the same time, increasing recognition was given to human or soft skills, including communication, leadership, and relationship management, which directly influence teamwork and stakeholder engagement (Kloppenborg & Petrick, 1999; Pinto, 2000; Gruden & Stare, 2018). Finally, conceptual and organisational skills were identified as critical for aligning projects with strategic goals and integrating them across functions and business units.

Accordingly, El-Sabaa (2001) model defined three core skill domains:

1. **Technical Skills**: Methodological and analytical capabilities required to apply project management tools, techniques, and specialised knowledge.
2. **Human Skills**: Interpersonal and behavioural competencies necessary for managing relationships, communication, and collaboration effectively.
3. **Conceptual and Organisational Skills**: Strategic capabilities that allow PMs to position projects within organisational objectives and integrate them across functions.

These three domains were subdivided into 15 specific elements, as shown in Table 3.4, which collectively define the skill sets required for effective PM practice (El-Sabaa, 2001).

Table 3.4: El-Sabaa's Project Manager Skill Areas (El-Sabaa, 2001)

Human skill	Mobilizing: Project manager is able to mobilize the mental and emotional energy of his subordinate
	Communication: Project manager is able to listen, persuade, and understand what others mean by their behavior
	Coping with situations: Project manager is flexible, patient, and persistent
	Delegating Authority: Project manager is able to give people the opportunity as group members to participate in making decisions
	Political sensitivity
	High self-esteem
	Enthusiasm
Conceptual and organizational skill	Planning
	Organizing
	Strong goal orientation
	Ability to see the project as a whole
	Ability to visualize the relationship of the project to the industry and the community
	Strong problem orientation
Technical skill	Special knowledge in the use of tools and techniques
	Project knowledge
	Understanding methods, processes, and procedures
	Technology required
	Skills in the use of computer

The enduring significance of El-Sabaa's model lies in its balanced treatment of technical, human, and strategic competencies. Technical skills provide the foundation for operational efficiency, while human and conceptual skills equip PMs with leadership capacity and organisational awareness. This balance influenced later frameworks, particularly Crawford's integrated model, which sought to merge these domains into a unified competency classification, as discussed in Section 3.6.3.

3.6.3 Crawford's Integrated Competency Model

One of the most influential contributions to project management competency research is the integrated model developed by Crawford (2005). This model addresses the divide between attribute-based and performance-based approaches by merging them into a holistic framework that recognises both the underlying characteristics of individuals and their observable workplace performance. In doing so, it provides a more comprehensive foundation for defining, assessing, and applying competencies in professional practice.

The framework is structured into three interrelated domains (Figure 3.3):

1. **Knowledge and skills (Attribute-Based):** This input domain reflects the qualifications, expertise, and technical abilities that individuals bring to their roles, representing the baseline capacity to apply professional practice.
2. **Core Personality Characteristics (Attribute-Based):** This input domain captures the enduring personality traits and behavioural attributes that underpin effectiveness, including motivation, interpersonal style, and values.
3. **Demonstrable Performance (Performance-Based):** This output domain focuses on workplace performance, defined as the ability to complete tasks and deliver outcomes at the proficiency expected within a professional context.

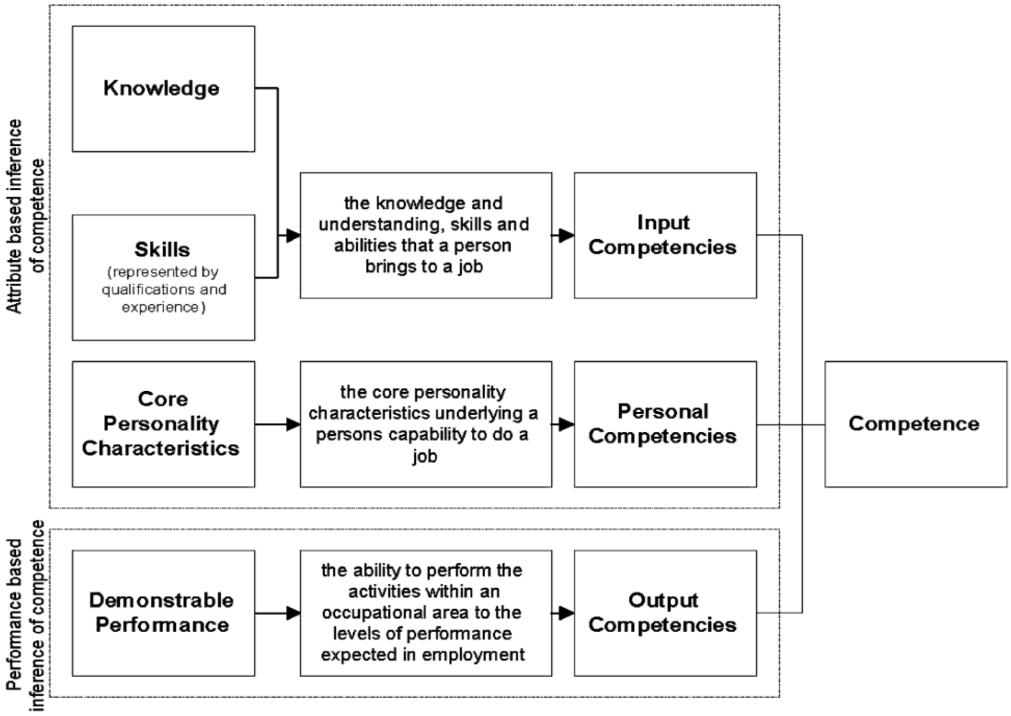

Figure 3.3: Crawford's Integrated Model of Competency (Crawford, 2005)

By integrating attributes and performance, Crawford's model emphasises that competency extends beyond knowledge or skills to include how effectively these capabilities are applied in practice. This dual focus addresses the limitations of earlier models that treated attributes and performance in isolation, highlighting instead their interdependence in shaping project management effectiveness.

Crawford's integrated perspective has since become a cornerstone in competency research, widely adopted in academic studies and professional standards. Its influence can be seen in the development of global frameworks such as the IPMA ICB and PMI Talent Triangle, which similarly embed both personal attributes and demonstrable performance into their competency structures. However, Crawford's model has not been substantially revised since its introduction in 2005, raising questions about its continued alignment with the evolving demands of digitally transforming industries.

This sets the stage for Section 3.6.4, which reviews the professional standards that institutionalised these integrated perspectives into widely adopted global competency frameworks.

3.6.4 Core Competencies Required of Project Managers – Birkhead et al. (2000)

While most competency frameworks have been developed by international professional associations or conceptual models, Birkhead et al. (2000) provide an important empirical perspective by identifying the core competencies required of PMs within a developing country context. Conducted in South Africa, their study investigated competencies across construction, engineering, and IT sectors, making it one of the earliest attempts to contextualise project management competency beyond global standards.

The study confirmed that many competencies are generic and transferable across industries, but it also highlighted contextual requirements such as legislative awareness, cultural sensitivity, and project context management, factors not always captured in international frameworks like PMI's PMBOK or IPMA's ICB. This duality underscores the need to balance universal competencies with those shaped by local environments and sector-specific demands.

Birkhead et al. (2000) identified seven major competency factors, subdivided into detailed elements, as shown in Table 3.5. These include planning and controlling, personal influence, goal focus, problem solving, team leadership, project team development, and project context. Together, they present a comprehensive yet practical skillset for effective project management.

Table 3.5: presents the competency factors and elements identified in this study (Birkhead et al., 2000)

Competency Factor	**Elements**
Planning and controlling	• Planning: Identifying objectives, defining tasks, and establishing timetables • Controlling: Ensuring activities align with objectives and making corrective actions as needed
Personal Influence	• Motivating: Stimulating the project team to achieve objectives • Honesty and Integrity: Demonstrating personal and professional credibility while respecting organizational values
Goal Focus	• Project Integration: Coordinating elements to achieve objectives • Scope Management: Defining clear objectives and preventing unnecessary changes • Human Resources: Managing team roles and dynamics effectively • Stakeholder Management: Understanding and managing expectations • Delegation: Assigning responsibilities appropriately • Communication: Conveying information clearly and effectively • Interpersonal Skills: Managing relationships and influencing stakeholders
Problem Solving	• Problem Solving: Gathering and analyzing data to develop solutions • Quality Management: Ensuring deliverables meet quality standards • Conflict Resolution: Addressing disputes constructively
Team Leadership	• Team Building: Fostering collaboration and a positive team environment • Delegation: Empowering team members with appropriate responsibilities • Decisiveness: Making and committing to decisions in challenging situations
Project Team Development	• Training of Team: Providing learning opportunities and development plans • Human Resources: Supporting team members' growth and well-being • Interpersonal Skills: Encouraging effective communication and collaboration
Project Context	• Sourcing of Funds: Securing financial resources for the project • Legislation Awareness: Understanding and adhering to legal requirements • Global Mobility: Managing projects across diverse geographical and cultural contexts • Sensitivity to Market: Adapting to market trends and demands • Financial Management: Overseeing project budgets and financial performance

Beyond its classification, the framework is valuable for emphasising interpersonal, leadership, and stakeholder competencies alongside traditional technical skills. These findings resonate with the tripartite categorisation of Skills, Knowledge, and Core Personality introduced in Section 3.4.1. One limitation is the absence of systematic updates and the model's primary focus on South Africa, which may constrain its direct applicability elsewhere.

Nevertheless, this study represents a milestone in competency research, bridging conceptual and institutional frameworks with empirical insights from practice, and reinforcing the argument that PM competencies must be adaptable to diverse and dynamic environments. This contextual perspective provides a useful complement to the international standards reviewed in the following section.

3.6.5 International Project Management Association (IPMA)

The IPMA has been one of the most influential organisations in defining and standardising project management competencies. Its framework, the Individual Competence Baseline (ICB), provides the foundation for professional certification and assessment worldwide.

The first edition of the ICB was released in 1999, based on contributions from four European project management associations. It focused primarily on the knowledge and experience required of PMs, reflecting an attribute-based orientation. A second edition (2001) introduced only minimal changes but reinforced the ICB's role as a reference for certification and assessment (IPMA, 1999).

The third edition (2006) marked a significant evolution by defining competency as a combination of knowledge, experience, and personal attitudes required for successful project management performance (IPMA, 2006). It introduced the Eye of Competence framework, grouping elements into three dimensions:

1. **Technical Competencies:** 20 elements including risk and opportunity, cost and finance, quality, scope and deliverables, and project structures.
2. **Behavioural Competencies:** 15 elements including leadership, motivation, assertiveness, ethics, and conflict management.
3. **Contextual Competencies:** 11 elements including programme orientation, permanent organisation, systems and technology, health and safety, and legal aspects.

This version recognised that project success depends not only on technical expertise but also on behavioural attributes and contextual awareness. It included a total of 46 elements, as shown in Table 3.6.

Table 3.6: IPMA Framework Version 3.0 (IPMA, 2006)

International Project Management Association (IPMA) version 3.0
Classifications attributes and elements

Technical competencies	*Behavioural competencies*	*Contextual competencies*
1. Project management success	1. Leadership	1. Project orientation
2. Interested parties	2. Engagement & motivation	2. Programme orientation
3. Project requirements & objectives	3. Self-control	3. Portfolio orientation
4. Risk & opportunity	4. Assertiveness	4. Project programme & portfolio implementation
5. Quality	5. Relaxation	5. Permanent organisation
6. Project organisation	6. Openness	6. Business
7. Teamwork	7. Creativity	7. Systems, products & technology
8. Problem resolution	8. Results orientation	8. Personnel management
9. Project structures	9. Efficiency	9. Health, security, safety & environment
10. Scope & deliverables	10. Consultation	10. Finance
11. Time & project phases	11. Negotiation	11. Legal
12. Resources	12. Conflict & crisis	
13. Cost & finance	13. Reliability	
14. Procurement & contract	14. Values appreciation	
15. Changes	15. Ethics	
16. Control & reports		
17. Information & documentation		
18. Communication		
19. Start-up		
20. Close-out		

After a nine-year gap, the fourth edition (2015) was released as the Individual Competence Baseline for Project, Programme & Portfolio Management. This version reflected the growing complexity of project environments, extending the framework beyond projects to include programme and portfolio management. It restructured the three dimensions as:

1. **People Competencies:** 10 elements focused on personal and interpersonal skills, such as self-reflection, communication, negotiation, teamwork, and leadership.
2. **Practice Competencies:** 14 elements covering technical and methodological aspects, including project design, scope, quality, procurement, risk, stakeholder management, and change management.
3. **Perspective Competencies:** 5 elements emphasising strategic and contextual aspects, including governance, compliance, culture, and power relations.

This edition provided 29 elements in total, as shown in Table 3.7

Table 3.7: IPMA Framework Version 4.0 (IPMA, 2015)

International Project Management Association (IPMA) version 4.0
Classifications attributes and elements

People competencies	*Practice competencies*	*Perspective competencies*
1. Self-reflection and self-management	1. Project design	1. Strategy
2. Personal integrity and reliability	2. Requirements and objectives	2. Governance, structure and processes
3. Personal communication	3. Scope	3. Compliance, standards and regulations
4. Relationships and engagement	4. Time	4. Power and interests
5. Leadership	5. Organisation and information	5. Culture and values
6. Teamwork	6. Quality	
7. Conflict and crisis	7. Finance	
8. resourcefulness	8. Resources	
9. Negotiation	9. Procurement	
10. Results orientation	10. Plan and control	
	11. Risk and opportunities	
	12. Stakeholder	
	13. Change and transformation	
	14. Select and balance	

The progression from ICB 3.0 to ICB 4.0 illustrates IPMA's efforts to adapt competency models to the evolving project management landscape. While the Eye of Competence remains central, the shift to people, practice, and perspective categories reflects a broader understanding of project management as a discipline embedded in social, organisational, and strategic contexts. However, the nine-year update gap highlights a limitation, as frameworks risk lagging behind rapid industry transformation. More regular and systematic revisions are needed to keep global baselines aligned with contemporary demands.

The following section examines how the Project Management Institute (PMI) developed its own standards, most notably the PMBOK Guide, the Talent Triangle, and the PMCD, to codify competencies at a global level.

3.6.6 The Project Management Body of Knowledge (PMBOK) – PMI Talent Triangle

The PMBOK is one of the most globally recognised standards for project management and serves as a foundation for professional certification. Successive editions reflect ongoing efforts to codify the knowledge, skills, and behavioural attributes required of PMs (PMI, 2022a, PMI, 2013, PMI, 2017a).

The 5th Edition (2013) addressed earlier limitations by incorporating interpersonal competencies that extend beyond technical expertise. Additions included leadership, team building, negotiation, conflict management, cultural awareness, coaching, and communication, competencies increasingly recognised as critical for navigating the human and organisational dimensions of project delivery (PMI, 2013).

The 6th Edition (2017) introduced the PMI Talent Triangle, which reframed competencies across three domains (PMI, 2017a):

1. **Technical:** Methodological, behavioural, and technical skills required to deliver projects, programmes, and portfolios.
2. **Leadership**: Interpersonal and motivational skills needed to guide, influence, and inspire teams.
3. **Strategic and Business Management**: Organisational and industry knowledge required to align project outcomes with broader business strategy.

This structure highlighted the need for PMs to balance technical proficiency with leadership and strategic foresight, and it defined 31 elements across the three domains. Table 3.8 summarises the 6th Edition Talent Triangle.

Table 3.8: PMBOK 6th Edition – PMI Talent Triangle (PMI, 2017a)

Project Management Body of Knowledge 6th Edition (PMBOK) – PMI Talent Triangle Classifications attributes and elements

Technical competencies	***Leadership competencies***	***strategic and business management competencies***
1. Agile practices 2. Data gathering and modelling 3. Earned value management 4. Governance (project, program, portfolio) 5. Lifecycle management (project, program, portfolio, product) 6. Performance management (project, program, portfolio) 7. Requirements management and traceability 8. Risk management 9. Schedule management 10. Scope management (project, program, portfolio, product) 11. Time, budget, and cost estimation	1. Brainstorming 2. Coaching and mentoring 3. Conflict management 4. Emotional intelligence 5. Influencing 6. Interpersonal skills 7. Listening 8. Negotiation 9. Problem solving 10. Team building	1. Benefits management and realization 2. Business acumen 3. Business models and structures 4. Competitive analysis 5. Customer relationship and satisfaction 6. Industry knowledge and standards 7. Legal and regulatory compliance 8. Market awareness and conditions 9. Operational functions (e.g., finance, marketing) 10. Strategic planning, analysis, alignment

In May 2022, the PMI updated the Talent Triangle in response to growing industry complexity, technological disruption, and evolving delivery approaches (PMI, 2022b, PMI, 2022a). The revised structure redefined the three domains as:

1. **Ways of Working**: Emphasising methodological flexibility, including agile, hybrid, predictive, and design thinking approaches.
2. **Power Skills**: Expanding leadership to include empathy, adaptability, creativity, communication, and collaborative influence.
3. **Business Acumen**: Deepening the strategic dimension with focus on market awareness, legal and regulatory compliance, and function-specific knowledge.

This update expanded the total number of elements to 35. Table 3.9 presents the revised structure.

Table 3.9: PMBOK – Updated PMI Talent Triangle (PMI, 2022a)

Project Management Body of Knowledge (PMBOK) – Updated PMI Talent Triangle Classifications attributes and elements		
Ways of Working competencies	***Power Skills competencies***	***Business Acumen competencies***
1. Agile and Hyper Agile	1. Leadership	1. Benefits Management and Realization
2. Hybrid	2. Active Listening	2. Business Models and Structures
3. Design Thinking	3. Communication	3. Competitive Analysis
4. Transformation	4. Adaptability	4. Customer Relationships and Satisfaction
5. Data Gathering and Modelling	5. Brainstorming	5. Industry Domain Knowledge
6. Earned Value Management	6. Coaching and Mentoring	6. Legal and Regulatory Compliance
7. Governance	7. Conflict Management	7. Market Awareness
8. Performance Management	8. Emotional Intelligence	8. Function-Specific Knowledge
9. Requirements Management and Traceability	9. Influencing	9. Strategic Planning, Analysis, Alignment
10. Risk Management	10. Interpersonal Skills	
11. Schedule Management	11. Negotiation	
12. Scope Management	12. Problem Solving	
13. Time, Budget, and Cost Estimation	13. Teamwork	

The evolution of the PMI Talent Triangle illustrates the profession's shift from a process-focused orientation toward a more holistic view of PM competency. Earlier editions emphasised technical processes and methodologies, while more recent frameworks reflect the growing importance of leadership agility and strategic intelligence. This progression aligns with the reality that project success in modern contexts depends on integrating technical proficiency with behavioural adaptability and business acumen. The next section examines the PMI Project Manager Competency Development (PMCD) framework, which operationalises these principles into structured development pathways.

3.6.7 Project Manager Competency Development (PMCD) – PMI Standard

The Project Manager Competency Development (PMCD) framework, first introduced by PMI in 2002, was among the earliest structured approaches for assessing and developing the competencies of individual PMs. It defined competency as a group of interrelated skills, knowledge, behaviours, attitudes, and personal traits that collectively influence job performance, can be evaluated against accepted standards, and may be enhanced through training and professional development (Cartwright & Yinger, 2007).

The PMCD was designed to guide both individuals and organisations in assessing, planning, and managing professional development. It specifically targeted practitioners with more than three years' experience managing medium to large projects, typically reporting to a senior project or portfolio manager for oversight. The framework was grounded in the PMBOK Guide (3rd Edition), the PMI Role Delineation Study, and the PMP Examination Specification, embedding PMCD firmly within PMI's certification ecosystem.

It distinguished three domains of competency (Cartwright, 2008), as summarised in Table 3.10:

1. **Knowledge Competency**: Acquisition of project management knowledge as validated through examinations such as PMP. Because these requirements were already assessed through certification, PMCD did not elaborate them further.
2. **Performance Competency**: Application of knowledge in practice, structured around the five process groups of initiating, planning, executing, monitoring and controlling, and closing.

3. **Personal Competency**: Behavioural traits, attitudes, and interpersonal attributes underpinning effective PM practice, including communication, leadership, cognitive ability, effectiveness, and professionalism.

Table 3.10: PMCD Framework Classifications (Cartwright, 2008)

Project Manager Competency Development (PMCD) Classifications attributes and elements		
Knowledge Competency	***Performance Competency***	***Personal Competency***
Not Applicable	1- Initiating 2- planning 3- executing 4- monitoring &controlling 5- closing	1- Communication 2- leading managing 3- cognitive ability 4- effectiveness 5- professionalism

While this study primarily references the first edition (2002) as the historical baseline for competency development, the PMCD underwent two subsequent updates. The Second Edition (2007) expanded descriptions of personal competencies, while the Third Edition (2017) broadened the framework to include program and portfolio managers. The 2017 version retained the three-domain structure but refined behavioural indicators and aligned more closely with the PMBOK Guide, The Standard for Program Management, The Standard for Portfolio Management, and the PMI Talent Triangle.

Although later PMI models, such as the Talent Triangle (2015; revised 2022), have partially superseded PMCD, its historical role remains significant. It represented one of the first comprehensive attempts to systematically integrate knowledge, performance, and behavioural competencies into a globally recognised standard, thereby advancing the professionalisation of project management and laying a foundation for subsequent frameworks. A key limitation, however, has been its irregular updates (2002, 2007, 2017), which restricted its ability to keep pace with the rapid changes affecting practice, particularly in relation to digital transformation.

3.6.8 Association for Project Management (APM) Competence Framework - Second Edition

The APM published the second edition of its Competence Framework in 2008, offering one of the most comprehensive models for defining PM competencies in the United Kingdom (APM, 2008). The framework was designed to provide a structured basis for professional development, assessment, and practice, integrating technical, behavioural, and contextual dimensions.

It is organised into three overarching domains, each supported by detailed competency areas summarised in Table 3.11:

- **Technical Competencies**: Project-specific processes and practices enabling effective delivery, such as budgeting, planning, scheduling, procurement, quality, and risk management.
- **Behavioural Competencies**: Interpersonal and intrapersonal skills that influence how PMs lead teams, manage relationships, and act with professionalism, including communication, teamwork, leadership, and ethics.
- **Contextual Competencies**: Competencies extending beyond the immediate project, including alignment with organisational strategy, governance, commercial awareness, and health, safety, and environmental responsibilities.

Table 3.11: APM Competence Framework - Second Edition (APM, 2008)

Association for Project Management (APM) Competence Framework Second Edition

Technical Competencies	***Behavioural Competencies***	***Contextual Competencies***
1. Budgeting and Cost Control 2. Business Case 3. Change Control 4. Contract Management 5. Earned Value Management 6. Governance Arrangements 7. Information Management 8. Issue Management 9. Planning 10. Procurement 11. Quality Management 12. Requirements Management 13. Resource Management 14. Risk Management 15. Scheduling 16. Scope Management 17. Solutions Development	1. Communication 2. Teamwork 3. Conflict Management 4. Leadership 5. Influencing 6. Negotiation 7. Professionalism and Ethics 8. Self-Management	1. Business and Commercial Context 2. Health, Safety, and Environmental Management

The APM Competence Framework (2nd edition) offered a balanced model of PM effectiveness, combining technical rigour with behavioural and contextual awareness. However, its lack of revision since 2008 limits its applicability in addressing the rapid technological changes and digital transformation shaping industries such as construction. The following section consolidates insights from all reviewed models and standards to enable comparative categorisation of competencies under Skills, Knowledge, and Core Personality domains.

In addition to the international project management frameworks reviewed above, AEC-specific professional bodies such as the Chartered Institute of Building (CIOB) and the Royal Institution of Chartered Surveyors (RICS) also provide relevant competency expectations for construction professionals. CIOB frameworks, including the postgraduate education framework, outline core learning outcomes and professional skills aligned with construction management practice, while RICS provides structured competency pathways across built environment disciplines (CIOB, 2025; RICS, 2025). These frameworks emphasise technical judgement, professional practice, leadership, and contextual awareness, including core areas such as planning, stakeholder engagement, risk management, and governance, within construction project delivery. Their inclusion further reinforces the relevance of competency-based approaches within the AEC industry, while also reflecting the sector-specific expectations placed on PMs in construction environments. However, similar to the frameworks discussed above, they remain primarily oriented toward established professional practice and do not explicitly address emerging digital competency requirements associated with construction's digital transformation.

3.7 Thematic Categorisation of Traditional Competency Frameworks

The preceding review of conceptual models and professional standards highlighted the diversity of approaches to defining PM competencies. To move beyond fragmented classifications, this section applies thematic categorisation to consolidate insights across sources into a unified structure. The aim is to provide conceptual clarity and establish a consistent foundation for the taxonomy developed later in this thesis.

3.7.1 Introduction to Thematic Categorisation

The review of conceptual models and professional frameworks in Section 3.6 reveals substantial variation in how PM competencies have been defined, categorised, and operationalised. Conceptual models such as Bloom's Taxonomy (1964), El-Sabaa's skills model (2001), and Crawford's integrated framework (2005) emphasised the theoretical underpinnings of competency, classifying attributes into domains of knowledge, skills, and personal characteristics. Complementing these, Birkhead et al. (2000) provided one of the earliest contextualised perspectives by identifying core competencies in South Africa, highlighting both transferable and context-specific demands. In contrast, institutionalised frameworks such as the IPMA (2015), PMI's PMBOK and Talent Triangle (PMI, 2022c), and the PMCD Framework (PMI, 2002) reflect professional consensus and certification requirements, embedding competencies into structured reference systems.

Three consistent domains underpin the categorisation:

1. **Skills** capture the practical and technical abilities required for project planning, execution, monitoring, and control. This domain is reflected in El-Sabaa's technical skills, Bloom's psychomotor domain, Birkhead et al. (2000) planning and control competencies, and the technical/process, ways of working, and knowledge elements of IPMA, PMI, and PMCD frameworks.
2. **Knowledge** encompasses theoretical understanding, contextual awareness, and cognitive capabilities required to situate projects within organisational and strategic settings. Bloom's cognitive domain, Crawford's input competencies, the perspective and business acumen dimensions of IPMA and PMI, and Birkhead et al.'s emphasis on contextual awareness (e.g., legislation, market sensitivity) align strongly with this category.
3. **Core Personality** reflects enduring traits, values, and interpersonal attributes such as leadership, motivation, communication, and resilience. These are emphasised in Bloom's affective domain, El-Sabaa's human skills, Crawford's personal competencies, Birkhead et al.'s interpersonal and leadership competencies, and the people-focused elements of IPMA and PMI frameworks.

Table 3.12 summarises how the reviewed frameworks and models align with the three overarching domains derived through thematic categorisation.

Table 3.12: Comparative categorisation of project management competency frameworks into Skills, Knowledge, and Core Personality domains

	PM Competency area		
	PM success criteria and success factors		
	Integrated approach		
	Skills	Knowledge	Core Personality
Bloom Taxonomy (1964)	Psychomotor (Skill)	Cognitive (Knowledge)	Affective (Attitude)
El-Sabaa Model (2001)	Technical skill	Conceptual and organisational skill	Human Skills
Crawford's Integrated Framework (2005)	Skills	Knowledge	Personal competencies (core traits and behaviours)
Birkhead et al. (2000)	Planning and controlling	Project context (e.g., legislation, market awareness)	Leadership, interpersonal influence

IPMA ICB v4 (2015)	Practice competencies	Perspective competencies	People competencies
PMI PMBOK Guide & Talent Triangle (PMI, 2022c)	Ways of Working competencies	Business Acumen competencies	Power Skills competencies
PMI PMCD Framework (2002)	Performance competencies	Knowledge competencies (validated via PMP exam)	Personal competencies
APM (2008)	Technical Competencies	Contextual Competencies	Behavioral Competencies

The thematic categorisation presented in Table 3.12 highlights both the diversity of terminology and the underlying convergence of frameworks into three stable domains. This consolidated lens, Skills, Knowledge, and Core Personality, provides a coherent basis for understanding traditional PM competencies. The detailed competency elements synthesised under each domain are outlined in Section 3.7.2 and visually consolidated in Figure 3.4.

3.7.2 Consolidated Summary of Competency Elements

Building on the thematic categorisation introduced in Section 3.7.1, the competency elements extracted from conceptual models, empirical studies, and professional frameworks are here consolidated into the three domains of Skills, Knowledge, and Core Personality, as defined in Section 3.4.1. This step reduces overlapping classifications and provides a unified foundation for analysing traditional PM competencies.

Each competency is introduced through multiple perspectives drawn from the frameworks, models, and early research reviewed in Section 3.6, followed by a synthesised definition. The consolidated competencies are presented below:

- Skills:
  - **Computer Proficiency in Project Management:** Scholarly research has defined this competency as the skill in the use of computers, reflecting proficiency in applying computer systems and software tools to project management tasks (El-Sabaa, 2001). This competency extends beyond basic operation to include the use of software for planning activities, scheduling workflows, monitoring progress, documenting outputs, and supporting communication. To distinguish it from lifecycle records governance, this competency focuses on day-to-day digital tool use that enables planning, coordination, and control. Proficiency in computer tools ensures that PMs can manage information accurately, coordinate tasks efficiently, and maintain control over project execution.
    Integrating this perspective, the comprehensive traditional definition can be articulated as *the PM's ability to effectively operate computer systems and software tools that support planning, scheduling, documentation, and overall project execution. This includes familiarity with digital environments and confidence in using essential project management software to facilitate daily project tasks.*
  - **Tool and Technique Application:** In the literature, this competency is defined as special knowledge in the use of tools and techniques, reflecting the PM's ability to understand and apply specific methods and instruments required for project delivery (El-Sabaa, 2001). This competency extends to selecting and utilising appropriate project management methodologies, construction-related technologies, and technical approaches that support planning, execution, and monitoring. Effective use of tools and techniques ensures that project activities are carried out

efficiently, challenges are addressed systematically, and outcomes remain aligned with project objectives.

Drawing on this, a traditional comprehensive definition can be articulated as *the PM's ability to understand and effectively apply specific tools, methodologies, and techniques necessary for managing and executing a construction project. This includes familiarity with construction-specific technologies and ensuring their proper use to improve efficiency, address challenges, and support delivery throughout the project lifecycle.*

- **Project Information Management:** This competency has been defined in the literature as the processes required to ensure the timely and appropriate generation, collection, and dissemination of project information (PMI, 2002). This competency involves systematically managing project-related data and documentation to ensure accuracy, accessibility, and reliability. By structuring information flows effectively, PMs support coordination among stakeholders, enhance clarity, and minimise the risks of delays or miscommunication.

  Bringing this insight, this competency is comprehensively characterised as *the PM's ability to systematically generate, collect, and disseminate project-related data and documentation in a timely and accurate manner. Its emphasis is on information flows that enable coordination and decision-making among stakeholders. This competency ensures that all project stakeholders are provided with the right information at the right time, thereby supporting informed decision-making, reducing miscommunication, and maintaining transparency across the project lifecycle.*
- **Cognitive Analysis, Data Gathering, and Information Synthesis:** Various scholars have defined this competency as the ability to analyse, synthesise, and evaluate information effectively, achieve project goals productively and efficiently (PMI, 2002), comprehend meaning and interpret data (Bloom, 1964), and gather and model information to support project decisions and strategies (PMI, 2022a). It also includes the capacity to separate material into component parts for analysis, build structures and patterns through synthesis (Bloom, 1964), and use perception to guide decision-making and activity. Together, these elements highlight the PM's role in transforming raw data and observations into actionable insights.

  Taken together, the comprehensive definition highlights this competency as *the PM's ability to understand, analyse, and synthesise complex information to support effective decision-making and project outcomes. It includes evaluating data, building conceptual models, interpreting meaning, and applying insights to achieve project goals efficiently. This skill draws on perception, comprehension, and structured reasoning, enabling the PM to make informed judgments and strategic plans grounded in evidence and stakeholder needs.*
- **Team Training and Skill Development:** Academic studies define this competency as the provision of learning opportunities and development plans for project team members (Birkhead et al., 2000), alongside mechanisms to support the intermediate stages of learning complex skills (Bloom, 1964). This competency emphasises the PM's role in guiding professional growth, ensuring team members build the capabilities needed to perform effectively, and supporting structured skill acquisition over time.

  A comprehensive definition can be drawn as *the PM's ability to support the learning and professional growth of team members by providing training opportunities, structured development plans, and guidance in mastering complex skills. This includes recognising the intermediate stages of learning, offering* *appropriate support mechanisms, and creating a culture of continuous improvement and skill acquisition to enhance team performance and project delivery.*

- **Information Management:** Researchers have described this competency as the ability to oversee the collection, storage, dissemination, archiving, and destruction of project information (APM, 2008). Renaming from "Information Management" clarifies its distinct focus on records lifecycle governance, avoiding overlap with "Project Information Management" above. This competency ensures that information is handled in a structured and secure manner, safeguarding data while maintaining accessibility and reliability for project use. Proper governance allows PMs to maintain transparency, meet compliance requirements, and support effective coordination across the project lifecycle.
  A comprehensive definition can ultimately be presented as *the PM's ability to systematically manage the collection, storage, dissemination, archiving, and eventual destruction of project-related information. This includes ensuring that data is properly recorded, protected, accessible, and disposed of in line with organisational protocols and project requirements to maintain project transparency, integrity, and compliance.*
- **Strategic and Innovative Problem Solving:** Scholars emphasise this competency as the ability to identify issues and develop effective solutions to overcome challenges (PMI, 2022a), manage and resolve problems that arise during the project life cycle (APM, 2008), and define and manage project requirements to meet stakeholder needs. This competency also reflects a strong problem orientation, emphasising proactive and strategic responses to emerging issues (El-Sabaa, 2001). It includes gathering and analysing data to inform decision-making (Birkhead et al., 2000), responding actively to phenomena, applying concepts to new situations, and using trial-and-error or adaptation to address unique challenges (Bloom, 1964). At its highest level, it incorporates origination, or the creation of novel approaches and innovative solutions that align with project objectives and stakeholder expectations (IPMA, 2015; Bloom, 1964).
  Taken together, a comprehensive definition can be expressed as *the PM's ability to identify, analyse, and resolve complex project challenges by combining strategic thinking with creative solution development. This includes managing emerging issues, gathering and interpreting data, and applying concepts to new contexts through trial-and-error, adaptation, and original thinking to meet project and stakeholder requirements.*
- **Financial Management and Performance Control:** Within the literature, this competency has been defined as the use of project management techniques such as Earned Value Management (EVM) to integrate scope, time, and cost data for assessing performance and progress (PMI, 2022a). It includes estimating and managing the time, financial resources, and costs required to complete project activities (PMI, 2022a), as well as implementing quality processes to ensure deliverables meet stakeholder expectations (IPMA, 2015). This competency also covers the processes of project cost management, including planning, estimating, budgeting, financing, funding, and controlling costs throughout the project lifecycle (PMI, 2002; APM, 2008). Further elements include sourcing funds and overseeing project budgets to maintain financial viability (Birkhead et al., 2000), alongside having expertise in specific business functions, such as finance, that support project success (PMI, 2022a).

Synthesising these elements, this traditional competency can be described as *the PM's ability to plan, estimate, secure, allocate, and control financial resources throughout the project lifecycle. This includes techniques such as EVM to integrate scope, time, and cost data for tracking performance and progress. It also involves budgeting, cost estimation, funding acquisition, and financial oversight to ensure project viability and alignment with business objectives. Additionally, it requires domain-specific knowledge in functions like finance to assess quality, manage financial performance, and meet stakeholder expectations.*

- **Procurement Management and Resource Planning:** According to scholarly work, this competency is defined as the ability to manage procurement processes, supplier relationships, and contractual obligations (IPMA, 2015). It also encompasses the processes required to purchase or acquire products, services, or results that support project delivery (PMI, 2002), as well as the broader capability to acquire goods, services, and works efficiently to meet project needs (APM, 2008). This competency ensures that resources are secured in a timely and cost-effective manner while maintaining compliance with procurement procedures and contractual standards.

  The final comprehensive definition can be articulated as *the PM's ability to plan, execute, and manage the acquisition of goods, services, and works necessary to support project delivery. This includes overseeing procurement strategies, supplier relationships, tendering, and compliance with contractual obligations, ensuring that resources are secured efficiently and in line with project requirements.*
- **Project Scheduling and Time Management:** Academic sources highlight this competency as the ability to plan and control project timelines to ensure the timely completion of milestones and deliverables (PMI, 2022a). This includes developing schedules, managing time effectively, and ensuring project outcomes are delivered as planned (IPMA, 2015). It also involves creating project plans, monitoring progress, and controlling deviations from the baseline plan, alongside the processes necessary for managing the timely completion of the project (PMI, 2002). Additional elements include establishing scope, objectives, and actions required to achieve project goals, as well as applying earned value analysis techniques to assess performance and progress (APM, 2008). Finally, it encompasses identifying objectives, defining tasks, and establishing timetables to guide project execution (Birkhead et al., 2000).

  Bringing these perspectives together, a comprehensive definition can ultimately be presented as *the PM's ability to plan, control, and optimise project timelines to ensure the timely completion of milestones and deliverables. This includes developing and maintaining schedules, identifying objectives, defining tasks, controlling deviations, and applying techniques such as EVM to track progress and performance. Effective time management ensures that project activities align with strategic goals and are executed within planned timeframes.*
- **Project Resource Management:** Scholarly perspectives define this competency as the ability to identify, acquire, and manage the resources, such as people, equipment, and materials, required to complete the project (IPMA, 2015). It encompasses the processes of project resource management to ensure that both human and material resources are available and deployed effectively (PMI, 2002). This competency also includes overseeing human resource utilisation and managing supporting resources critical for project delivery (APM, 2008). Further elements involve organising and structuring tasks and resources efficiently to

optimise performance (El-Sabaa, 2001), as well as applying on-site construction management skills that require complex and coordinated actions (Bloom, 1964).
Taken together, a traditional competency definition can be expressed as *the PM's ability to identify, acquire, organise, and oversee resources, including human capital, materials, and equipment, to support the successful execution of project tasks. It includes the efficient structuring of work packages, task delegation, and on-site management of construction activities, ensuring that both physical and human resources are used effectively and responsibly.*

- **Project Quality Assurance:** In academic research, this competency is defined as the ability to set quality criteria, implement quality processes, and ensure that project deliverables meet stakeholder expectations (IPMA, 2015). It includes the processes of project quality management to confirm that outputs comply with specified requirements, alongside monitoring, reviewing, and regulating activities to achieve performance objectives (PMI, 2002). This competency also encompasses ensuring deliverables meet required quality standards throughout the lifecycle (APM, 2008, Birkhead et al., 2000), maintaining a results-oriented approach that focuses on delivering value to stakeholders (IPMA, 2015). Finally, it extends to managing the project's closing phase, ensuring that all activities are finalised and quality outcomes are documented (PMI, 2002).
  In summary, a comprehensive definition can ultimately be presented as *the PM's ability to define quality criteria, implement and monitor quality processes, and ensure that deliverables meet stakeholder expectations and established standards. This includes tracking and controlling project activities, verifying compliance with requirements, and focusing on results that deliver tangible value. It also involves overseeing the closing phase to ensure all quality and performance objectives are met and documented.*
- **Scope, Requirements, and Change Management:** Studies have defined this competency as the ability to identify, document, and track project requirements to ensure they are met across the lifecycle (PMI, 2022a). It includes defining and controlling what is included or excluded in the project to ensure all required work is completed (PMI, 2022a), as well as identifying, managing, and aligning requirements and objectives with stakeholder needs and expectations (IPMA, 2015). This competency also covers defining project boundaries, deliverables, and the necessary work to achieve objectives, alongside managing organisational change and transformation within the project context (IPMA, 2015). Further elements include applying the processes of scope management to ensure only the necessary work is undertaken (PMI, 2002), managing scope, schedule, and cost changes in a structured and controlled manner (APM, 2008), and preventing unnecessary changes while ensuring clarity in objectives (Birkhead et al., 2000).
  Taken together, this competency can ultimately be defined as *the PM's ability to identify, define, document, and control project requirements and boundaries throughout the project lifecycle. This includes aligning deliverables with stakeholder expectations, ensuring traceability of requirements, and managing any changes to scope, schedule, or costs through structured processes. The goal is to ensure that all necessary work is completed, and only the necessary work, while controlling scope creep and facilitating smooth project transitions.*
- **Agility, Transformation, and Market Responsiveness:** The academic discourse frames this competency as the ability to implement iterative and flexible methodologies that allow swift adaptation to changing project requirements while delivering value efficiently (PMI, 2022a). It also encompasses leading and

managing organisational transformations to improve processes, technologies, or culture (PMI, 2022a), as well as understanding business models and structures that shape how value is created and delivered (PMI, 2022a). Additional elements include sensitivity to market trends and demands (Birkhead et al., 2000), and maintaining awareness of external dynamics that may affect project or organisational performance (PMI, 2022a).

Synthesising these elements, a comprehensive definition may be expressed as *the PM's ability to adapt quickly to changing project requirements, lead transformative initiatives, and align project strategies with evolving market conditions, business models, and organisational structures. It includes the adoption of iterative methodologies, sensitivity to trends, and the capacity to manage cultural and technological shifts to maintain relevance, efficiency, and value delivery.*

➢ Knowledge:

- **Industry and Project Domain Knowledge:** Scholars have characterised this competency as possessing an in-depth understanding of the specific industry in which a project operates, including trends, regulations, and best practices (PMI, 2022a). It also involves having detailed knowledge of the project's domain, ensuring awareness of sector-specific processes, standards, and requirements that influence project execution (El-Sabaa, 2001). This competency enables PMs to anticipate challenges, align practices with industry norms, and respond effectively to regulatory and contextual demands.

  Taken together, this competency may be comprehensively described as *the PM's ability to understand the specific context, regulations, trends, and best practices of the construction industry and the particular project domain. This includes knowledge of standards, compliance expectations, workflows, and sector-specific challenges, allowing for effective risk identification, decision-making, and stakeholder alignment within construction projects.*
- **Technology Required:** Research has identified this competency as familiarity with the technical aspects and technologies necessary for project execution (El-Sabaa, 2001). Renaming from "Technology Required" clarifies scope and avoids ambiguity. This competency reflects the PM's ability to recognise, understand, and apply the tools, systems, and equipment that support project delivery, ensuring their effective use throughout the project lifecycle.

  Bringing this element together, the definition can be formulated as *the PM's ability to understand and apply the technical tools, systems, and equipment necessary to manage and execute construction projects successfully. It includes both traditional and emerging technologies, ensuring that the PM can select and integrate appropriate advanced tools to enhance performance, efficiency, and project delivery outcomes.*
- **Strategic Planning, Business Case, and Benefits Realisation:** Scholarly definitions present this competency as the ability to combine predictive and adaptive approaches to tailor strategies to the project's needs (PMI, 2022a). It also encompasses benefits management and realisation, involving the identification, planning, and monitoring of project benefits to ensure they are achieved and sustained (PMI, 2022a). Strategic planning, analysis, and alignment require developing and adjusting project objectives and plans to support the organisation's strategic goals (PMI, 2022a; IPMA, 2015), while also prioritising and balancing portfolio elements to maximise value delivery (IPMA, 2015). Additional aspects include initiating projects with clear authorisation (PMI, 2002), preparing and maintaining business cases to justify investments and demonstrate value (APM,

2008), and understanding the wider business and commercial context in which projects operate. This competency also reflects the ability to set clear goals, maintain a strong results orientation (El-Sabaa, 2001), and organise values into priorities (Bloom, 1964).
Taken together, this traditional competency can be expressed as *the PM's ability to develop, align, and adapt project plans to meet both organisational strategic objectives and changing project needs. It includes creating and evaluating business cases, understanding the commercial environment, and balancing portfolios or project elements for maximum value delivery. The PM applies hybrid approaches, engages in benefits realisation, and maintains a strong goal orientation, ensuring that project efforts are strategically justified and continuously aligned with overarching business goals.*

- **Project Integration, Managing, and Executing:** Academic contributions define this competency as the ability to design, structure, and plan a project while considering its objectives, context, and requirements (IPMA, 2015). It includes establishing project structures, roles, and responsibilities, as well as managing the flow of information across stakeholders (IPMA, 2015). This competency also covers the processes of project integration management, ensuring that diverse project elements are properly coordinated, and executing the project by organising people and resources to carry out the plan effectively. Further aspects include managing tasks, processes, and teams (PMI, 2002), recognising the interconnectedness of various project components (El-Sabaa, 2001), and coordinating elements to achieve overall project objectives (Birkhead et al., 2000).
Bringing these insights together, a comprehensive definition can ultimately be presented as *the PM's ability to design, structure, coordinate, and execute all elements of a project in a unified and cohesive manner. It includes the ability to define project objectives, assign roles and responsibilities, and manage the flow of information across project phases. A strong focus is placed on seeing the project holistically, integrating diverse resources, and ensuring alignment between planning, execution, and control activities to achieve strategic outcomes.*
- **Health, Safety, and Environmental Management:** The literature defines this competency as the ability to ensure that health, safety, and environmental considerations are addressed consistently across all phases of the project (APM, 2008). This competency requires identifying potential hazards, implementing safety measures, and ensuring that project activities comply with established regulations and standards. It also involves embedding environmentally responsible practices into project workflows, thereby safeguarding both workers and the surrounding environment.
In summary, the competency definition can be drawn as *the PM's ability to address and uphold health, safety, and environmental standards throughout all project phases. It includes identifying potential hazards, ensuring compliance with safety regulations, and integrating environmentally responsible practices into project workflows. The PM must promote a culture of safety, ensure safe work conditions, and minimise environmental risks to protect both workers and the surrounding ecosystem.*
- **Contract and Negotiation:** Scholarly accounts describe this competency as the ability to reach mutually beneficial agreements through discussion and compromise (PMI, 2022a; IPMA, 2015). This competency includes negotiating terms that satisfy all parties, managing expectations, and resolving differences constructively. It also extends to contract management, involving the selection, negotiation,

administration, and oversight of procurement processes to ensure contractual obligations are met effectively throughout the project lifecycle (APM, 2008).
Taken together, the comprehensive definition highlights this competency as *the PM's ability to engage in effective negotiations that result in mutually beneficial agreements. It includes facilitating discussions, managing expectations, and resolving differences to secure favourable outcomes. Additionally, it encompasses administering contracts, overseeing procurement processes, and ensuring that obligations are met throughout the project lifecycle. The PM must maintain a balance between legal compliance, strategic value, and relationship management.*

- **Legal and Regulatory Compliance:** Academic sources define this competency as the ability to establish governance frameworks and processes to ensure projects align with organisational objectives and comply with standards and regulations (PMI, 2022a). It includes ensuring that project activities adhere to relevant laws, regulations, and industry requirements (PMI, 2022a), as well as applying governance structures and organisational processes to support delivery (IPMA, 2015). This competency also covers developing and maintaining governance arrangements for decision-making and accountability (APM, 2008), alongside demonstrating awareness of legislation and applying compliance requirements consistently across project activities (Birkhead et al., 2000).
  Bringing these elements together, the final comprehensive definition can be articulated as *the PM's ability to establish and maintain governance structures, ensuring that project activities align with organisational goals, comply with legal and regulatory frameworks, and follow industry standards. It includes developing decision-making frameworks, promoting accountability, and ensuring transparency across all project processes. The PM must be aware of legislation, apply appropriate policies and procedures, and integrate compliance considerations throughout the project lifecycle.*
- **Project Risk Management:** The research literature defines this competency as the ability to identify, assess, and mitigate risks that could affect project objectives (PMI, 2022a). It also includes managing risks and opportunities across the project lifecycle (IPMA, 2015), applying structured processes for risk planning, identification, analysis, response, and monitoring (PMI, 2002). This competency further involves analysing risks and opportunities to ensure objectives are achieved (APM, 2008), maintaining awareness of potential issues, and making corrective actions as necessary to keep project activities aligned with goals (Birkhead et al., 2000). It also incorporates situational awareness and attentiveness to external and internal phenomena that may impact project performance (Bloom, 1964).
  In summary, this competency can ultimately be defined as *the PM's ability to identify, assess, analyse, and manage risks and opportunities across the project lifecycle to ensure objectives are met. This includes planning for uncertainty, implementing appropriate risk response strategies, maintaining situational awareness, and taking corrective actions when needed to align project execution with performance goals.*
- **Understanding Methods, Processes, and Procedures:** Scholarly work recognises this competency as the knowledge of standard practices and workflows relevant to the project (El-Sabaa, 2001). This competency ensures that the PM is familiar with recognised methods and procedures, allowing for consistent application of established practices throughout the project lifecycle. It supports effective coordination, compliance with industry standards, and contributes to both efficiency and quality in project execution.

Taken together, a comprehensive definition may be expressed as *the PM's ability to understand and apply recognised industry practices, procedures, and workflows specific to the construction sector. It ensures alignment with established protocols, supports efficient coordination, and contributes to the consistency, quality, and compliance of project execution.*

- Core Personality:
  - **Team Leadership:** Scholars commonly define this competency as the ability to monitor and evaluate project and team performance to ensure objectives are met efficiently, while guiding and motivating teams to achieve project goals in a collaborative environment (PMI, 2022a). This competency includes inspiring and influencing others to gain support for desired outcomes (PMI, 2022a; IPMA, 2015), providing direction and motivation (PMI, 2002; APM, 2008), and mobilising the mental and emotional energy of team members (El-Sabaa, 2001). It further involves delegating authority and responsibilities appropriately (El-Sabaa, 2001; Birkhead et al., 2000), managing team dynamics effectively, and fostering team building to strengthen collaboration and morale (Birkhead et al., 2000). Additional elements include providing guidance and coaching to support professional growth (PMI, 2022a), as well as addressing and resolving disagreements and crises constructively to maintain a positive team dynamic (PMI, 2022a; IPMA, 2015; APM, 2008; Birkhead et al., 2000).

    Synthesising these perspectives, this competency is comprehensively characterised as *the PM's ability to guide, inspire, and motivate project teams to achieve shared objectives through strong leadership, communication, and support. It includes delegating authority, managing team roles, and fostering a collaborative environment. The PM is responsible for monitoring team and individual performance, providing coaching and development, and resolving conflicts constructively. By mobilising the mental and emotional energy of team members and maintaining team morale, the PM ensures a productive and resilient team dynamic.*
  - **Stakeholder Leadership:** The academic consensus highlights this competency as the ability to assess competitors to understand their strengths, weaknesses, and market positions in order to inform strategic project decisions (PMI, 2022a). It also involves understanding and managing power dynamics, interests, and influence within the project environment (IPMA, 2015), while identifying, engaging, and maintaining effective relationships with stakeholders to ensure their expectations are met (IPMA, 2015; PMI, 2002). This competency includes influencing and persuading stakeholders to achieve desired outcomes (APM, 2008), demonstrating political sensitivity and awareness of organisational dynamics, and recognising how projects interact with industry and the wider community (El-Sabaa, 2001). Further aspects include managing expectations constructively and applying interpersonal skills to build trust and sustain collaboration across stakeholder groups (Birkhead et al., 2000).

    Taken together, the comprehensive definition highlights this competency as *the PM's ability to identify, engage, and manage diverse stakeholders, while navigating power dynamics, organisational politics, and industry context to achieve successful project outcomes. It includes the skills to analyse competitors, understand external influences, influence stakeholder decisions, and build trusted relationships that align project efforts with broader organisational and societal goals.*
  - **Self-Management and Emotional Regulation:** Scholarly discussions portray this competency as the ability to adapt flexibly to new conditions, challenges, and

changes in the project environment (PMI, 2022a). It also includes self-reflection and the capacity to manage one's own behaviour and growth effectively (IPMA, 2015), alongside managing personal performance, time, and development goals (APM, 2008). This competency further involves coping with complex or stressful situations through patience and persistence, while maintaining high self-esteem, confidence, and a positive self-image (El-Sabaa, 2001).

Bringing these perspectives together, the final comprehensive definition can be formulated as *the PM's ability to adapt to change, reflect on personal behaviour, and manage their own performance, time, and growth in dynamic project environments. It includes maintaining emotional balance, self-confidence, and patience when facing pressure, setbacks, or shifting project demands. By demonstrating persistence and flexibility, the PM ensures consistent leadership and personal effectiveness across project stages.*

- **Decision-Making and Ethics:** Scholarly perspectives emphasise this competency as the ability to demonstrate personal integrity and reliability through continuous self-management and improvement (IPMA, 2015). It also encompasses professionalism, requiring adherence to ethical standards and professional conduct in all project environments (PMI, 2002; APM, 2008). This competency includes honesty, integrity, and credibility in respecting organisational values, while exercising decisiveness in challenging circumstances (Birkhead et al., 2000). It further draws on the capacity to evaluate situations critically, accept and commit to ethical principles, and internalise values that guide behaviour consistently in complex contexts (Bloom, 1964).

  Taken together, a synthesised definition can be expressed as *the PM's ability to act with honesty, reliability, and professionalism, consistently adhering to ethical standards and organisational values. It includes the capacity to make sound judgments, evaluate situations ethically, and demonstrate internalised principles that guide behaviour in complex and high-pressure environments. The PM leads by example, maintaining credibility, fairness, and a commitment to doing what is right, even under challenging conditions.*
- **Cultural Sensitivity and Team Support:** Academic studies highlight this competency as the ability to recognise, respect, and integrate cultural and value-based considerations into project management practices (IPMA, 2015). It also includes supporting team members' growth, well-being, and professional development to sustain motivation and performance (Birkhead et al., 2000). This competency reflects the PM's role in fostering inclusivity, acknowledging diversity, and promoting a team culture that values respect and collaboration.

  In summary, a comprehensive definition frames this competency as *the PM's ability to recognise, respect, and integrate cultural diversity and value systems into project environments. It also involves supporting the personal and professional growth, health, and morale of team members. By promoting cultural sensitivity, equity, and inclusiveness, the PM fosters a collaborative, respectful, and high-performing team culture that enhances both individual well-being and project success.*
- **Communication and Interpersonal Skills:** The literature frequently defines this competency as the ability to effectively exchange information, ideas, and feedback with stakeholders through a variety of channels (PMI, 2022a). It also involves building and maintaining relationships through empathy, collaboration, and clear communication (PMI, 2022a; IPMA, 2015). This competency includes conveying and receiving information accurately and efficiently (IPMA, 2015; PMI, 2002; APM, 2008; Birkhead et al., 2000), while also demonstrating active listening,

persuasion, and interpreting non-verbal cues to understand others' behaviour (El-Sabaa, 2001). Teamwork is an essential component, emphasising collaboration with others to achieve shared objectives and project success (PMI, 2022a; IPMA, 2015; APM, 2008; Birkhead et al., 2000).
Synthesising these elements, the final comprehensive definition can be formulated as *the PM's ability to convey and receive information clearly, accurately, and efficiently across a range of project environments and stakeholder groups. This includes active listening, persuasion, understanding non-verbal cues, and engaging in empathetic, two-way communication to support relationship-building, resolve misunderstandings, and ensure aligned expectations.*

- **Client Engagement and Relationship Management:** Scholarly literature describes this competency as the ability to build and maintain positive relationships with customers to meet their needs and enhance satisfaction (PMI, 2022a). It also includes establishing strong relationships and active engagement with stakeholders to support collaboration and trust (IPMA, 2015). This competency further extends to managing projects across diverse geographical and cultural contexts, requiring adaptability and cultural awareness to sustain effective client and stakeholder relationships (Birkhead et al., 2000).
  Taken together, the final comprehensive definition can be articulated as *the PM's ability to build and maintain positive relationships with clients and stakeholders, ensuring their needs are understood, met, and integrated into project delivery. This includes fostering trust, responsiveness, and satisfaction through effective communication and relationship-building. It also involves managing relationships across geographically and culturally diverse environments, requiring cultural sensitivity and adaptability to engage clients in global project contexts.*
- **Creative Problem-Solving and Design Thinking:** Research in the field defines this competency as the ability to apply user-centred design principles to solve complex problems creatively, focusing on understanding user experiences and needs (PMI, 2022a). It also includes generating innovative ideas and solutions through collaborative methods such as brainstorming. This competency emphasises creativity, empathy, and iterative thinking to ensure solutions are practical, effective, and responsive to stakeholder needs.
  In summary, the comprehensive definition highlights this competency as *the PM's ability to apply user-centred design principles and facilitate collaborative ideation to address complex challenges in innovative ways. This involves understanding user needs, fostering empathy, and generating effective solutions through methods such as brainstorming and iterative development, ensuring project outcomes are both functional and human centric.*

The consolidation of competencies across conceptual models, empirical studies, and professional standards provides a clarified foundation for understanding the traditional role of the PM. By applying thematic categorisation, fragmented and overlapping classifications have been synthesised into a coherent structure, ensuring both conceptual rigour and professional relevance. The resulting set of Skills, Knowledge, and Core Personality competencies offers a stable baseline for subsequent integration with digital competencies and empirical validation in the next chapters. The next section presents the traditional PM competency framework, which visually consolidates these domains and their associated competencies into a structured framework, as illustrated in Figure 3.4.

3.7.3 Traditional PM Competency Framework

The consolidation of traditional PM competencies across conceptual models, empirical studies, and professional standards has resulted in a structured framework organised under three domains: Skills, Knowledge, and Core Personality. This framework integrates the detailed elements in Section 3.7.2 into a cohesive foundation that informs the unified model validated in later chapters.

The Traditional PM Competency Framework provides a clear and coherent representation of the competencies required of PMs in construction and related sectors. By clustering overlapping items and harmonising definitions, the framework reduces fragmentation across prior studies and aligns diverse perspectives into a consistent structure.

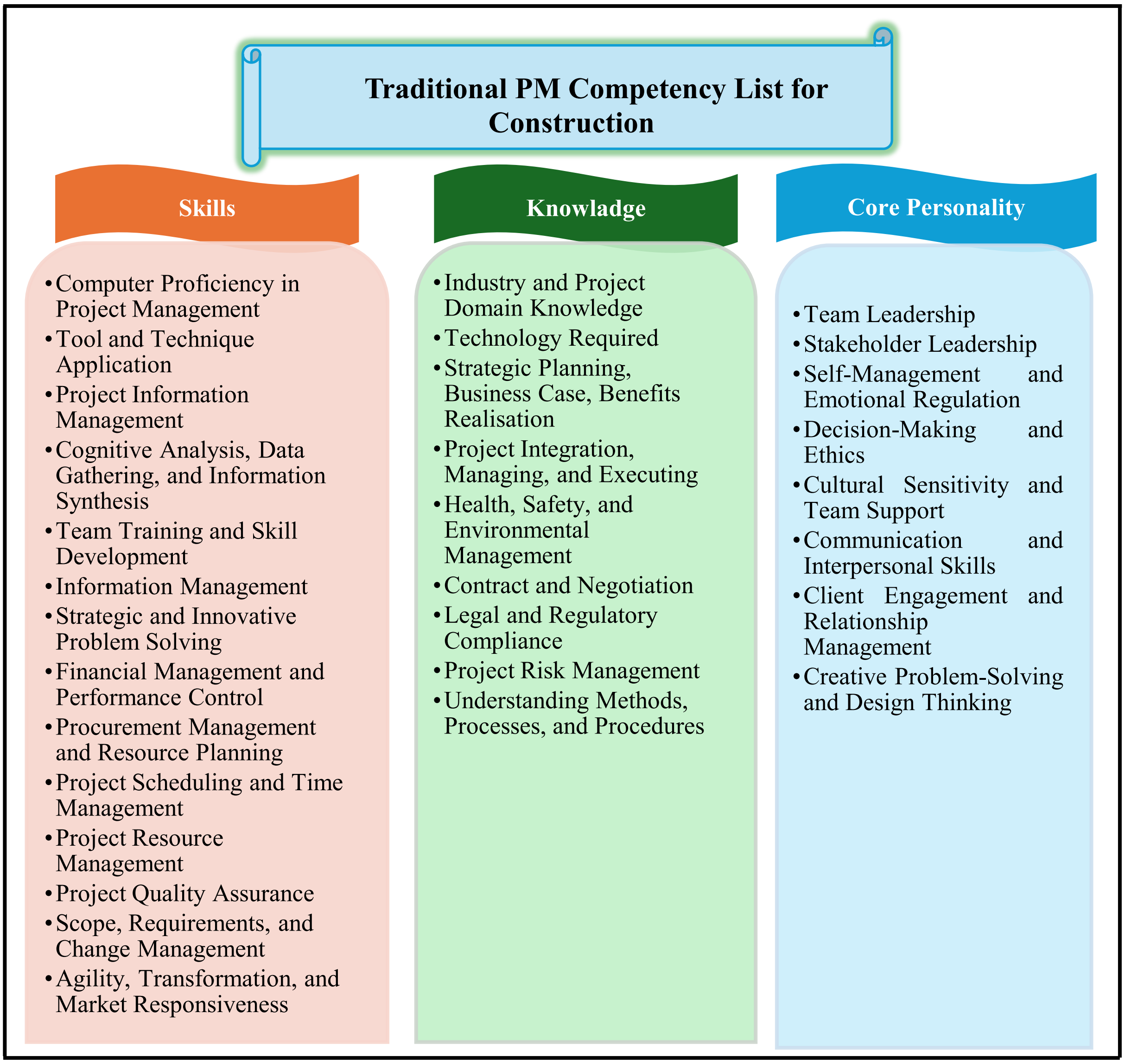

Figure 3.4: Traditional Project Manager Competency Framework

As shown in Figure 3.4, Skills represent technical and functional abilities, Knowledge captures theoretical and contextual understanding, and Core Personality comprises behavioural and interpersonal traits that collectively underpin PM effectiveness. Together, these domains establish a stable baseline for understanding traditional PM competencies and provide the foundation for Chapter 5, where traditional and digital competencies are integrated through a taxonomy-based classification and validated through empirical analysis.

In this thesis, competency is defined as a diverse set of knowledge, abilities, skills, experiences, behaviours, and personal attributes that enable individuals to achieve superior performance in specific roles or tasks. Competency is measurable and trainable, includes both visible elements such as skills and knowledge and underlying traits and motives, can be evaluated against accepted standards, and is developed progressively through training and experience. For analytic clarity, competency is organised into three domains: technical and practical skills, knowledge-based elements, and core personality traits.

- **Skills:** Encompass the technical, functional, and methodological abilities that enable PMs to plan, organise, execute, and control projects effectively. They cover proficiency in tools, techniques, and processes, ranging from scheduling and budgeting to risk management and digital platform use. Skills describe the practical capacity to select and apply appropriate approaches to achieve tasks and objectives with efficiency and accuracy.
- **Knowledge:** Refers to the theoretical understanding, contextual awareness, and cognitive capabilities that allow PMs to interpret industry trends, organisational strategies, and project processes. It includes domain specific expertise, accumulated experience, and the ability to situate projects within broader organisational, strategic, and global contexts. Knowledge enables informed decision making and supports the integration of project activities with long term value creation.
- **Core Personality Traits:** Encompass the enduring behavioural, interpersonal, and psychological attributes that shape how PMs apply skills and knowledge in practice. These traits include leadership, resilience, adaptability, ethical responsibility, motivation, and communication. Together, they influence collaboration, conflict resolution, and team guidance under conditions of uncertainty and complexity.

While the framework consolidates and clarifies traditional PM competencies, it also has boundaries shaped by the scope and timeliness of the reviewed sources. The next section outlines these limitations and their implications for interpretation and application.

3.8 Limitations of Traditional Competency Frameworks

While the review of traditional competency frameworks provides valuable insight into the evolution of project management practice, several limitations constrain their applicability to the contemporary AEC sector.

A key limitation is the infrequent and static update cycles of major frameworks. For example, the IPMA required almost nine years to update its ICB from version 3.0 (2006) to version 4.0 (2015), despite rapid advances in industry practice during this period (IPMA, 2006; IPMA, 2015). Similarly, the PMI did not revise its Talent Triangle until 2022, even though the sixth edition of the PMBOK Guide had been released in 2017 (PMI, 2022a; PMI, 2017a). The earlier PMI PMCD framework, introduced in 2002, also exemplifies this challenge: while it provided one of the first structured approaches to linking knowledge, performance, and personal competencies, it underwent little subsequent evolution and was eventually superseded by later PMI models (Cartwright, 2008; Cartwright & Yinger, 2007). These long revision intervals create persistent risks of misalignment between professional guidelines and the realities of project delivery in rapidly changing environments such as construction.

A second limitation is the lack of explicit digital and technological coverage within these frameworks. While the PMBOK Guide, IPMA ICB, and related models emphasise technical, behavioural, and contextual domains, they give limited attention to emerging digital competencies. Critical capabilities associated with Artificial Intelligence (AI), Building Information Modelling (BIM), the Internet of Things (IoT), and Digital Twins (DTs) are largely absent. This omission creates a competency gap, as modern PMs must increasingly integrate digital tools, data-driven decision making, and automation into project delivery. The absence of systematic integration of digital transformation requirements represents a significant shortcoming of frameworks designed primarily in the pre-digital era.

A third limitation lies in the over-reliance on certification-oriented standards, which often reduce competencies to codified checklists of knowledge, skills, and personality traits. While this provides consistency for assessment and benchmarking, it constrains adaptability and overlooks the dynamic, context-specific nature of project management practice. Competency frameworks designed for certification and accreditation are therefore less responsive to emergent industry challenges, where PMs are required to adapt rapidly to organisational change, technological disruption, and global complexity.

In summary, traditional frameworks remain valuable for establishing baseline skills, knowledge, and personality traits, yet they fall short in addressing the realities of digital transformation in the AEC sector. Bridging this gap requires the development of a digital PM competency taxonomy that complements and adapts existing frameworks to modern professional demands.

Accordingly, Chapter 4 identifies, defines, and categorises digital PM competencies, while Chapter 5 develops a taxonomy that integrates both traditional and digital competencies into a unified framework. Chapter 6 then employs Exploratory Factor Analysis (EFA) to empirically identify the underlying factor structure, and Chapter 7 applies Confirmatory Factor Analysis (CFA) to validate the Next-Gen Digital PM Competency Model, ensuring its robustness and applicability for practice.

3.9 **Conclusion**

This chapter consolidated traditional project manager (PM) competencies by systematically reviewing conceptual models (e.g., Bloom’s Taxonomy, El-Sabaa’s skills model, Crawford’s integrated framework) and institutional frameworks (e.g., IPMA ICB, PMI PMBOK, PMI Talent Triangle, and PMCD Framework). Through thematic categorisation, these diverse approaches were synthesised into three overarching domains, Skills, Knowledge, and Core Personality Traits, reducing fragmentation and establishing a coherent, evidence-based foundation for understanding PM competencies in the construction sector.

The outcome was a set of comprehensive traditional competency definitions for each domain, ensuring conceptual clarity while maintaining practical relevance for the Architecture, Engineering, and Construction (AEC) industry. This represents a key contribution of the chapter, as it formalises the traditional competency baseline in a way that supports both academic understanding and professional application.

At the same time, several limitations must be acknowledged. Traditional frameworks often differ in terminology and categorisation, leading to overlaps and inconsistencies. Many models remain context-specific with limited adaptability across industries or regions, and most have not been systematically updated to address the demands of digital technologies. As a result, they do not fully capture the impact of ongoing digital transformation, which is reshaping project management practices.

Taken together, these limitations underscore that while traditional frameworks provide valuable foundations, they are not sufficient to meet the demands of digital transformation in the AEC sector. They capture essential aspects of PM practice but fail to reflect the digital competencies now required to operate in technology-driven environments. This gap highlights the need for a unified taxonomy that extends traditional competencies into digitally enhanced domains.

In addressing RQ1, "*Which traditional project manager competencies are identified in literature and professional frameworks, and how can these be categorised into skills, knowledge, and core personality traits?*" this chapter has systematically identified and categorised traditional PM competencies into the three domains of Skills, Knowledge, and Core Personality Traits. Accordingly, Chapter 4 identifies and defines emerging digital PM competencies, while Chapter 5 integrates these with the traditional baseline into a comprehensive taxonomy. This taxonomy bridges past and present, providing the groundwork for empirical validation in later chapters and ensuring that the framework is both conceptually rigorous and practically relevant for the evolving digital construction era.

Chapter 4 Building the Next-Gen Digital PM Competency List: Theme Identification and Refinement

This chapter is extended from:

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4.1 Abstract

The digital transformation of the construction industry is reshaping the competencies required of project managers (PMs), necessitating a structured competency framework that integrates both traditional project management skills and emerging digital capabilities. This study systematically identifies, categorises, and refines 55 critical digital competencies essential for construction PMs, as presented in Figure 4.15: Next-Gen Digital PM Competency List for Construction, tailored to the evolving construction sector. Employing a three-phase methodological approach, the research begins with a Systematic Literature Review (SLR), extracting competencies from 15 high-quality academic sources. This is followed by Thematic Analysis using NVivo, classifying competencies into Skills, Knowledge, and Core Personality to align with traditional project management models. Lastly, Large Language Models (LLMs) are utilised to refine competency definitions, which were subsequently validated through expert review to ensure accuracy, clarity, and industry relevance.

The findings emphasise the growing importance of digital literacy, AI-driven decision-making, data analytics, automation expertise, and adaptive leadership in construction project management. The study underscores the need for structured competency development programs, urging construction firms, academic institutions, and policymakers to integrate digital competency training into professional development initiatives. It also advocates for certification pathways and continuous learning programs to equip PMs with the expertise needed to lead digital transformation and enhance project efficiency, collaboration, and innovation.

By presenting a validated Next-Gen Digital PM Competency List for Construction comprising 55 key competencies, this research contributes to the ongoing discourse on digital transformation in construction. The framework serves as a practical foundation for training, industry policies, and future research. Further studies should focus on empirical validation, longitudinal competency tracking, and cross-industry benchmarking to ensure continued alignment with rapid technological advancements shaping the construction sector.

4.2 Introduction

The construction sector has long been a cornerstone of economic development and societal progress, playing a pivotal role in providing infrastructure, housing, and industrial advancements. Historically, the industry has been labour-intensive and heavily reliant on conventional methods of planning, execution, and communication. However, global challenges, such as rapid urbanisation, population growth, and the increasing demand for sustainable development, have amplified the need for innovative practices in construction (van Wyk et al., 2024). Additionally, rising expectations for cost efficiency, faster project delivery, and high-quality outcomes have compelled construction firms to modernise their approaches and adopt advanced technological solutions. Despite being one of the largest industries globally, the construction sector has traditionally lagged behind others in digital adoption, resulting in inefficiencies, delays, and cost overruns in projects (Dlamini & Cumberlege, 2021; Whyte et al., 2024).

Currently, the construction sector is undergoing a significant transformation, driven by the rapid advancement and integration of digital technologies. This digital transformation has become a critical factor in achieving project success (Olanipekun & Sutrisna, 2021). Advanced technologies such as Building Information Modelling (BIM), the Internet of Things (IoT), artificial intelligence (AI), cloud computing, and Digital Twin (DT) technologies are revolutionising how construction projects are conceptualised, planned, and executed (Papuraj et al., 2025; Tran et al., 2024; Liu et al., 2022). These technologies streamline workflows, reduce inefficiencies, and improve overall project outcomes by fostering greater accuracy, collaboration, and real-time decision-making among stakeholders in the digital construction era.

This transformation is shaped by three interconnected but distinct concepts, digitisation, digitalisation, and digital transformation. Digitisation refers to the process of converting analogue information into digital formats, such as transforming traditional blueprints, records, and physical workflows into Computer-aided design (CAD) drawings, digital schedules, and electronic documentation. While digitisation enhances operational efficiency, it does not fundamentally alter project workflows or decision-making structures (Yoo et al., 2010).

Building upon digitisation, the industry is experiencing a broader shift through digitalisation, which involves the adoption of digital technologies to optimise business processes. For instance, BIM and project management software enhance collaboration and streamline workflows, allowing construction firms to work more efficiently (Parviainen et al., 2017). However, while digitalisation improves operations, it does not necessarily reshape leadership structures or strategic decision-making processes.

By contrast, digital transformation extends beyond technological adoption; it requires a fundamental restructuring of business models, workflows, and leadership dynamics. In the construction sector, this shift is not only about using BIM, IoT, AI, robotics, and DTs but also aligning organisational strategies and cultures to support these technologies (Merschbrock & Munkvold, 2015). Unlike digitalisation, this transformation fundamentally reshapes decision-making, value delivery, and innovation-driven project management methodologies (Vial, 2019).

For instance, BIM enables project teams to visualise and plan construction activities in real time, minimising errors, optimising resource allocation, and enhancing risk management throughout the project lifecycle (Aghimien et al., 2020; Demagistris et al., 2022). Similarly, IoT applications, such as sensor-based monitoring systems, provide real-time data on construction site conditions, allowing for proactive decision-making and improved operational efficiency (Samuelson & Stehn, 2023). Cloud-based platforms facilitate seamless communication across geographically dispersed teams, while AI-driven analytics offer actionable insights to enhance productivity and project outcomes (Naji et al., 2024). Additionally, robotics and automation are optimising on-site operations, further contributing to improved efficiency and precision in construction processes (Zharov, 2024).

In this evolving landscape, project managers (PMs) are expected to adapt to new roles and expectations. They must not only possess traditional competencies but also acquire digital skills that enable them to effectively navigate and lead construction projects in a technology-driven environment (Liu et al., 2022). Digital competency can be understood as a combination of traditional project management skills and the full adoption of digital tools (Wu, 2022; Vuorikari et al., 2022). Understanding these emerging digital competencies is critical, as they directly impact project outcomes, foster innovation, and ensure the successful execution of complex construction projects. These advancements underscore the urgent need for PMs to develop comprehensive digital competencies tailored to the expanding digital transformation of the construction sector.

Various researchers have attempted to identify digital competencies for PMs in the construction sector. A notable contribution comes from Kissi et al. (2025), who conducted an extensive literature review and empirical analysis to examine PM competencies in the digitalised construction industry. Their work provides valuable insights into the existing competencies required for PMs to function within a digitalised construction environment. Through Fuzzy Synthetic Evaluation (FSE), they ranked competencies based on perceived importance, offering a structured perspective on the skills, knowledge, and attributes needed by PMs. Their study plays a crucial role in advancing discussions on digital competency development.

However, while Kissi et al. (2025) present a valuable contribution, their work is limited in scope, as it focuses on PMs operating within a digitalised construction industry, rather than on PMs leading digital transformation initiatives. Their study primarily identifies how PMs can adapt to and utilise digital tools, such as BIM, cloud computing, and automation, but does not explore the broader leadership, innovation, and strategic competencies required to drive digital transformation at an industry-wide level. Furthermore, their framework lacks multi-source validation and deeper theoretical refinement, both of which are essential for developing a comprehensive competency model.

Other studies, such as Papuraj et al. (2025), have emphasised the integration of BIM into construction project management education, highlighting the growing importance of digital competencies. While these studies provide useful insights, they fall short of delivering a comprehensive framework that captures the full spectrum of digital competencies necessary for PMs to lead large-scale digital transformation initiatives in construction.

Despite the increasing demand for digital competencies, the construction industry faces several challenges in fostering these skills among PMs. A prominent issue is the skills gap, with many professionals lacking the technical expertise required to adopt and utilise digital tools effectively (Papuraj et al., 2025; Kissi et al., 2025). While accreditation and professional frameworks acknowledge evolving competency requirements within the construction industry (e.g., CIOB, 2025; RICS, 2025), gaps persist in the depth and consistency of digital competency integration within construction project management education and training. Another challenge is the rapid pace of technological advancements, making it difficult for PMs to continuously update their skills to keep up with evolving tools and methodologies (Carvalho et al., 2024; Mandicak et al., 2020). Resistance to change within organisations also poses a significant barrier, as some stakeholders hesitate to embrace new technologies due to concerns about costs, disruptions, and unfamiliar workflows (Leontie, 2022; Zharov, 2024).

Therefore, as the construction industry continues to evolve, future PMs must be equipped not just to operate within a digitalised industry but to actively lead digital transformation initiatives. This includes integrating emerging technologies, such as blockchain for contract management, 5G networks for enhanced connectivity, advanced robotics for automated processes, and 3D printing for innovative construction methods (Tran et al., 2024). Unlike previous studies that focus on digital competency adoption, this research develops a comprehensive framework tailored to the specific needs of PMs tasked with leading digital transformation efforts in construction.

Moreover, leadership in digital transformation is not solely about technical competency, it requires strong strategic decision-making, adaptability, and an innovation-driven mindset. Studies in the information technology sector highlight the need for leaders who can drive organisational change and digital excellence, a requirement that is becoming increasingly relevant in the construction industry (Carvalho et al., 2024). As organisations strive to improve project outcomes and compete in an increasingly digital landscape, the development of digital leadership competencies among PMs is not just beneficial but essential.

While the construction sector continues its digital revolution, PMs remain at the centre of this transformation. They are expected to leverage digital tools and methodologies to drive efficiency, productivity, and innovation in their projects (Damek et al., 2022). This evolution necessitates the development of new digital competencies, encompassing both traditional project management skills and the full adoption of digital technologies. Despite the growing demand, digital PM competencies specific to the construction sector are not yet fully established. This gap in knowledge underscores an urgent need for developing a comprehensive framework tailored to the unique requirements of the construction industry.

To address this transformation, this chapter focuses on the following Research Question 2 (RQ2): *What are the emerging digital competencies required for project managers to excel in the evolving construction sector?* By addressing this question, the chapter aims to provide a foundation for understanding the skills, knowledge, and core personal attributes required for construction PMs to successfully lead digital transformation initiatives. Furthermore, it emphasises the importance of bridging the skills gap through targeted training, continuous learning, and industry–academic collaboration to ensure that the construction sector remains competitive in the digital age. The remainder of this chapter is organised as follows: Section 4.3 describes the methodology, Section 4.4 provides the literature background, Section 4.5 presents the results, Section 4.6 discusses the findings, Section 4.7 introduces the Next-Gen Digital PM Competency List for Construction, and Section 4.8 concludes with recommendations and final thoughts.

4.3 **Literature Background**

4.3.1 The Digital Transformation of Construction Project Management

The digital transformation of the construction industry is fundamentally reshaping project management practices, driving greater efficiency and effectiveness across all project phases. Technologies such as BIM, AI, and the IoT have become integral to modern construction workflows. BIM, for instance, provides a shared digital environment that enhances project coordination, visualisation, and lifecycle management, significantly reducing errors and inefficiencies (Tran et al., 2024). When integrated with AI, BIM's capabilities extend further, enabling predictive analytics to mitigate risks, optimise designs, and automate repetitive tasks (Zharov, 2024).

Similarly, IoT is transforming construction operations by enabling real-time monitoring of construction sites and automating quality control processes (Papuraj et al., 2025). Data collected from IoT-enabled devices can be analysed to enhance decision-making, optimise resource allocation, and improve operational efficiency (Naji et al., 2024). Additionally, cloud computing facilitates seamless communication and data sharing among geographically dispersed teams, fostering collaboration and reducing project delays (Leontie, 2022).

While these technologies offer substantial benefits, their adoption is not without challenges. Studies indicate that organisational inertia, financial constraints, and resistance to change are among the primary barriers to digital adoption in the construction sector (Whyte et al., 2024). However, digital transformation extends beyond the mere adoption of technologies; it necessitates a fundamental restructuring of business models, workflows, and leadership dynamics. This transformation does not merely enhance project execution but redefines decision-making processes, value delivery, and innovation-driven project management methodologies (Vial, 2019).

Recognising this shift, this research develops a comprehensive framework tailored to the specific needs of PMs tasked with leading digital transformation efforts in construction. By bridging the gap between technological advancements and strategic leadership, this framework aims to equip PMs with the essential skills, knowledge, and core competencies required to navigate and lead construction projects in an increasingly digitally transformed environment. The following sub-sections aim to discuss the influence of digital transformation on the digital PM in the era of construction digital transformation. Besides, the key competency categories identified in the literature and aligned with the traditional PM frameworks.

4.3.2 The Influence of Digital Transformation on Digital PM Competencies

The concepts of digitisation, digitalisation, and digital transformation were introduced in Chapter 1; this section builds on those foundations by examining their implications for construction project management and competency development. Digital PM competencies in the construction sector are shaped by the progressive adoption and integration of these technologies, which represent distinct stages of technological advancement influencing the evolution of project management practices.

- **Digitisation** refers to the conversion of analogue information into digital formats. In the construction sector, this includes transforming traditional blueprints, records, and manual workflows into digital representations such as CAD drawings, digital schedules, and electronic documentation. While digitisation lays the foundation for technological adoption, it primarily enhances operational efficiency without fundamentally altering organisational workflows (Yoo et al., 2010).

- **Digitalisation** involves the application of digital technologies to improve and optimise business processes. For instance, the adoption of BIM and project management software exemplifies digitalisation, as these tools enhance project workflows, coordination, and collaboration. Digitalisation introduces incremental improvements by streamlining processes and enabling better communication, yet it does not fundamentally alter how organisations or projects are managed (Parviainen et al., 2017).
- **Digital transformation** represents a more systemic shift, involving the integration of advanced technologies across organisational operations. It fundamentally redefines value delivery, requiring organisations to rethink strategies, workflows, and management structures (Vial, 2019). In the construction industry, digital transformation extends beyond the adoption of BIM, IoT, AI, robotics, and Digital Twins; it also necessitates significant cultural and organisational changes to accommodate these innovations (Merschbrock & Munkvold, 2015). This transformation does not merely enhance operational efficiency; rather, it reshapes strategic decision-making, leadership structures, and project management methodologies.

The influence of digital transformation on PM competencies is most evident in its ability to drive comprehensive organisational change. Unlike digitisation or digitalisation, digital transformation fundamentally alters project workflows, stakeholder interactions, and team management approaches. For example, BIM has revolutionised project coordination and visualisation, enabling PMs to plan and manage construction activities more effectively while fostering collaboration across multidisciplinary teams (Succar et al., 2013). Similarly, IoT integration has introduced real-time site monitoring and data-driven decision-making, requiring PMs to interpret and act on vast amounts of information efficiently (Gerbert et al., 2016; Whyte, 2019).

Another critical feature of digital transformation is the convergence of physical and digital systems through IoT-enabled devices and DT technologies. IoT applications, including sensor-based monitoring systems, provide real-time insights into construction site conditions, enabling proactive decision-making and risk mitigation (Rao et al., 2022). DTs allow PMs to simulate and optimise construction activities virtually before execution, reducing errors and improving resource efficiency (Whyte, 2019). These technological advancements demand advanced analytical and technical skills, requiring PMs to navigate hybrid physical–digital environments effectively.

Beyond technology, digital transformation is reshaping organisational structures and leadership dynamics. The emergence of new roles, such as BIM managers, digital coordinators, and data analysts, introduces new leadership challenges for PMs. Traditional hierarchical leadership structures are evolving into collaborative, interdisciplinary frameworks, where technical experts and PMs share responsibilities (Sacks et al., 2018). PMs must now demonstrate interpersonal and political skills to coordinate diverse teams while ensuring alignment between technical objectives and strategic goals (Whyte & Levitt, 2011). Navigating these dynamics requires a blend of technical expertise and leadership competencies tailored to a digitalised project environment.

Digital transformation has also redefined project management roles and responsibilities. While technical roles such as BIM managers focus on the operational application of digital tools, PMs are increasingly expected to integrate these tools into broader project strategies. This shift necessitates a balance between traditional project management skills and advanced technical, conceptual, and strategic competencies (Sacks et al., 2018). For example, AI-driven analytics, robotics, and IoT applications require PMs to leverage these tools to optimise outcomes while maintaining a strategic focus on long-term project goals.

Ultimately, while digitisation and digitalisation laid the foundation for technological advancements in construction, the competencies required of PMs are primarily shaped by digital transformation. This transformation extends beyond technology adoption to encompass cultural, organisational, and managerial change. PMs must now demonstrate a combination of traditional and emerging digital competencies, including technical proficiency, data-driven decision-making, strategic thinking, and leadership skills, to navigate the challenges and opportunities of this evolving digital landscape.

In this thesis, a Digital PM is defined as a professional who extends the responsibilities of the traditional PM by integrating advanced digital skills, knowledge, and traits required to lead technology-enabled projects. Beyond managing scope, time, cost, and quality, the Digital PM harnesses tools such as BIM, IoT, AI, robotics, and DTs to optimise project outcomes, enable data-driven decision-making, and foster collaborative, interdisciplinary teamwork. This role requires a unique blend of technical proficiency, strategic vision, and adaptive leadership, positioning the Digital PM as both a delivery leader and a transformation enabler within the construction industry. This definition is consistent with recent research that positions the Digital PM as the fusion of traditional PM responsibilities with the adoption of advanced digital tools and technologies, requiring them to combine technical expertise, strategic awareness, and adaptive leadership in order to thrive in rapidly evolving digital environments (Wu, 2022).

4.3.3 Key Digital Competencies Categories Identified in Literature: Skills, Knowledge, and Core Personality

The evolution of competencies in the construction industry is increasingly influenced by digital transformation, highlighting the need for structured frameworks to define and organise emerging digital competencies (Vuorikari et al., 2022; Waqar et al., 2023). Traditional frameworks, such as the Project Manager Competency Development (PMCD) framework, the IPMA Individual Competence Baseline (ICB), and the PMI Talent Triangle, classify PM competencies into three primary dimensions: Skills, Knowledge, and Core Personality Traits. These dimensions have traditionally guided competency development, ensuring that PMs possess the technical proficiency, strategic insight, and leadership capabilities needed to execute projects effectively.

However, the increasing integration of digital technologies, including BIM, AI, the IoT, and cloud-based collaboration platforms, has significantly reshaped competency requirements for construction PMs in the context of digital transformation (Kissi et al., 2025; Atuahene et al., 2023). While the fundamental structure of skills, knowledge, and core personality traits remains relevant, its content must evolve to reflect the realities of digital construction management. Existing frameworks, such as PMI (2021b) and IPMA (2015b), provide general competency structures but do not explicitly define sector-specific digital competencies. The European Commission (2019) framework for key competencies for lifelong learning further emphasises that effective competencies are a dynamic combination of knowledge, skills, attitudes, and values, essential for continuous personal and professional development in a digital age. To ensure consistency and industry relevance, the categorisation of Skills, Knowledge, and Core Personality Traits was benchmarked against established competency frameworks, including the PMBOK Guide, PMI Talent Triangle, and IPMA Individual

Competence Baseline, so that the adapted categories reflect both traditional PM structures and the emerging demands of digital transformation.

To align digital PM competencies with traditional framework categories while accommodating digital transformation, the following three sections define and structure digital competencies into Skills, Knowledge, and Core Personality categories.

1 Skills: Enhancing Digital Capabilities in Construction Project Management

Traditional PM skills have long been essential in the construction industry, providing the fundamental abilities required to efficiently plan, execute, and monitor projects. These skills fall into three broad categories: technical, conceptual, and interpersonal competencies. Technical skills encompass project management methodologies, scheduling software, risk management systems, and financial forecasting models, all of which help PMs maintain project control and ensure timely completion (Rodrigues et al., 2023). Conceptual skills, such as strategic thinking and process integration, enable managers to oversee multiple workflows and align them with broader organisational goals (Lee et al., 2021). Meanwhile, interpersonal skills, including leadership, communication, and negotiation, are vital for engaging stakeholders and ensuring seamless collaboration among teams (Omer et al., 2022). These traditional competencies remain foundational in construction project management; however, the industry's increasing reliance on digital technologies has significantly expanded the skillset required for effective project execution.

The digitalisation of construction processes has introduced new skill requirements for PMs, focusing on the incremental adoption of digital tools to enhance efficiency and coordination. Digitalised skills involve the use of technology-driven solutions to optimise existing workflows without fundamentally altering project management methodologies (Kissi et al., 2025). For example, proficiency in BIM has become an essential digitalised skill, enabling PMs to visualise, analyse, and manage construction models in a shared digital environment (Hosseini et al., 2018). Similarly, cloud-based collaboration platforms improve team coordination by facilitating real-time data exchange, reducing project delays, and streamlining communication between stakeholders (Mandičák et al., 2020). Another critical aspect of digitalisation is the ability to integrate IoT applications for site monitoring and automated quality control, ensuring that PMs can make data-driven decisions based on real-time project conditions (Atuahene et al., 2023).

Digitalised project management also requires enhanced data literacy. PMs must be proficient in managing digital documents, interpreting automated reports, and understanding predictive analytics to anticipate project risks (Waqar et al., 2023). These skills enhance traditional competencies by optimising existing construction processes but do not yet fundamentally reshape how PMs lead projects. Instead, digitalisation represents an evolution of traditional skills rather than a complete transformation of project management practices.

While digitalisation improves project efficiency, digital transformation represents a more systemic shift in project management, encompassing the full integration of emerging technologies with fundamental changes in organisational structures, leadership approaches, and strategic decision-making (Vuorikari et al., 2022). Digital transformation skills extend beyond the operational use of BIM or IoT and require a new set of strategic and leadership capabilities. PMs must develop competencies in AI-driven decision-making, involving the use of machine learning algorithms for automated risk assessment, project forecasting, and real-time performance optimisation (Raza et al., 2023).

Moreover, digital transformation fosters innovation-driven leadership, requiring PMs to manage hybrid digital-physical environments and navigate interdisciplinary collaboration across traditional construction teams and emerging technology specialists (Lukianov et al., 2021). Unlike digitalised skills, which primarily focus on enhancing existing processes, digital transformation skills require PMs to redesign workflows, redefine value delivery, and champion organisational change (Atuahene et al., 2023). PMs must also possess agility and resilience, as digital transformation introduces continuous technological evolution, demanding adaptive learning and strategic innovation (Waqar et al., 2023).

While traditional competencies remain a foundation, digitalisation and digital transformation are reshaping the required skillsets for construction PMs. Digitalisation refines traditional skills through technology-driven enhancements, whereas digital transformation redefines project management by integrating advanced digital methodologies into every aspect of construction practice. To bridge this evolving competency gap, PMs must develop a dynamic skillset that blends technical expertise, digital literacy, and transformational leadership (Vuorikari et al., 2022). This research emphasises the importance of lifelong learning in project management, ensuring that PMs remain adaptable in a rapidly digitising industry.

2 Knowledge: Strengthening Theoretical and Industry-Specific Expertise

Knowledge in project management has traditionally encompassed the theoretical foundation required to plan, execute, and monitor construction projects effectively. Traditional PM knowledge areas are well-documented in the PMBOK Guide (PMI, 2021b) and include integration, scope, schedule, cost, quality, risk, procurement, and stakeholder management (Rodrigues et al., 2023). These knowledge areas provide a structured framework that ensures project success by enabling PMs to anticipate challenges, implement best practices, and apply strategic decision-making throughout a project's lifecycle (Liu et al., 2022).

However, the emergence of digital technologies has significantly expanded the knowledge base required for effective project execution. Modern PMs must go beyond traditional frameworks by understanding and applying digital tools that enhance project efficiency, collaboration, and decision-making. The evolution of PM knowledge from traditional principles to digitalised and transformation-driven expertise reflects the increasing complexity of managing construction projects in a highly connected and data-driven industry (Waqar et al., 2023).

Digitalisation has introduced new knowledge areas that build on traditional PM expertise through the incremental adoption of digital technologies (Kissi et al., 2025). One key aspect of digitalised knowledge is proficiency in BIM, which allows PMs to create and manage real-time digital representations of construction projects (Hosseini et al., 2018). Beyond basic usage, PMs must also understand BIM standards and protocols to ensure data consistency, interoperability, and compliance with industry regulations (Mandičák et al., 2020).

Another critical digitalised knowledge area is IoT-driven project monitoring, in which PMs must understand the principles of sensor-based data collection and real-time analytics to enhance site safety, logistics, and resource management (Atuahene et al., 2023). Additionally, data analytics and cybersecurity awareness have become fundamental for PMs to manage and protect sensitive project information, ensuring secure digital transactions, cloud-based data storage, and risk mitigation in construction projects (Atuahene et al., 2023).

Kissi et al. (2025) specifically define digitalised knowledge as the theoretical understanding required to leverage digital tools for decision-making, problem-solving, and workflow optimisation. This definition aligns with the European Commission (2019) lifelong learning framework, which emphasises the importance of continuous upskilling in an industry where digital technologies evolve rapidly.

While digitalisation enhances specific knowledge areas, digital transformation represents a fundamental shift in how project management knowledge is structured and applied (Vuorikari et al., 2022). Digital transformation knowledge extends beyond the functional understanding of BIM, IoT, and AI and requires PMs to rethink project execution strategies, leadership approaches, and stakeholder engagement models (Raza et al., 2023).

For instance, PMs must now develop expertise in AI-driven predictive analytics, which enables data-driven decision-making for risk assessment, cost forecasting, and automated project scheduling (Lukianov et al., 2021). Additionally, understanding blockchain technology for contract management is becoming crucial in ensuring transparency, trust, and efficiency in digital transactions (Rodrigues et al., 2023).

Another transformative knowledge area is DT technology, where PMs must integrate real-time data with virtual simulations to optimise construction planning, operational efficiency, and sustainability (Lee et al., 2021). Unlike digitalisation, which focuses on enhancing workflows, digital transformation requires PMs to redesign traditional project management knowledge frameworks to incorporate emerging innovations, strategic foresight, and agile decision-making (Atuahene et al., 2023).

To remain competitive, PMs must continuously expand their knowledge base by integrating traditional project management principles, digitalised expertise, and digital transformation insights (Vuorikari et al., 2022). While digitalised knowledge improves project efficiency, digital transformation knowledge reshapes how projects are conceptualised, executed, and managed. This shift underscores the urgent need for a structured competency framework that aligns theoretical understanding with practical digital applications, ensuring that PMs can lead in an era of continuous technological evolution (Waqar et al., 2023).

3 Core Personality Traits: Adapting to Leadership and Change in a Digitalised Industry

Core personality traits are essential for effective leadership, decision-making, and stakeholder management in construction project management. Traditionally, successful PMs have demonstrated key personality attributes such as conscientiousness, resilience, evaluative thinking, and social confidence (Omer et al., 2022). These traits enable PMs to maintain project control, navigate uncertainties, and foster strong professional relationships (Rodrigues et al., 2023).

However, as the construction sector undergoes digital transformation, PMs must develop additional personality traits that align with the demands of technology-driven leadership, interdisciplinary collaboration, and continuous adaptation (Vuorikari et al., 2022). The evolution from traditional personality traits to digitalised and transformation-oriented attributes reflects the changing landscape of construction project management.

The digitalisation of construction has redefined leadership attributes, requiring PMs to develop a new set of interpersonal and cognitive traits (Kissi et al., 2025). One of the most critical traits in digitalised project management is adaptability, which enables PMs to adjust to new technologies, digital workflows, and evolving industry standards (Lee et al., 2021). Kissi et al. (2025) further highlight digital collaboration, which includes the ability to communicate effectively through digital platforms, manage virtual teams, and foster online stakeholder engagement.

Additionally, data-driven decision-making has become an essential personality attribute, requiring PMs to be comfortable interpreting analytics, assessing digital reports, and making informed project adjustments based on real-time insights (Mandičák et al., 2020). These skills enhance traditional leadership attributes by integrating technology-based cognitive agility into project management decision-making (Liu et al., 2022).

While digitalised personality traits enable PMs to operate effectively in a technology-enhanced environment, digital transformation requires them to lead change at organisational and industry-wide levels (Vuorikari et al., 2022). One of the most crucial transformational traits is innovation-driven leadership, where PMs must champion digital change, foster an innovative mindset, and encourage cross-disciplinary collaboration (Raza et al., 2023).

Strategic foresight is another key transformational personality trait, requiring PMs to anticipate future trends, integrate emerging technologies, and align digital initiatives with long-term organisational goals (Rodrigues et al., 2023). Unlike digitalised adaptability, which focuses on adjusting to change, strategic foresight is about proactively shaping industry advancements and leading large-scale digital initiatives (Waqar et al., 2023).

Additionally, resilience in digital transformation is critical, as PMs must navigate resistance to change, manage technological disruptions, and drive continuous improvement (Lukianov et al., 2021). Unlike traditional resilience, which focuses on overcoming project-specific challenges, digital transformation resilience requires long-term commitment to digital adoption, ongoing training, and the ability to foster a digital-ready organisational culture (Vuorikari et al., 2022).

As digital transformation reshapes project management, PMs must cultivate a leadership identity that integrates traditional, digitalised, and transformation-driven personality traits. While traditional traits provide a leadership foundation, digitalised attributes enhance adaptability, and digital transformation traits empower PMs to drive change and innovation. This evolution underscores the need for a structured personality competency framework that prepares PMs to lead, innovate, and sustain technological advancements in construction project management (Waqar et al., 2023).

In this thesis, digital competencies are defined as the evolving skills, knowledge, and core personality traits that enable PMs to lead effectively in digitally transformed construction environments. They encompass both digitalised capabilities, which enhance traditional project management practices through technology-driven improvements, and transformation-oriented attributes, which empower PMs to integrate advanced tools such as BIM, IoT, AI, and DTs into strategic workflows. Digital competencies therefore combine technical proficiency, data-driven decision-making, contextual knowledge, and adaptive leadership traits to ensure innovation, resilience, and sustained value delivery in complex, technology-enabled project ecosystems.

4.4 Methods

This chapter adopts a structured, multi-phase methodology to identify, categorise, and redefine the digital competencies required for PMs in the evolving construction sector. This approach ensures that emerging digital competencies are systematically aligned with established traditional project management frameworks, including the PMBOK Guide (PMI, 2021a), the IPMA Individual Competence Baseline (IPMA, 2015), the PMI Talent Triangle, and the Project Manager Competency Development Framework (PMI, 2017b), which served as benchmarks for alignment, while addressing the rapid integration of digital technologies in construction.

To answer the research question: *"What are the emerging digital competencies required for project managers to excel in the evolving construction sector?"*, this study follows a three-phase methodological framework, which systematically progresses as follows:

1. **Phase one (Systematic Literature Review (SLR)):** This phase identifies existing digital competencies for construction PMs by reviewing peer-reviewed academic sources. The competencies extracted from the literature are mapped, analysed, and documented using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework.
2. **Phase two (Thematic Analysis):** In this phase, the competencies identified in Phase One are categorised into a structured framework based on their practical application, theoretical foundation, and behavioural attributes, aligning them with the Skills, Knowledge, and Core Personality framework.

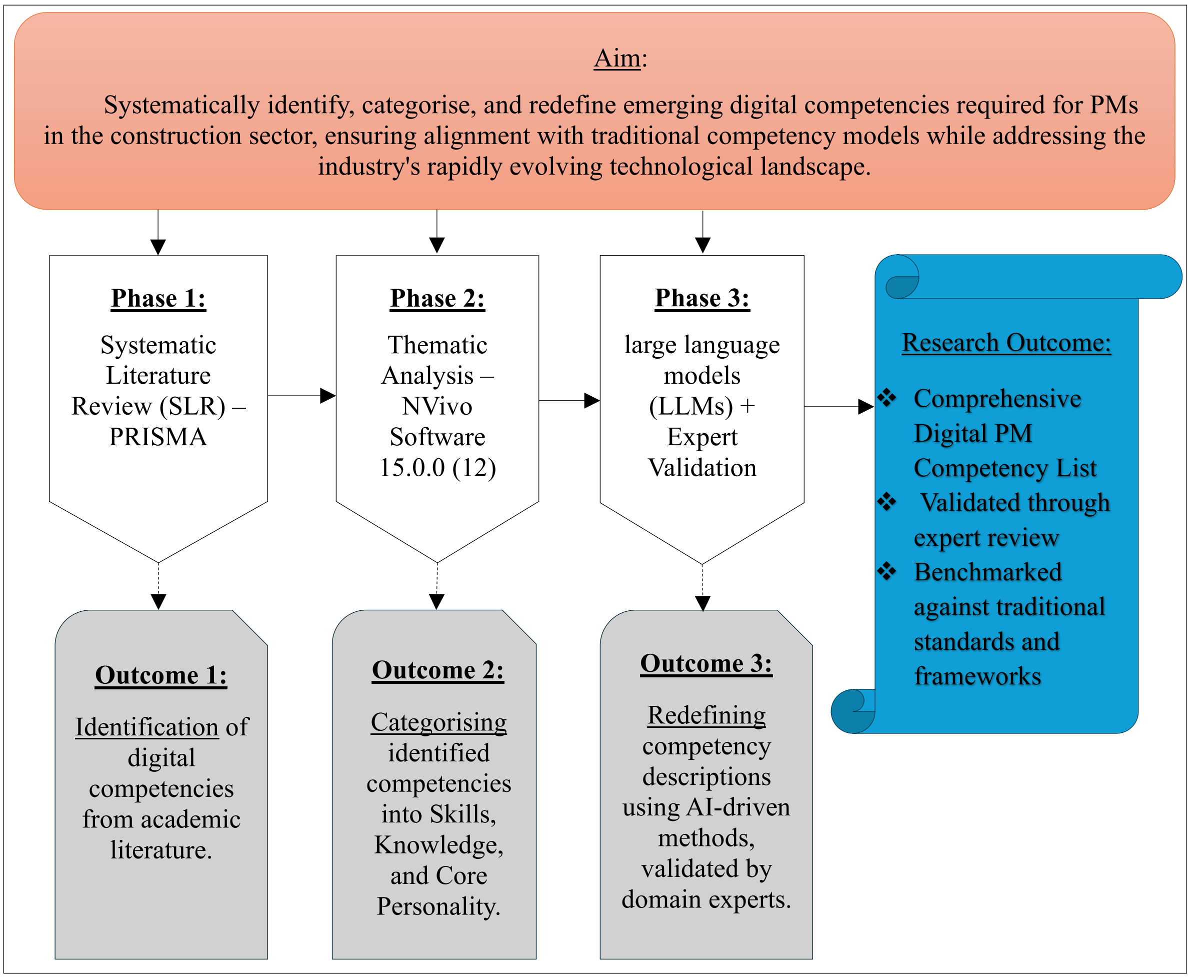


Figure 4.1: Three Phase Methodological Approach

3. **Phase three (LLM-Based Competency Definition):** This phase synthesises the multiple competency definitions from Phases One and Two into comprehensive definitions using a Large Language Model (LLM). The LLM is employed to enhance accuracy, minimise subjective bias, and ensure consistency across competency definitions by systematically integrating insights from various sources. By leveraging natural language processing, the model refines definitions to align with both theoretical foundations and real-world applicability, ensuring clarity and coherence in competency categorisation. Following this synthesis, a multi-step

expert validation process was undertaken. Two independent domain experts with over ten years of experience in construction project management and digital transformation reviewed each competency definition to ensure technical accuracy, industry relevance, and alignment with established PM standards.

The methodological workflow is illustrated in Figure 4.1, detailing the sequential process of SLR, Thematic Analysis, LLM-Based Competency Definition, and Expert Validation. This structured methodology enhances rigor, ensures replicability, and strengthens validity, providing a clear framework for defining digital PM competencies in the era of construction digital transformation.

4.4.1 Phase One (Systematic Literature Review (SLR)):

The *first phase* of this chapter employs a SLR to identify the digital competencies required for PMs in the evolving construction sector. An SLR is a structured, transparent, and replicable approach that synthesises existing research on a specific question, ensuring a rigorous, evidence-based analysis (Grant & Booth, 2009). The SLR approach was selected over traditional narrative reviews due to its ability to minimise selection bias, enhance transparency, and provide a systematic and reproducible synthesis of the literature (Kitchenham & Charters, 2007), thereby providing a robust foundation for competency identification.

To enhance methodological rigour, this study adheres to the PRISMA 2020 guidelines (Page et al., 2021). PRISMA provides a standardised framework for systematically identifying, screening, and selecting relevant literature while ensuring transparency and reproducibility in the review process. The PRISMA flow diagram, Figure 4.2, illustrates the study selection process.

The SLR methodology consists of six structured steps:

1. **Identification:** This step involves the systematic retrieval of relevant academic literature using predefined search strategies. To ensure comprehensive coverage, the study utilised the Scopus database. Scopus was selected due to its extensive coverage of peer-reviewed literature across multiple disciplines, indexing a larger number of journals compared to Web of Science, and providing broad interdisciplinary representation, which is particularly valuable for capturing applied and emerging research domains such as digital construction (Mongeon & Paul-Hus, 2016). A structured Boolean search query was developed to capture a wide range of studies by combining terms related to construction (*e.g., "Construction," "building," or "Civil"*) with terms related to digital technologies (*e.g., "digital technolog*," "digital transformation," "construction technolog*," "smart construction," "construction 4.0," "digital twin," "BIM," "building information modelling," "Internet of Things," "IoT," "construction automation," "construction software," "augmented reality," "virtual reality," "drones," "robotics," "AI," "artificial intelligence," "machine learning," and "cloud computing"*). These were further combined with project management terms (*e.g., "project manage*," "PM," "project leadership," "project planning," "project execution," "project delivery," "project control," "project performance," and "project success"*) and competency-related terms (*e.g., "competenc*," "skill*," "capabilit*," "knowledge," "proficiency," and "attribute*"*). The search encompassed studies published up to 2024 to capture recent advancements, and was limited to English-language, peer-reviewed journal articles, conference proceedings, and industry reports.

2. **Screening:** This step employs a structured process to filter the relevant studies. First, duplicate studies were removed using EndNote and manually cross-checked in Microsoft Excel. Next, a title and abstract screening was conducted to exclude studies unrelated to digital competencies in construction project management, retaining only those that explicitly addressed these competencies for full-text review. Finally, the eligibility criteria, Table 4.1, was applied to ensure that only high-quality, thematically relevant studies were included.
3. **Eligibility:** After screening, the remaining studies underwent a full-text assessment to ensure both methodological quality and relevance. The structured inclusion and exclusion criteria, Table 4.1, ensured that only research explicitly addressing digital competencies for PMs in construction was retained.

Table 4.1: Eligibility Criteria for Systematic Literature Review

Inclusion criteria	Exclusion criteria
○ Studies that explicitly investigate and define digital competencies relevant to PM in construction.	○ Research that does not explicitly examine digital competencies related to PM.
○ Studies analysing the integration and application of digital technologies in construction project management.	○ Studies discussing digital transformation technologies in construction without linking them to PM competencies.
○ Peer-reviewed journal articles or conference proceedings, ensuring scholarly credibility.	○ Articles published in non-peer-reviewed sources.
○ Studies available in English for consistency in analysis and interpretation.	○ Studies published in languages other than English.
○ Studies within the subject areas of Engineering, Computer Science, Business Management and Accounting, Decision Sciences, and Multidisciplinary fields.	○ Studies outside the aforementioned subject areas.

This approach ensured that only high-quality, thematically relevant studies were included in the analysis.

4. **Inclusion Phase & Data Extraction:** After the eligibility assessment, the final set of studies meeting all inclusion criteria was selected for in-depth analysis. This phase involved systematically extracting relevant data from these studies to ensure a structured synthesis of findings related to digital competencies for PMs in the construction sector.
   The data extraction process comprised two main procedures. First, the selected studies were cross-checked for consistency, ensuring that each explicitly addressed the identification of digital competencies for construction PMs, as intended for this chapter. The study selection process is visually represented by the PRISMA flow diagram, Figure 4.2. Second, a structured data extraction framework was employed to ensure consistency and reproducibility. Table 4.2 outlines the data categories used in this process.

Table 4.2: Data Extraction and Classification

Data Category	Description
Study Reference	Citation details (authors, year).
Research Aim	The purpose of the study and relevance to digital competencies.
Methods / Techniques	The research design and methods employed (e.g., qualitative, quantitative, mixed methods, literature review).

Technology Focus	The digital tools studied (e.g., BIM, AI, IoT, DTs).
Key Findings	The main conclusions regarding competencies and their implications.

This systematic approach ensured that the data extracted from each study contributed to a coherent and comprehensive understanding of digital competencies for construction PMs.

5. **Ensuring Reliability and Validity:** To ensure methodological rigour and the credibility of the selected studies, multiple validation measures were implemented throughout the SLR process. First, a systematic search strategy was applied using clearly defined inclusion and exclusion criteria to identify relevant studies from Scopus as a reputable academic database. This process ensured that only peer-reviewed, high-quality sources were considered. Next, during the screening phase, a two-stage review process was conducted: the title and abstract screening to eliminate irrelevant or low-quality studies, and a full-text review to assess alignment with the study's objectives and methodological standards. To enhance reliability, independent reviewers evaluated the selected studies, ensuring inter-coder agreement and reducing selection bias (O'Connor & Joffe, 2020).
In the eligibility phase, papers were assessed based on predefined quality assessment criteria, including methodological rigour, relevance to digital PM competencies, and empirical robustness. Studies that failed to meet these criteria were excluded. Additionally, competency extraction methods within the included studies were cross validated against widely recognised frameworks as a benchmark, such as the PMI Talent Triangle, IPMA Competency Baseline, and PMBOK guidelines, ensuring industry alignment. This benchmarking was applied qualitatively, comparing the extracted competencies against core categories in these standards to confirm thematic consistency and alignment, with a more detailed thematic benchmarking conducted in Phase Two. Finally, in the inclusion and data extraction phase, only studies that passed all validation checkpoints were systematically analysed. An independent verification step was implemented, where a second researcher reviewed the extracted competency data to confirm accuracy and completeness. This structured validation process ensures that the SLR findings provide a robust, high-quality dataset of digital competencies for Phase Two (Thematic Analysis), forming a strong foundation for the development of the Digital PM Competency List.

Despite its strengths, the SLR approach is subject to certain limitations. The reliance on a single database may result in the omission of relevant studies indexed in alternative sources such as Web of Science or domain-specific repositories. However, Scopus was selected due to its extensive coverage and strong representation of peer-reviewed literature across engineering, construction management, and interdisciplinary research domains, offering broader journal coverage compared to Web of Science. Nevertheless, no single database provides complete coverage of all scientific outputs, and database selection may introduce bias depending on field, language, and publication type (Mongeon & Paul-Hus, 2016).

Additionally, the review was limited to English-language publications to ensure consistency in analysis and interpretation, which is a common practice in systematic literature reviews, although it may introduce language bias. To mitigate these limitations, a comprehensive and structured search strategy was employed, supported by clearly defined inclusion and exclusion criteria, as well as backward and forward citation tracking to identify influential studies beyond the initial database search. These measures enhance the transparency, robustness, and reproducibility of the review process (Kitchenham & Charters, 2007).

6. **PRISMA Flow Diagram:** To ensure transparency and replicability, this study follows the PRISMA 2020 framework (Page et al., 2021) for systematically identifying, screening, excluding, and including studies in the final analysis, as illustrated in Figure 4.2. The PRISMA flow diagram provides a structured, rigorous, and unbiased selection process (Moher et al., 2009).

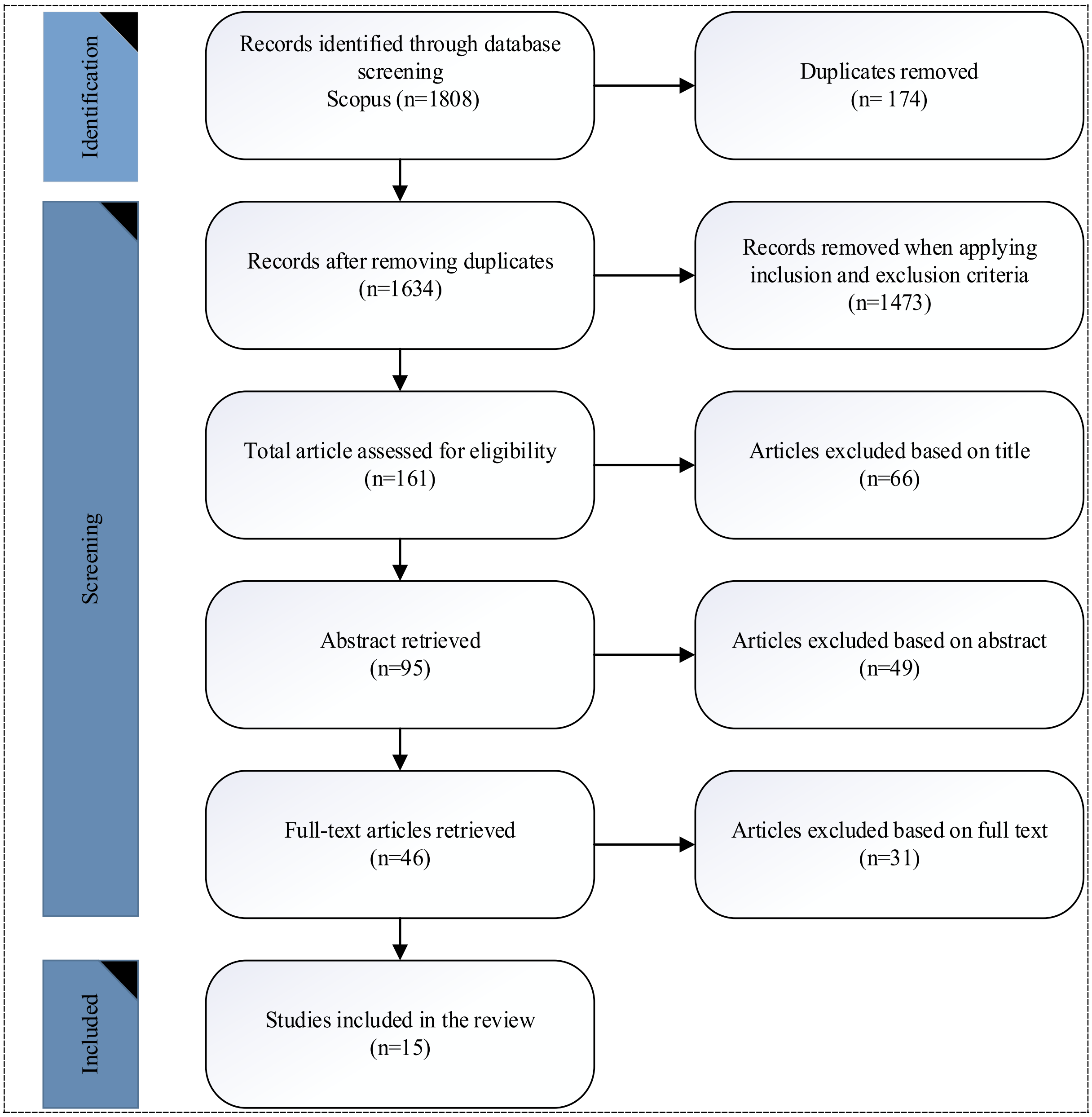


Figure 4.2: PRISMA Flow Diagram

By applying the PRISMA guidelines, this study enhances clarity, methodological rigor, and reproducibility. This approach ensures that only high-quality, relevant studies contribute to the definition and classification of digital competencies for construction PMs, thereby bridging the existing gap in this evolving technological landscape.

4.4.2 Phase Two: Thematic Analysis of Digital Competencies

The *second phase* of this study builds on Phase One (SLR) by employing Thematic Analysis to categorise and organise the digital competencies identified in the literature. Thematic Analysis is a qualitative research method used to systematically classify, interpret, and identify patterns within data, ensuring that competencies are meaningfully structured (Braun & Clarke, 2012). This approach enables a structured classification of competencies into the categories of Skills, Knowledge, and Core Personality, benchmarking them against established traditional project management competency frameworks. This benchmarking involved a qualitative comparison, aligning technical competencies with PMI's Technical PM domain, behavioural attributes with IPMA's "People" elements, and digital literacy themes with DigComp 2.2, ensuring thematic consistency and alignment with globally recognised standards.

By applying Thematic Analysis, this phase goes beyond identifying digital competencies, ensuring they are systematically grouped and structured, thereby enabling a clear understanding of their role in digital construction PM.

The thematic analysis consists of the following three steps:

1. **Thematic Analysis Approach:**

The analysis follows the six-phase framework proposed by Braun and Clarke (2006), enhanced by the use of NVivo software for qualitative data analysis. This approach facilitates structured data organisation, pattern identification, and thematic categorisation. The six phases are as follows:

I. **Familiarisation with Data:** Reviewing the extracted digital competencies from the SLR findings to develop an initial understanding of the themes. Besides, NVivo software was employed for data visualisation and pattern recognition, enabling a preliminary exploration of competency relationships.

II. **Generating Initial Codes:** Assigning preliminary labels (codes) to competencies based on their meaning, function, and relevance. Moreover, NVivo assisted in automating text-based pattern identification, reducing subjectivity and enhancing consistency.

III. **Searching for Themes:** Grouping similar digital competency definitions into overarching thematic categories, Skills, Knowledge, and Core Personality. NVivo's coding comparison tools also facilitated the detection of commonalities across extracted competency definitions.

IV. **Reviewing Themes:** Refining and validating the emerging themes to ensure logical coherence and distinct categorisation. Furthermore, NVivo-generated thematic maps and hierarchical node structures supported category verification and refinement.

V. **Defining and Naming Themes:** Assigning final competency labels that best describe each theme. Additionally, NVivo's auto-clustering function was used to confirm the distinctiveness of each identified theme.

VI. **Producing the Final Thematic Map:** Structuring the digital competencies into the three primary categories: Skills, Knowledge, and Core Personality. Moreover, NVivo-generated word frequency analysis and relationship mapping validated the coherence of thematic classifications. To ensure structural validity and alignment with industry standards, the final categorisation was benchmarked against established project management competency frameworks, including the IPMA Competency Baseline (IPMA, 2015b), PMI Talent Triangle (PMI, 2021b), and PMI (2017b) Framework. This benchmarking process provided a reference point for confirming that the derived categories were both conceptually sound and practically relevant to the construction sector's digital project management context.

NVivo-supported process ensures that the categorisation of competencies remains objective, data-driven, and replicable across different studies.

2. Thematic Classification of Digital Competencies

Using Thematic Analysis coupled with NVivo-assisted classification, the digital competencies were grouped into three distinct categories to align with the findings from Phase One.

- **Skills:** This category encompasses practical digital capabilities for project execution. It includes competencies involving the direct application of digital tools in construction project management. For instance, BIM proficiency, IoT integration, AI-driven analytics, and cloud-based project coordination are key examples (Mandičák et al., 2020; Rodrigues et al., 2023; Hosseini et al., 2018). NVivo was used to track competencies linked to technological proficiency and automation
- **Knowledge:** This category focuses on theoretical and domain-specific digital understanding. It involves competencies related to comprehending and leveraging digital transformation for digital PM in the construction sector. Examples include data analytics, cybersecurity awareness, digital workflow optimisation, and process automation (Liu et al., 2022; Vuorikari et al., 2022). NVivo facilitated text analysis, ensuring accurate categorisation based on conceptual depth and strategic digital insight.
- **Core Personality:** This category comprises leadership and behavioural attributes essential for digital management. It includes competencies related to adaptability, decision-making, and digital leadership in tech-driven environments. Examples include change management, strategic thinking, an innovative mindset, and digital leadership (Kissi et al., 2025; Rodrigues et al., 2023; Mesaros et al., 2020). NVivo's sentiment analysis tools helped identify behavioural and managerial themes within competency descriptions.

Each digital competency was systematically coded, classified, and mapped to ensure consistency with the established framework from the SLR phase. This classification forms the basis for Phase Three, where competencies will be redefined using LLM-based synthesis.

3. Ensuring Reliability and Validity in Thematic Analysis

To enhance credibility, rigour, and methodological validity, several validation measures were applied. First, inter-coder agreement was achieved by having multiple researchers independently review the NVivo-coded thematic classifications, which helped minimise subjective bias (O'Connor & Joffe, 2020). Additionally, NVivo-enabled thematic verification was conducted by cross-checking automated coding patterns against manually assigned competency themes, thereby enhancing categorisation reliability. An external peer review further evaluated the final digital competency classification to bolster objectivity and reliability (Bryman, 2016). Finally, the entire thematic analysis process was thoroughly documented to ensure reproducibility, allowing future researchers to replicate the methodology and validate the findings (Nowell et al., 2017). Collectively, these measures reinforce the validity of the digital competency categorisation, ensuring that the findings accurately reflect the competencies required to navigate digital transformation in the evolving construction environment.

4.4.3 Phase Three: Large Language Models (LLMs) - Comprehensive Competency Definition

The *third phase* of this study builds upon Phase One (SLR) and Phase Two (Thematic Analysis) by employing Large Language Models (LLMs) to generate a single, comprehensive definition for each digital competency identified in the SLR and categorised through Thematic Analysis. An LLM, GPT-4, was used to refine and merge multiple definitions from various academic sources (OpenAI, 2023), generating a single, consolidated definition for each competency. The goal of this phase is to ensure that each competency is well-defined and practically applicable to digital PM in the construction sector (Schröder, 2023). By synthesising multiple competency definitions from the literature, this phase refines and consolidates competency definitions, ensuring clarity, consistency, and alignment with industry-recognised competency frameworks as a benchmark such as the IPMA Competency Baseline (IPMA, 2015b), PMBOK guidelines, PMI Talent Triangle (PMI, 2021a), and the PMCD Framework (PMI, 2017b).

The LLM consists of the following three steps:

1. **LLM Approach to Competency Definition:**

The LLM-based definition process was structured into three interconnected steps, ensuring a seamless transition from competency identification to synthesis and validation:

- **Firstly,** Competency Identification (Phase One): The SLR identified multiple definitions for each digital competency across various academic sources. These definitions were extracted, documented, and stored for further processing (Tranfield et al., 2003).
- **Secondly**, Competency Categorisation (Phase Two): The definitions identified in the SLR were used as a database for the Thematic Analysis, which grouped multiple competency definitions related to the same concept into a consolidated category. NVivo software was employed to facilitate qualitative coding, thematic pattern recognition, and categorisation into three groups: Skills, Knowledge, and Core Personality (Braun & Clarke, 2006).
- **Thirdly,** Comprehensive Definition Generation (Phase Three): The grouped competency definitions from Thematic Analysis and NVivo coding were structured as input for the LLM, which synthesised a single, comprehensive definition for each competency based on the collective meaning derived from the literature. The LLM-generated definitions were then reviewed and refined to ensure accuracy, clarity, and industry alignment (Floridi & Chiriatti, 2020).

This structured integration of AI and human expertise ensures that digital competencies are comprehensively defined, contextually relevant, and practically applicable to research, education, and industry settings (Dwivedi et al., 2021).

2. **Methodological Process for LLM-Based Competency Definition**

To ensure accuracy, validity, and industry alignment, the LLM-based competency definition process followed a three-step methodology.

i. Input Data Preparation: The main objective of this step was to format the grouped competency definitions from the Thematic Analysis (NVivo-processed) into a structured input for LLM synthesis. In this phase, the Thematic Analysis (Phase Two) consolidated multiple competency definitions under a comprehensively defined category, whether Skills, Knowledge, or Core Personality. These grouped definitions were then formatted into structured input datasets for LLM processing. Additionally, the LLM was provided with multiple competency definitions along with contextual prompts (see Appendix A3) to guide its synthesis process (Bender et al., 2021). The outcome was a well-structured dataset that ensured the LLM synthesised each competency based on a collective understanding rather than isolated definitions.

ii. Definition Synthesis & Refinement: The objective here was to generate and refine a single, comprehensive definition for each competency through LLM-generated synthesis, ensuring consistency, clarity, and alignment with industry standards. At this stage, prompts were constructed using a standardised framework that included: (1) a descriptive title for each competency, (2) a list of extracted textual descriptors and keyword phrases, and (3) instructions for tone, length, and industry alignment. The LLM processed multiple competency definitions to produce a single definition for each competency. The research team then manually refined these definitions to guarantee that they were clear, accurate, and practically relevant. This refinement ensured that each definition was concise, well-structured, and easily interpretable by industry professionals. Accuracy was assessed through cross-referencing with existing literature, ensuring faithful representation of each competency, while practical relevance was emphasised by aligning definitions with real-world PM applications in digital construction. NVivo-assisted qualitative validation further confirmed that the LLM-generated definitions retained the thematic patterns established in Phase Two (Palermo et al., 2016).

iii. The outcome of this step was a well-articulated definition for each competency, reflecting a consensus across multiple sources and addressing the evolving demands of digital PM within the construction sector's digital transformation. For example, in the case of S2. Digital Technology Integration, the input dataset contained four distinct definitions from the literature, relevant keywords such as integration, digital systems, and project delivery, and explicit guidance to align the output with digital construction industry terminology, as further detailed in Section 4.5.3. This ensured that the LLM synthesised each competency based on a collective understanding rather than isolated definitions, while retaining fidelity to the original source material.

Building upon the above methodological steps, additional procedural controls were implemented to enhance transparency and ensure replicability of the LLM-based synthesis process. This study adopted a structured and controlled implementation of LLMs, rather than an open-ended generative approach. The process was operationalised through a sequential workflow consisting of four stages: (1) structured input preparation, (2) standardised prompt execution, (3) LLM-generated draft synthesis, and (4) multi-level validation. This approach ensured that the role of the LLM was limited to synthesising existing knowledge rather than generating new or unverified content.

In terms of input structuring, the data provided to the LLM were strictly derived from validated outputs of the preceding phases. Each competency input included: (i) the competency name, (ii) NVivo-derived keywords and descriptors from thematic coding, and (iii) multiple definitions extracted from peer-reviewed literature. These inputs were consistently structured across all competencies to ensure comparability and standardisation in the synthesis process. Importantly, no external or implicit knowledge sources were introduced into the LLM at this stage, ensuring full traceability to the original literature base.

A standardised prompt template (see Appendix A3) was consistently applied across all competencies to maintain methodological consistency. The prompt explicitly instructed the

LLM to synthesise, rather than generate new knowledge, by integrating the provided inputs into a single coherent definition. The prompt included strict constraints such as: “use only the provided inputs,” “do not introduce new concepts,” “remove redundancy,” and “ensure alignment with source material.” These instructions ensured that the LLM output remained grounded in the extracted literature and aligned with the intended academic and industry context.

To minimise the risk of hallucination and bias, multiple control mechanisms were implemented. First, input restriction ensured that the LLM operated exclusively on pre-validated literature-derived content. Second, explicit prompt constraints limited generative deviation by prohibiting the introduction of unsupported ideas. Third, all LLM-generated outputs underwent manual verification, where each definition was systematically cross-checked against the original source materials to confirm conceptual accuracy and fidelity. This process ensured that the LLM functioned as a synthesis tool rather than a knowledge generator.

Furthermore, an additional layer of expert validation was incorporated to reinforce the reliability and practical relevance of the generated definitions. Domain experts reviewed each competency definition to assess its clarity, technical accuracy, and alignment with industry expectations within the construction sector. This validation focused on ensuring that the definitions were understandable, contextually appropriate, and applicable to real-world project management practices, rather than verifying their direct linkage to specific literature sources.

Accordingly, the overall LLM-based synthesis process can be summarised as a sequential workflow consisting of source-derived inputs, LLM-assisted synthesis, manual verification, expert validation, and final competency definition. This structured approach strengthens methodological rigour, enhances transparency, and supports the reproducibility of the competency development process. A detailed example of the prompt template and input–output traceability is provided in Appendix A3.

3. Validation & Alignment with Industry Standards

The final step ensured that the refined competency definitions were fully aligned with recognised project management competency frameworks, maintaining industry relevance while addressing emerging demands in digital PM. At this stage, benchmarking served as a final quality check, confirming that the synthesised definitions were consistent with standards such as the IPMA Competency Baseline (IPMA, 2015b), PMBOK Guide, PMI Talent Triangle (PMI, 2021b), and the Project Manager Competency Development Framework (PMI, 2017b).

A multi-step expert validation process was then undertaken, involving two independent subject-matter experts with over a decade of individual experience in construction project management and digital transformation. Their review assessed each LLM-generated definition for technical accuracy, domain relevance, and alignment with established industry expectations, including the European Commission’s DigComp 2.2 framework (Vuorikari et al., 2022). While the panel size was intentionally small, their highly specialised expertise ensured a focused, high-quality evaluation, consistent with contemporary qualitative validation practices that consider small expert groups sufficient for domain-specific synthesis and refinement tasks (Pilcher & Cortazzi, 2024). Discrepancies in interpretation were addressed collaboratively until consensus was reached. In total, 89% of definitions were accepted with only minor edits, while 11% required substantive revision to enhance specificity or contextual relevance.

By integrating AI-driven synthesis with human expert validation, this process ensures the development of high-quality, standardised competency definitions for digital PM in the construction sector.

4.5 Results

This section presents the findings of the study, structured according to the three-phase methodological approach outlined in Section 4.4: Methods. The results reflect the systematic identification, categorisation, and definition process of digital competencies for construction PMs, ensuring alignment with both traditional competency models and emerging technological advancements.

To maintain consistency with the methodological process, the results are divided into three phases, reflecting the progression from competency identification to refinement. The first phase involved identifying digital competencies using a SLR, ensuring a comprehensive foundation based on existing research. In the second phase, competencies were categorised through Thematic Analysis, grouping them into Skills, Knowledge, and Core Personality Traits based on patterns and relationships within the data. Finally, in the third phase, competency definitions were refined using LLM synthesis and expert validation, ensuring conceptual clarity, coherence, and alignment with the evolving digital transformation landscape in construction project management.

These results directly address the research question outlined in Section 4.2: "*What are the emerging digital competencies required for project managers to excel in the evolving construction sector?"* by systematically identifying, structuring, and refining a validated set of competencies tailored to digital transformation in construction.

4.5.1 Findings from the SLR – Phase One

The first phase of this study employed a SLR to identify the digital competencies required for PMs in the evolving construction sector. This phase aimed to establish a comprehensive, evidence-based identification of competencies by systematically reviewing existing academic literature.

SLR is a structured, transparent, and replicable method for synthesising knowledge from multiple sources while ensuring methodological rigour (Grant & Booth, 2009). To enhance reliability and objectivity, this study adhered to the PRISMA 2020 guidelines (Page et al., 2021), which provide a standardised approach to identifying, screening, selecting, and reviewing relevant academic studies.

The findings from this phase serve as the foundation for the subsequent phases of the study, where competencies are categorised using Thematic Analysis (Phase Two) and refined using LLM-based synthesis (Phase Three). This structured approach ensures that digital competencies for PMs are systematically mapped, validated, and classified, thereby bridging the gap between traditional PM competencies and emerging technological requirements in the construction industry.

The following sub-sections present the study selection process, data extraction, and mapping of competencies across studies.

4.5.1.1 Study Selection Process

The study selection process was conducted in accordance with the PRISMA guidelines (Page et al., 2021) to ensure a transparent, rigorous, and replicable identification of digital competencies for construction PMs.

The process involved six structured steps:

1. **Identification:** Relevant studies were systematically retrieved using predefined search strategies in Scopus, ensuring a comprehensive collection of academic literature.
2. **Screening:** Retrieved articles underwent title and abstract screening to eliminate irrelevant, duplicate, or low-quality studies that did not explicitly address digital competencies for PMs.
3. **Eligibility:** The remaining studies underwent a full-text review to ensure alignment with the study's objectives and methodological standards.
4. **Inclusion:** Final studies were selected based on predefined eligibility criteria, Table 4.1, and formed the foundation for competency extraction categories, Table 4.2.
5. **Ensuring reliability and verification:** Rigorous checks were conducted to ensure accuracy, consistency, and reliability in the selected studies, reducing bias and enhancing credibility.
6. **PRISMA Flow Diagram:** To enhance clarity and transparency, the PRISMA Flow Diagram, Figure 4.2, visually represents the selection process, illustrating the number of studies retrieved, screened, excluded, and included in the final analysis.

This structured selection process ensures that only high-quality, thematically relevant research contributes to the identification of digital competencies for PMs in the evolving construction sector.

*4.5.1.2 **Data Extraction and Competency Identification***

Following study selection, data extraction was conducted in a structured and systematic manner to ensure that the findings are accurate, reliable, and reproducible. A data extraction framework was applied to synthesise information from each study, categorising it based on research aim, methods/techniques, technology focus, and key findings.

This process ensured that each digital competency identified in the literature was systematically documented and prepared for thematic categorisation in the next phase. The structured extraction strategy also enabled the identification of recurrent themes, emerging trends, and competency gaps in existing literature. Table 4.3 presents the structured extraction of key elements from the reviewed studies, providing an overview of how digital competencies were identified across multiple academic sources and mapping each study's technological focus to relevant digital innovations, such as BIM, AI, IoT, and digital twin technologies.

Moreover, the findings from the SLR will serve as a database for a structured Thematic Analysis (Phase 2), where competencies will be further categorised into Skills, Knowledge, and Core Personality using NVivo.

Table 4.3: Data Extraction Categories

Stud. Num.	Study Reference	Research Aim	Methods / Techniques	Technology Focus	Key Findings
1.	(Rodrigues et al., 2023)	Identify core competencies required for	Two-step approach using PRISMA for	Smart building technologies, including IoT,	Key competencies for smart building PMs: technical competencies,

		project managers in smart building projects.	systematic review and meta-analysis.	BIM, and Digital Twins.	leadership, communication, budgeting, attitudes toward risk, strategic management, organisation, and specifying real requirements.
2.	(Liu et al., 2022)	Develop a competence model for construction project managers in the digital era.	Data mining method analysing 2387 recruitment advertisements.	Digital capability in construction project management.	Identifies digital capability as a crucial emerging competence with three levels: technology, knowledge, and management.
3.	(Vuorikari et al., 2022)	Define a general digital competence framework for citizens (DigComp 2.2).	Policy analysis and literature review.	Digital skills, AI, cybersecurity, and digital safety.	Provides structured digital competencies applicable across various sectors, including construction project management.
4.	(Mesaros et al., 2020)	Investigate the impact of BIM technology on digital and managerial competencies of project managers.	Case studies and literature review.	BIM technology in project management.	BIM adoption enhances digital and managerial competencies, necessitating training for project managers.
5.	(Lukianov et al., 2021)	Examine digital competence transformation in project management.	Comparative analysis of PMI and IPMA competency models.	Digital transformation in project management.	Proposes integrating digital competency assessment into project management standards.
6.	(Hosseini et al., 2018)	Assess the viability of BIM manager as a distinct role.	Text mining of 199 job advertisements.	BIM role evolution in construction.	BIM expertise will be absorbed into general project management roles over time.
7.	(Mandičák et al., 2020)	Explore the development of digital and managerial competencies in construction project management.	Theoretical review and expert analysis.	Digitalisation and managerial competencies.	Emphasises the growing need for digital skills alongside managerial competencies.
8.	(Kissi et al., 2025)	Identify essential competencies for project managers in the digital era.	Fuzzy synthetic evaluation (FSE) with survey data.	Digitalisation in construction project management.	Technical knowledge, leadership, and interpersonal skills are critical for digital project managers.
9.	(Inguva et al., 2014)	Analyse skill differences in construction professionals using BIM/VDC.	Survey of 122 professionals across the US.	BIM and Virtual Design Construction (VDC).	Professionals using BIM/VDC report enhanced problem-solving and digital skills.
10.	(Waqar et al., 2023)	Model the relationship between BIM	Structural Equation	BIM adoption in project success.	BIM integration significantly impacts project success, requiring

		and construction project success.	Modelling (SEM).		digital proficiency among managers.
11.	(Raza et al., 2023)	Identify potential features of BIM for project management knowledge areas.	Systematic literature review and factor analysis.	BIM adoption in construction project management.	BIM enhances project managers' capabilities in project integration, cost, time, quality, and risk management.
12.	(Atuahene et al., 2023)	Examine the transformative role of big data in construction through capability recognition.	Interviews with construction professionals and literature review.	Big data applications in construction management.	Big data requires project managers to develop analytical, strategic, and digital transformation competencies.
13.	(Omer et al., 2022)	Analyse constructive and destructive leadership behaviours in BIM-based projects.	Explorative qualitative study with interviews and thematic analysis.	BIM-based leadership and management.	Effective leadership skills and adaptability are crucial for managing BIM-integrated projects.
14.	(Uhm et al., 2017)	Analyse BIM jobs and competencies using industry terminology.	Social Network Analysis (SNA) and job postings review.	BIM job roles and competency frameworks.	Identifies essential BIM competencies and their application in various project management roles.
15.	(Lee et al., 2021)	Assess BIM competencies and their correlation with career characteristics.	Survey and correlation analysis of construction professionals.	BIM competency assessment for project participants.	Project managers must develop strong BIM capabilities to optimise digital workflows in construction.

This structured approach ensures clarity, consistency, and methodological rigour, providing a strong foundation for competency classification and thematic analysis in the next phase.

4.5.1.3 Digital Competencies Identified in the Literature

After extracting key information from the selected studies, the next step involved systematically mapping the identified digital competencies across the literature. The objective was to understand the frequency, distribution, and thematic emphasis placed on each competency within academic research.

To achieve this, each study was reviewed in full to identify which competencies were explicitly addressed. Competency mentions were coded based on full-text analysis, rather than relying solely on abstracts, to enhance validity and minimise interpretive bias. Each competency was then linked to its corresponding source, producing a traceable and transparent dataset that laid the foundation for thematic categorisation in Phase Two.

The following Table 4.4 illustrates the mapping of final studies to identified competencies, providing a detailed visual representation of how each study contributes to the identification of digital competencies for PMs in the construction sector. This mapping ensures that competency identification remains systematic, evidence-based, and aligned with the evolving digital competency requirements of PMs. By visually linking competencies to their corresponding studies, the table enhances transparency, traceability, and methodological rigour, thereby reinforcing the credibility and comprehensiveness of the competency dataset.

Table 4.4: Mapping of Final Studies to Identified Competencies

Studies / *Competencies*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Advanced Digital Technology Proficiency	✓	✓		✓		✓	✓		✓				✓	✓	✓
2. Digital Technology Integration	✓	✓							✓			✓			
3. Digital Building Performance Optimisation										✓					✓
4. Advanced Digital Construction Knowledge	✓	✓					✓	✓				✓		✓	
5. Emerging Technology Integration Knowledge		✓							✓			✓			
6. Smart Systems and Applications Knowledge								✓		✓				✓	✓
7. Team Leadership in Digital Construction	✓	✓		✓		✓	✓	✓	✓				✓	✓	
8. Stakeholder Leadership in Digital Construction	✓	✓									✓				
9. Digital Self-Leadership and Emotional Agility				✓				✓	✓				✓	✓	
10. Decision-Making and Accountability				✓			✓	✓					✓		
11. Team Well-Being Leadership													✓		
12. Digital Project Strategy and Goal Alignment	✓	✓		✓			✓					✓			
13. Digital Project Integrated Management									✓		✓				
14. Digital Safety and Risk Mitigation		✓								✓	✓				
15. Digital Quality Assurance and Lifecycle Management		✓								✓					
16. Contract and Negotiation Management		✓						✓	✓						
17. Regulatory and Compliance		✓								✓				✓	✓
18. Digital Team Communication and Collaboration	✓	✓		✓			✓					✓	✓	✓	
19. Digital Stakeholder Communication and Collaboration	✓							✓			✓			✓	
20. Language Proficiency		✓												✓	
21. Digital Communication and Interaction Strategies	✓		✓		✓			✓							
22. Real-Time Digital Information Exchange			✓		✓	✓	✓	✓		✓					✓
23. Digital Collaboration and Knowledge Retention			✓		✓	✓		✓		✓		✓			
24. Digital Information and Data Literacy			✓		✓										
25. Digital Data Evaluation and Analytics			✓		✓		✓					✓			✓
26. Cloud-Based Digital Content Management			✓		✓							✓			✓

27. Digital Content Development Skills			✓		✓										
28. Advanced Digital Content Management			✓		✓										
29. AI-Assisted Programming and Automation			✓					✓							
30. Smart Construction Digital Tool Utilisation					✓	✓	✓	✓						✓	✓
31. Digital Technologies Training and Development						✓				✓		✓		✓	
32. Smart Digital Documentation and Archiving														✓	
33. Digital Problem Solving and Technical Support			✓	✓			✓	✓					✓	✓	
34. Digital Skills Gap Analysis and Development			✓		✓										
35. Cybersecurity and Digital Device Protection			✓		✓							✓			
36. Digital Privacy and Data Protection Compliance			✓		✓										✓
37. Digital Construction Risk Management	✓										✓				
38. Digital Technology Adoption Risk Mitigation	✓									✓		✓			
39. Financial Risk Management	✓														
40. Emerging Technologies Cost Management	✓											✓			
41. Real-Time Cost Optimisation and Digital Budgeting		✓		✓							✓				✓
42. Automated Digital Procurement Management				✓							✓				✓
43. Digital Scheduling Management	✓			✓						✓	✓		✓	✓	✓
44. Digital Resource Management	✓	✓		✓			✓			✓	✓		✓	✓	✓
45. Digital Quality Control	✓										✓			✓	
46. Digital Scope and Change Management								✓			✓				
47. Innovation Management in Digital Construction	✓											✓			
48. Digital Innovation and Creativity in Smart Construction	✓				✓			✓						✓	
49. AI-Powered Data-Driven Decision-Making					✓				✓			✓			
50. Standardising Digital Technology Processes						✓				✓					
51. Energy Efficiency and Carbon Management	✓									✓					
52. Sustainability Reporting and Monitoring	✓		✓												
53. Sustainable Construction Strategies	✓								✓						
54. Qualifications and Professional Development		✓				✓								✓	✓
55. Curriculum Development												✓		✓	

This mapping process identified a total of 55 distinct digital competencies across the final study set, forming the structured input for thematic classification. This enabled a systematic comparison across studies and revealed distinct patterns in emphasis. Technical competencies, particularly those associated with digital technologies, data analytics, and digital collaboration, emerged as recurring priorities. Leadership-related competencies also featured prominently, especially those concerning digital team coordination and stakeholder engagement. By contrast, competencies related to cybersecurity, AI integration, and digital ethics appeared less frequently. These were identified as emerging, yet underexplored, domains that may require increased attention in future competency development efforts.

The SLR phase successfully identified a broad range of digital competencies relevant to construction PMs by systematically analysing peer-reviewed academic sources. Through PRISMA-guided selection and data extraction, competencies were mapped, documented, and categorised based on their frequency and relevance in existing literature.

However, while this phase provided a foundational dataset, it did not structure or categorise the competencies into a meaningful framework. To bridge this gap, the next phase applies NVivo-supported Thematic Analysis to systematically classify the identified competencies into three structured categories: Skills, Knowledge, and Core Personality. The dataset generated through the SLR serves as the direct input for this classification process, ensuring continuity, analytical rigour, and alignment with established PM competency models. The next section details how NVivo software was used to support the thematic classification of these competencies, ensuring a structured and data-driven categorisation process.

4.5.2 Findings from Thematic Analysis (NVivo Categorisation) – Phase two

Following the SLR in Phase One, which identified digital competencies from academic literature, Phase Two applies Thematic Analysis to systematically categorise and structure these competencies into a meaningful framework. Thematic Analysis is a widely used qualitative research method for systematically identifying, analysing, and reporting patterns (themes) within datasets (Braun & Clarke, 2012). By employing this approach, the study ensures that digital competencies are organised into a structured classification aligned with traditional PM competency frameworks.

To enhance rigour and ensure accuracy, NVivo software was used for qualitative coding, relationship mapping, and theme validation, making the competency classification more structured, transparent, and replicable. NVivo’s visual tools, automated coding, and hierarchical structuring facilitated the efficient classification of digital competencies into three primary categories:

1. Skills: Action-based competencies that enable the practical application of digital tools and technologies.
2. Knowledge: Theoretical and domain-specific understanding necessary for managing digital transformation.
3. Core Personality: Behavioural attributes essential for leadership, adaptability, and decision-making in a digitally transformation construction environment.

By structuring the competencies into these three categories, this phase lays the foundation for Phase Three, where an LLM will synthesise a single, comprehensive definition for each competency based on multiple definitions found in the literature.

To ensure transparency and replicability, the following three sub-sections elaborate on the thematic analysis approach, competency classification, and validation measures used to enhance reliability.

4.5.2.1 Thematic Analysis Approach

To ensure a systematic classification of digital competencies, this study follows the six-phase Thematic Analysis framework by Braun and Clarke (2006), enhanced with NVivo software for qualitative data analysis. This approach facilitates structured data organisation, pattern identification, and thematic categorisation, ensuring that digital competencies are systematically grouped and analysed.

1. Familiarisation with Data: The digital competencies extracted during Phase One (SLR) were uploaded into NVivo for an initial thematic review. This step involved an in-depth reading of competency descriptions to develop a preliminary understanding of their relevance and thematic relationships. NVivo's text recognition and word frequency analysis, Figure 4.3, helped identify recurring competency terms in the dataset, providing insights into their relative importance and prevalence. For example, the most prominent terms, such as "digital," "construction," "data," "project," and "management", highlighted the central focus areas of the extracted competencies, while less frequent but significant terms (e.g., "automation," "cybersecurity," and "collaboration") hinted at emerging yet underexplored themes. This early visualisation supported a targeted thematic exploration in the next phases.

Figure 4.3: NVivo Word Cloud – Frequency of Key Competency Terms

2. Generating Initial Codes: After familiarisation, preliminary labels (codes) were assigned to the extracted competencies based on their meaning, function, and relevance to construction project management. NVivo's automated coding feature assisted in identifying patterns within the dataset, ensuring that frequently occurring competency themes were recognised and structured efficiently. The software enabled auto-classification, Figure 4.4, of keywords related to emerging digital competencies, facilitating the identification of broad thematic patterns before further manual refinement. For example, clusters of terms such as "data,"

"management," and "system" were grouped together under broader digital management themes.

3. Searching for Themes: After initial coding, similar competencies were grouped into overarching themes. Competencies were classified according to their practical application, theoretical foundation, and behavioural attributes. NVivo's thematic mapping tools, Figure 4.5, were used to identify patterns and relationships among competencies, ensuring that the grouping accurately reflected their functional relevance in digital construction project management. For instance, competencies such as "Cost and Budget Management," "Risk Management," and "Scope and Change Management" are visually connected in NVivo's thematic map, illustrating their shared relationship under a broader project oversight cluster.

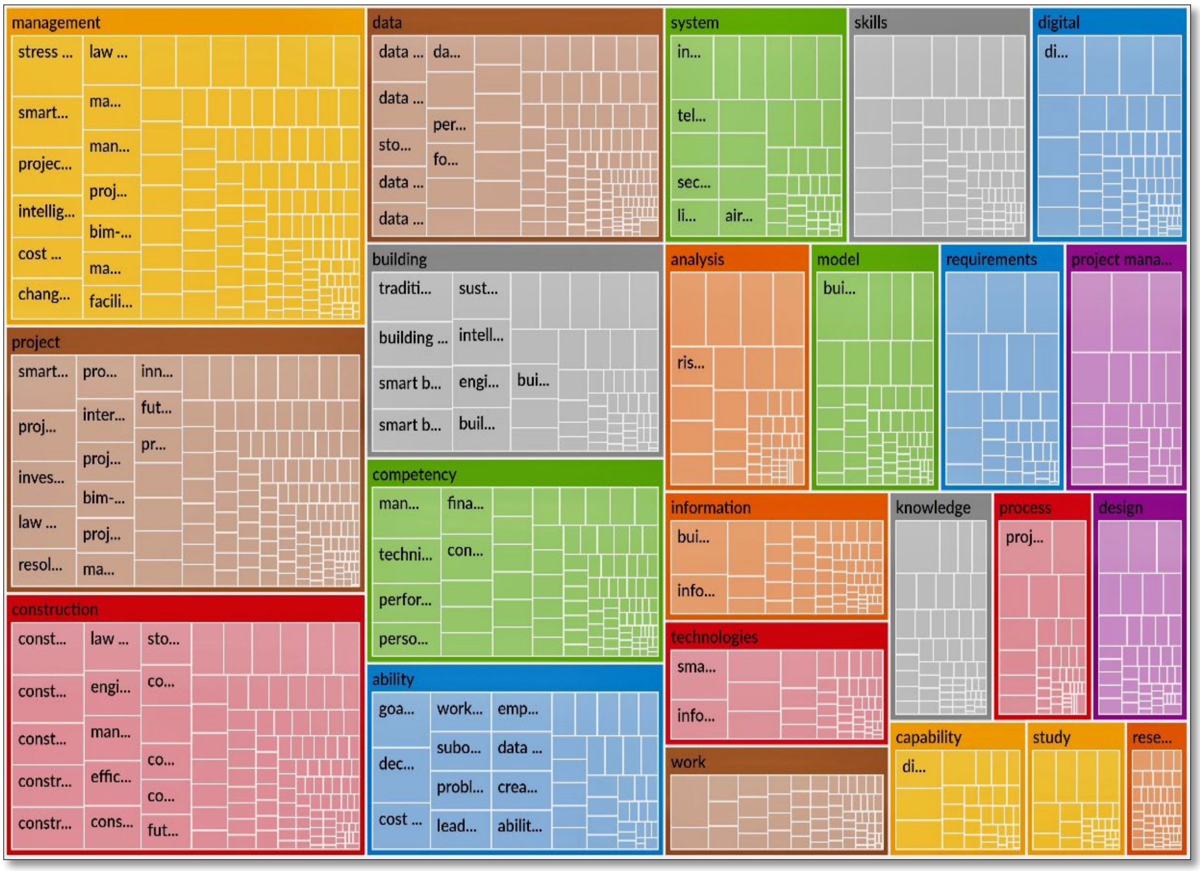


Figure 4.4: NVivo Auto-Coding of Competencies

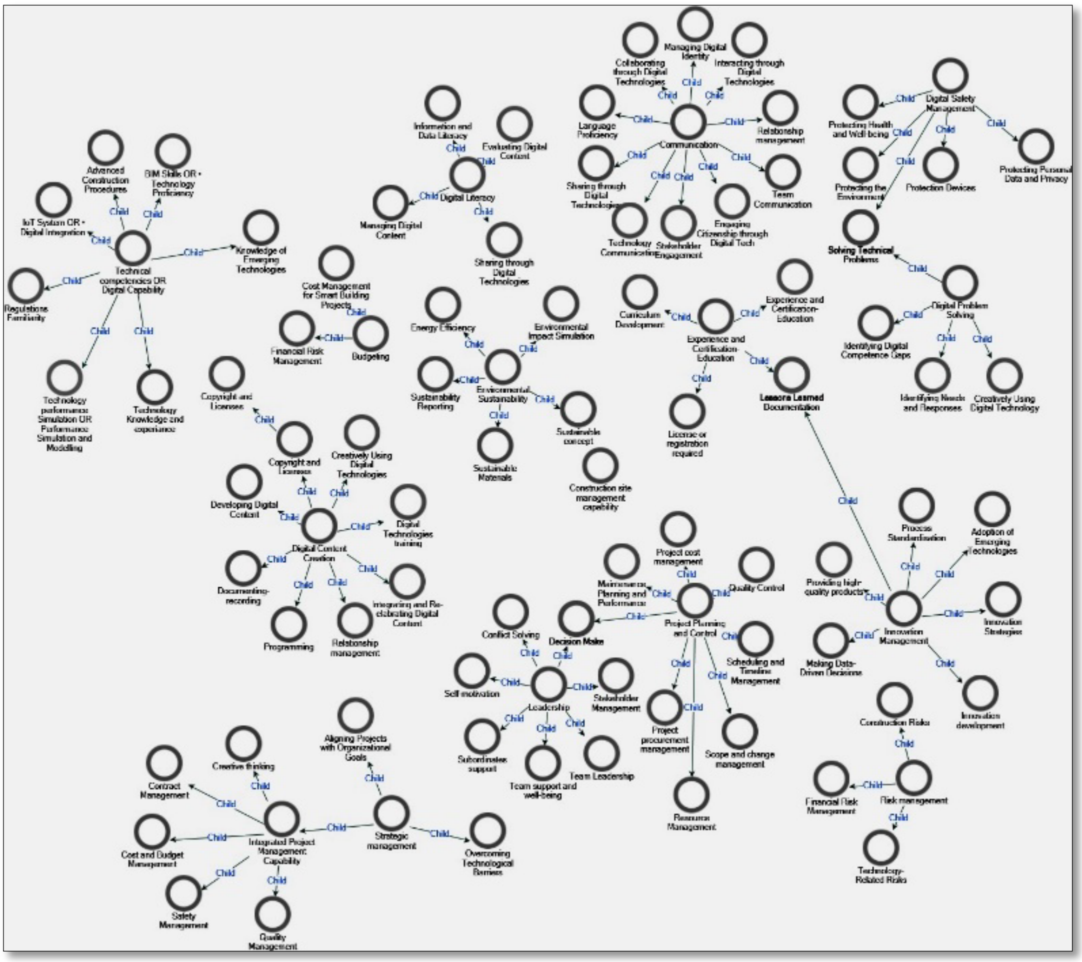


Figure 4.5: NVivo Thematic Mapping – Relationship Between Competencies and Themes

4. Reviewing Themes: To validate the accuracy and coherence of the identified themes, the dataset was reassessed to ensure logical consistency and distinct categorisation. NVivo-generated thematic maps and hierarchical node structures, Figure 4.6 and Figure 4.7, supported this process by visually representing how competencies were grouped into broader categories. Any overlaps between competency categories were reviewed and adjusted, ensuring that each competency was distinctly classified under its most appropriate theme. For example, competencies such as "Digital Scope and Change Management," "Digital Scheduling and Quality Management," and "Digital Resource Management" were reviewed together under the broader Project Planning and Control theme, ensuring their grouping accurately reflected the coordinated oversight functions required in digital project delivery.

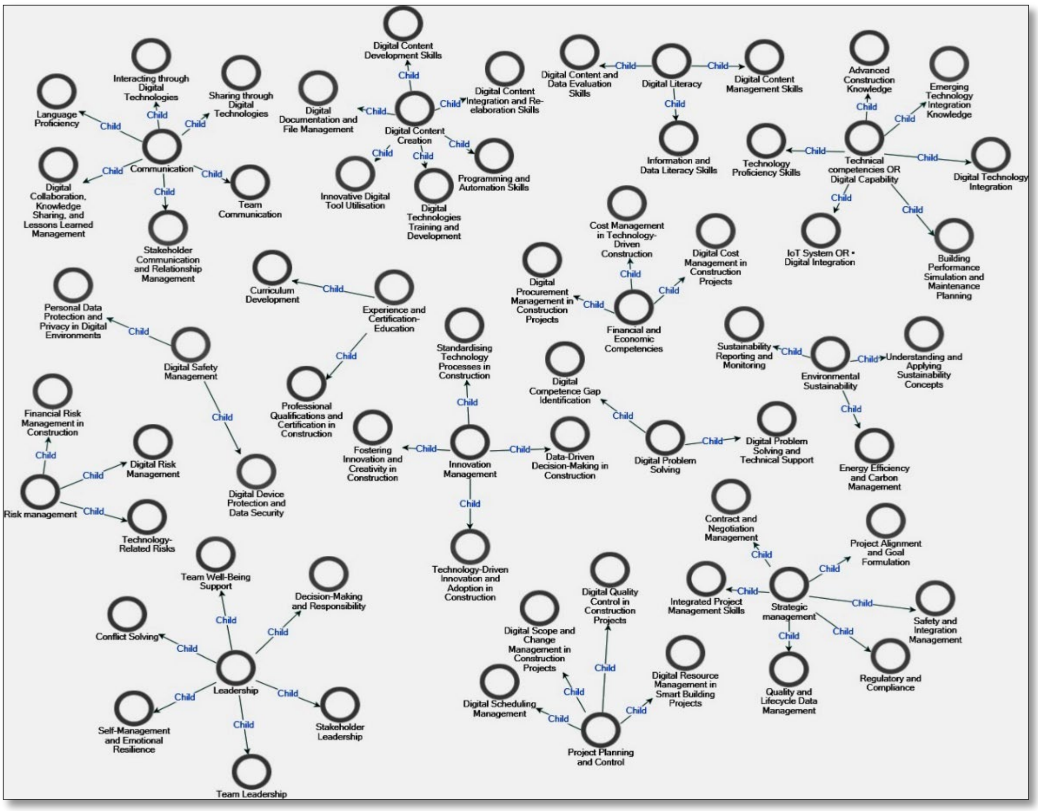


Figure 4.6: NVivo Thematic Mapping – Competency Visual Representation

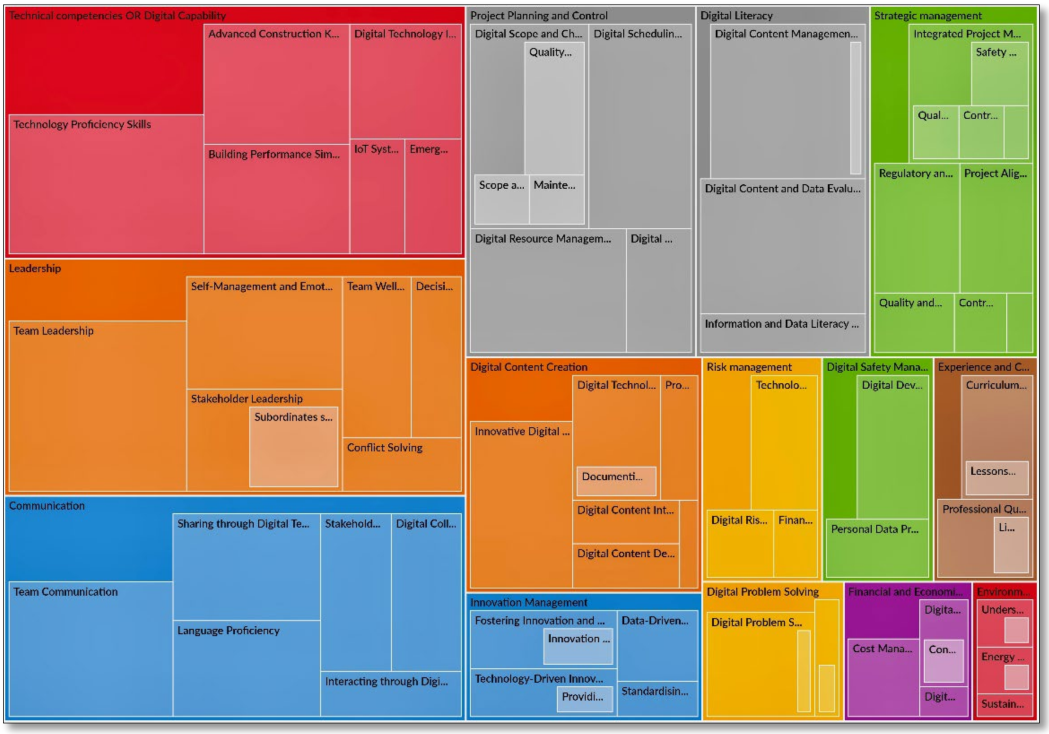


Figure 4.7: NVivo Hierarchical Node Structures - Competency Classification Structure

5. Defining and Naming Themes: Once the themes were finalised, clear competency labels were assigned to each category. NVivo's clustered by coding similarity function, Figure 4.8, helped refine theme distinctiveness, ensuring that no

competency overlapped between categories. This process was benchmarked against traditional PM competency frameworks, ensuring compatibility with established industry standards. For example, "Risk management" is closely clustered with "Financial Risk Management" and "Technology-Related Risks," indicating coding similarity within a risk-oriented theme.

6. Producing the Final Thematic Map: The final stage involved structuring digital competencies into the three core categories: Skills, Knowledge, and Core Personality, as illustrated in Figure 4.9. This cleaned and finalised structure of the competency classification, output by NVivo, reflects a rigorous thematic approach that ensured logical grouping, reduced subjectivity, and improved alignment across categories. NVivo-generated word frequency analysis and relationship mapping, Figure 4.10, further validated the coherence of the thematic classifications.

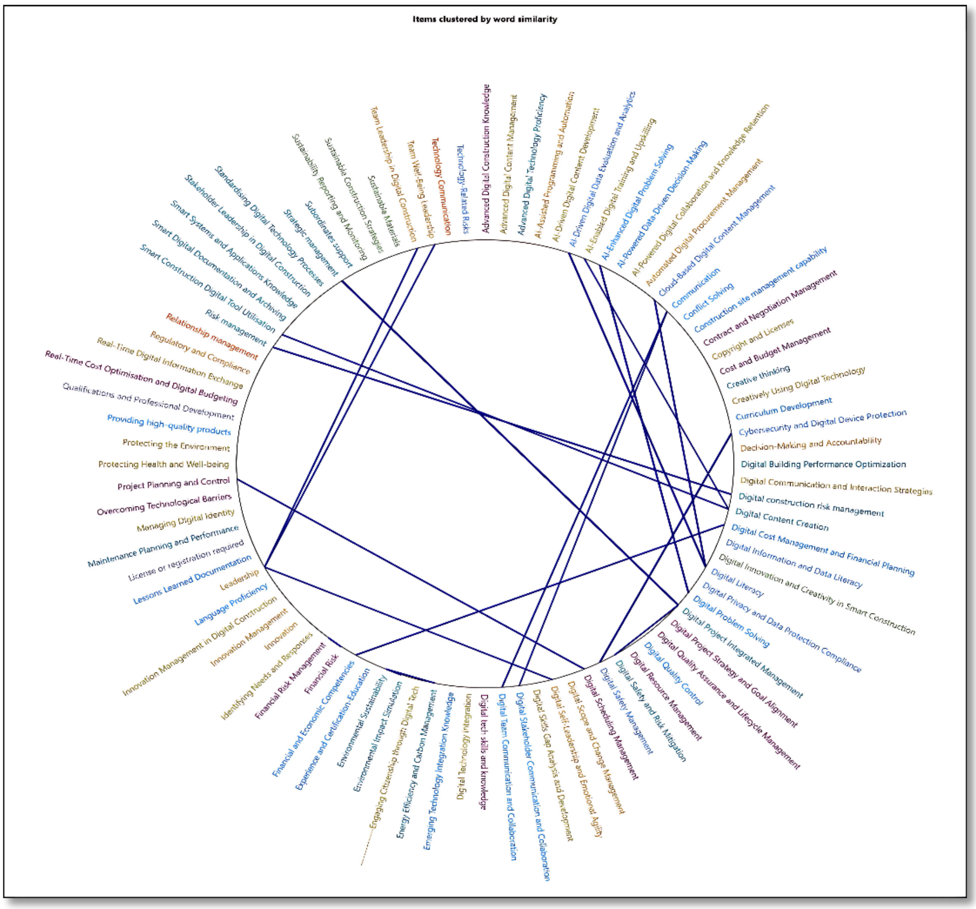


Figure 4.8: NVivo's Cluster Analysis by Coding Similarity

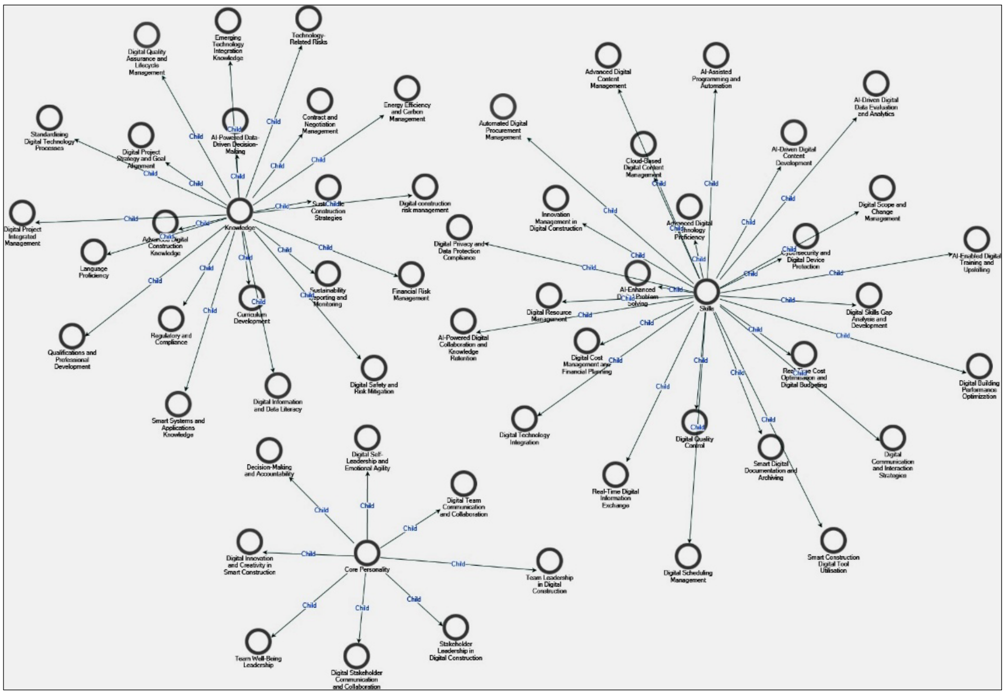


Figure 4.9: NVivo Final Thematic Mapping – Structured Digital Competency Categorisation

Figure 4.10: NVivo-generated word frequency analysis

4.5.2.2 Thematic Classification of Digital Competencies

Following the systematic identification of digital competencies in SLR Phase One, this phase categorises them into three primary competency groups based on their practical application, theoretical foundation, and behavioural attributes. By applying NVivo-assisted Thematic Analysis, the competencies were refined and structured to align with traditional PM competency frameworks, as illustrated in the previous steps.

In the Skills category, practical, action-oriented capabilities were identified that enable PMs to effectively implement digital tools and technologies in the construction sector, improving project efficiency, enhancing automation, and increasing accuracy. These include the Advanced Digital Technology Proficiency, which involve expertise in BIM systems, project management software, and digital design tools such as AutoCAD and Navisworks (Mesaros et al., 2020). Digital Technology Integration focuses on the ability to operate IoT systems, manage digital data, and coordinate digital teams for innovation-driven project execution (Waqar et al., 2023). Digital Building Performance Optimisation emphasises the use of BIM and other digital tools for optimising the lifecycle performance of building systems, ensuring resource efficiency and sustainability (Rodrigues et al., 2023). Digital Scheduling Management further highlights PMs' ability to control and optimise project timelines through 4D BIM-based scheduling (Liu et al., 2022).

NVivo was employed to track competencies linked to technological proficiency and automation, Figure 4.11, and the coding frequency analysis revealed that digital, skills, technology, and analysis terms/topics emerged among the most frequently mentioned skill areas in the literature.

Word	Length	Count	Weighted Percentage (%)
digital	7	1997	1.36
project	7	1659	1.13
construction	12	1592	1.09
management	10	1020	0.70
skills	6	816	0.56
information	11	790	0.54
level	5	734	0.50
knowledge	9	667	0.46
competencies	12	662	0.45
based	5	521	0.36
projects	8	513	0.35
competence	10	493	0.34
building	8	492	0.34
technologies	12	460	0.31
research	8	442	0.30
content	7	427	0.29
using	5	378	0.26
analysis	8	365	0.25

Figure 4.11: NVivo Coding Frequency Analysis for Digital Skills

The Knowledge category focuses on providing the intellectual foundation necessary to navigate the complexities of digital transformation in project management. Key knowledge-based competencies include Advanced Digital Construction Knowledge, which entails expertise in integrating technical data into project deliverables, understanding complex construction systems such as HVAC, plumbing, and electrical systems, and utilising digital workflows (Mandičák et al., 2020). Emerging Technology Integration Knowledge covers the understanding of AI, Virtual Reality (VR), drones, and IoT for enhancing construction processes (Atuahene et al., 2023). Quality and Lifecycle Data Management ensures PMs can track, analyse, and maintain quality standards using digital tools like BIM to improve long-term sustainability and efficiency (Raza et al., 2023). Additionally, Regulatory and Compliance Knowledge emphasises PMs' ability to navigate industry laws, regulations, and international standards such as New Engineering Contract (NEC), British Standard (BS) 1192, and Publicly Available Specification (PAS) 1192 (Hosseini et al., 2018). NVivo facilitated cluster analysis, Figure 4.12, ensuring that competencies related to digital knowledge were accurately categorised.

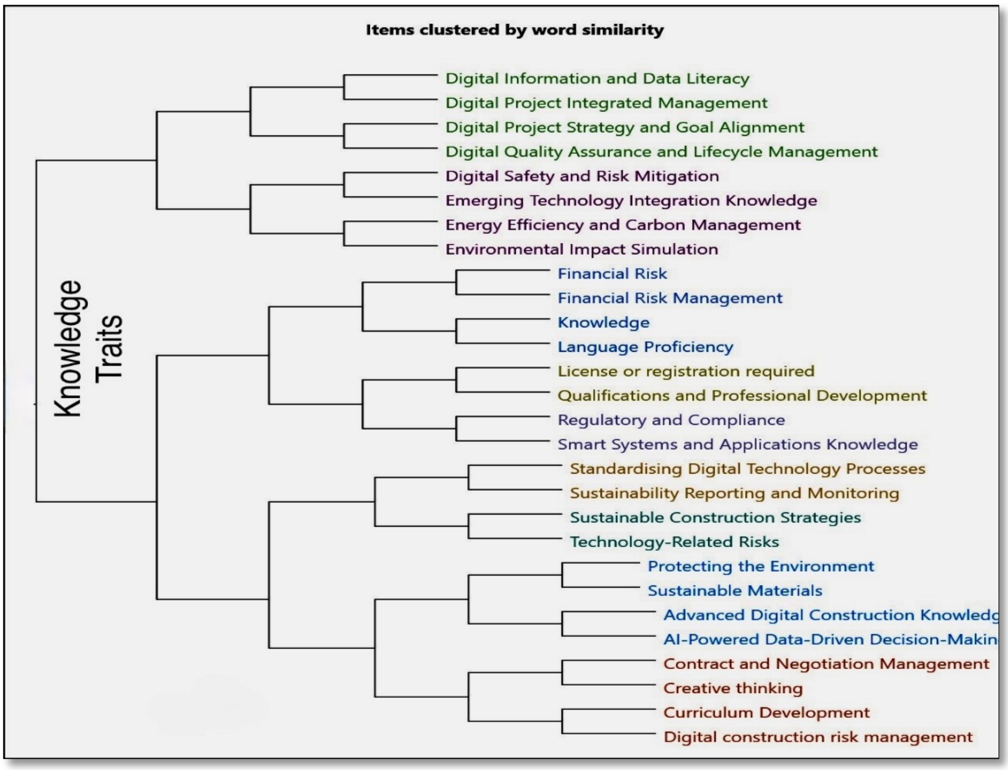


Figure 4.12: NVivo Cluster Analysis - Digital Knowledge Competencies

The Core Personality category refers to non-technical attributes essential for managing technology-driven projects. These competencies include Team Leadership in Digital Construction, which highlights a PM's role in inspiring multidisciplinary teams and fostering collaboration in a digital work environment (Mesaros et al., 2020). Stakeholder Leadership focuses on managing relationships with clients, government agencies, and project teams to ensure alignment with strategic goals (Kissi et al., 2025). Self-Management and Emotional Agility is critical for PMs navigating high-pressure digital environments, requiring adaptability, stress management, and emotional intelligence to maintain team morale and productivity (Omer et al., 2022). Digital Change Management and Innovation Leadership emphasise the ability to lead digital transformation initiatives, integrating emerging technologies while fostering a culture of continuous learning and adaptability (Rodrigues et al., 2023). NVivo's sentiment analysis and qualitative coding tools, Figure 4.13, identified patterns in leadership-related competencies, highlighting recurring themes of adaptability, strategic vision, and digital leadership.

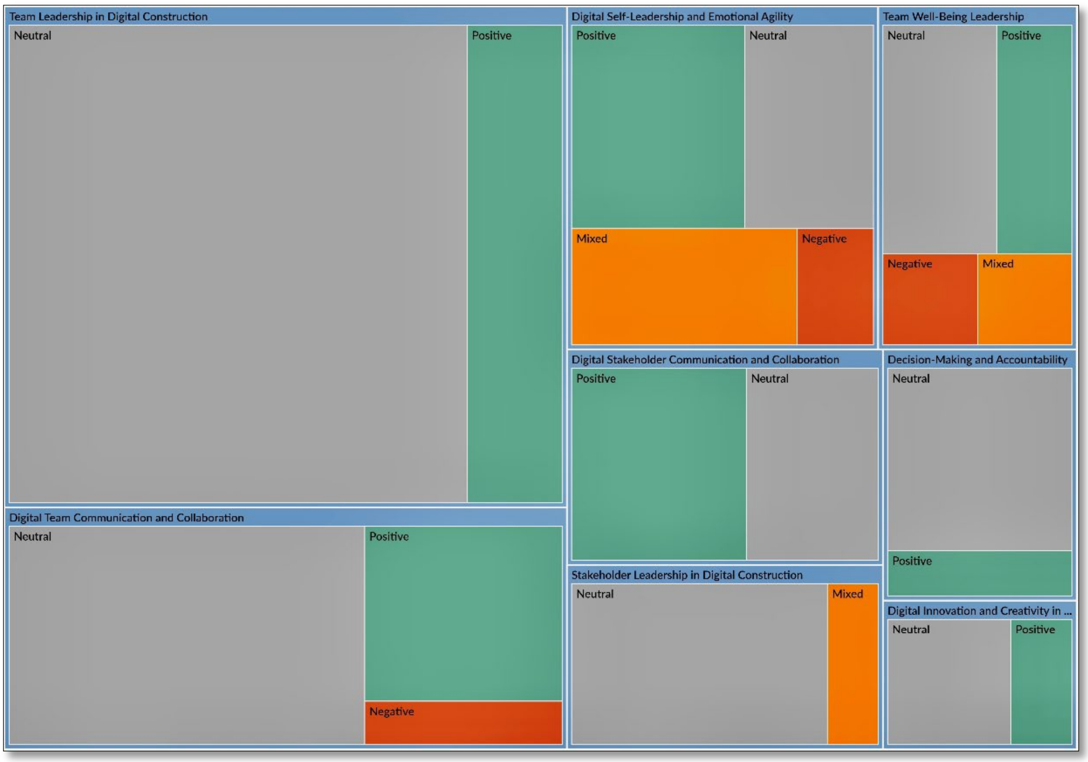


Figure 4.13: NVivo Sentiment Analysis - Leadership & Digital Competencies

This structured categorisation supports a clearer understanding of how PMs must adapt their competencies in the digital construction era. The final thematic map summarising all competencies is shown in Figure 4.14, which visualises the hierarchical structure of the classified competencies across the three overarching domains: Core Personality, Knowledge, and Skills. Each parent node represents a thematic domain, branching into child nodes that reflect specific, classified competencies. This NVivo-generated hierarchy confirms the integrity of the three-domain structure developed during thematic analysis and illustrates how each competency is distinctly yet thematically situated. It also highlights the wide-ranging scope of the Skills domain, spanning from AI-assisted programming to real-time digital budgeting, while clarifying how Knowledge competencies are grounded in regulatory, environmental, and technological understanding. The Core Personality domain shows clear leadership and emotional intelligence dimensions, reinforcing their non-technical yet strategic importance. This domain-level classification was benchmarked against the PMI Talent Triangle, IPMA ICB 4.0, and DigComp 2.2 to confirm alignment with recognised project management standards prior to the LLM-based definition stage.

By mapping competencies visually, Figure 4.14 enhances both the thematic coherence and practical utility of the competency classification, aligning the final competency model with established digital project management needs.

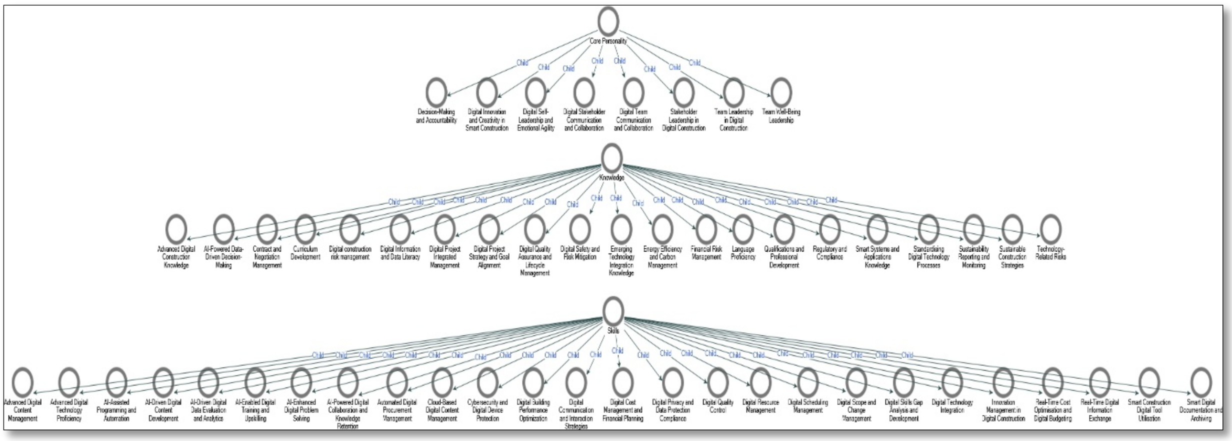


Figure 4.14: NVivo Final Thematic Map of Digital Competencies

4.5.2.3 Ensuring Reliability and Validity in Thematic Analysis

To enhance the credibility and methodological rigour of the thematic analysis, several verification measures were implemented. Ensuring that the classification of digital competencies remains accurate, reliable, and replicable is crucial to producing meaningful and actionable insights for the construction project management sector. This study employed four key validation techniques to strengthen the robustness of the findings.

Firstly, Inter-Coder Agreement: To reduce bias and improve consistency in the classification of digital competencies, multiple researchers independently reviewed the NVivo-coded thematic classifications. Each researcher examined the competency groupings and theme assignments, ensuring alignment with the Skills, Knowledge, and Core Personality categories. The coded data, and iterative consensus-building resulted in an 85% agreement rate, confirming coding reliability and minimising subjectivity (O'Connor & Joffe, 2020).

Secondly, Peer Review for Thematic Classification: To enhance objectivity and minimise potential subjectivity in competency grouping, an external researcher with expertise in digital PM competencies reviewed the final thematic classification. This step ensured that the categorisation followed logical coherence, industry relevance, and theoretical alignment with established competency models (Bryman, 2016). Any inconsistencies were critically evaluated, and necessary refinements were made to strengthen the classification structure.

Thirdly, Cross-Validation Against Industry Standards: To ensure alignment with established competency frameworks, the classification of digital competencies was cross-validated against the Project Manager Competency Development framework (PMI, 2017b), the Competency Baseline - IPMA (2015b), and the PMBOK guidelines - PMI (2021b). This process ensured that emerging digital competencies were mapped alongside traditional competencies, maintaining coherence between conventional PM skills and evolving digital capabilities. Any deviations or emerging trends were documented and integrated into subsequent analysis, ensuring that the framework remains relevant to the ongoing digital transformation in construction project management.

Finally, Reproducibility and Transparency Check: To enhance transparency and ensure methodological replicability, the entire thematic analysis process was meticulously documented, detailing the criteria used for competency classification and thematic grouping. This structured documentation provides a clear framework for future researchers to replicate the methodology and validate findings in different contexts (Nowell et al., 2017). Additionally, a consistency check was conducted by applying the thematic classification framework to a random subset of studies, verifying that digital competencies were consistently categorised.

By applying these verification techniques, the study ensures that the categorisation of digital competencies is rigorous, systematic, and aligned with best practices in qualitative research. The classified thematic structure now serves as the foundation for Phase Three, where LLM will be employed to refine and consolidate competency definitions. These validation measures confirm the robustness and reliability of the thematic classification, reinforcing its relevance in guiding the development of digital PMs' competencies in the construction sector.

In the next phase, each competency will be examined in greater detail, presenting the various definitions identified in Phases One and Two. The study will then synthesise these perspectives into a comprehensive competency definition, forming the cornerstone of the Digital PM Competency List. This final list will be further developed into a framework to ensure that construction PMs are equipped to navigate the evolving digital landscape, leveraging emerging technologies to enhance performance, efficiency, and strategic decision-making in the construction sector, as detailed in the next chapter.

4.5.3 Findings from LLM-Base process – Phase Three

Phase Three employed LLMs to synthesise and refine the digital competency definitions identified and categorised in the earlier phases. GPT-4 was used to consolidate multiple literature-based definitions into single, comprehensive descriptors for each competency. LLMs, as advanced AI systems capable of generating contextually rich, human-like text, have been shown to enhance qualitative synthesis in research (Bender et al., 2021; Floridi & Chiriatti, 2020). In this study, GPT-4's ability to analyse, compare, and integrate multiple perspectives was leveraged to merge diverse definitions into standardised, practically applicable competency statements.

Importantly, these definitions were not generated from scratch. All input material originated from the final studies retained in the SLR and is mapped in Table 4.4: Mapping of Final Studies to Identified Competencies. This ensured that each refined definition remained grounded in published evidence and was traceable to original sources. The synthesis process followed a standardised prompting framework comprising: (1) the competency title, (2) extracted textual descriptors and keyword phrases, and (3) instructions for tone, length, and alignment with industry terminology. This ensured that the role of GPT-4 was restricted to linguistic synthesis, with outputs grounded in empirical evidence and aligned with industry terminology, thereby ensuring transparency and replicability in the application of AI within this study. All GPT-4 outputs underwent manual verification to ensure technical accuracy, prevent misinterpretation, and maintain fidelity to the source material.

This AI-enhanced process bridged the gap between the raw competency extraction of Phase One and the structured thematic classification of Phase Two, reducing the subjective bias inherent in purely manual synthesis. It introduced a clear, auditable workflow that can be replicated in future studies, thereby improving methodological transparency and enabling independent verification.

The impact of this approach is illustrated through the example of S2: Digital Technology Integration. Four key sources informed its definition: Rodrigues et al. (2023) emphasised IoT system operation and real-time data integration; Liu et al. (2022) focused on leadership in managing integrated digital systems and fostering innovation; Atuahene et al. (2023) highlighted collaboration with technology providers for big-data capture and management; and Inguva et al. (2014) reinforced the importance of BIM model viewing, analysis, and integration to support seamless digital project delivery. GPT-4's role was confined to harmonising terminology and phrasing into a coherent, industry-aligned descriptor, without introducing new conceptual elements.

Finally, all competency definitions underwent structured expert validation, as detailed in Section 4.4.3. Two independent domain experts, both experienced in construction project management and digital transformation, reviewed each definition for technical accuracy, domain relevance, and alignment with established frameworks such as the PMBOK Guide (PMI, 2021b) and IPMA ICB (IPMA, 2015b). This process confirmed that 89% of definitions required only minor adjustments, while 11% were refined to improve specificity or relevance. By combining transparent AI-driven synthesis with expert review, this phase delivered a competency framework that is robust, industry-aligned, and reproducible, providing a sound basis for application in research, training, and professional development.

4.6 Discussion

Beyond synthesising comprehensive competency definitions, this study systematically aligns the final set of definitions with the established PM competency categories: Skills, Knowledge, and Core Personality. As outlined in Section 4.5.2.1 (Step 6: Producing the Final Thematic Map, Figure 4.9), digital competencies were grouped into these three foundational dimensions during thematic analysis, reinforcing their practical, theoretical, and behavioural relevance to digital PM.

By structuring digital competencies into Skills, Knowledge, and Core Personality, this study ensures that each competency is properly contextualised based on its functional application, theoretical foundation, or leadership attributes. This structured categorisation enhances the robustness and applicability of the competency framework, making it more practical for implementation in the evolving digital construction sector.

Ultimately, the comprehensive competency framework underscores the critical role of digital PMs in driving project performance, fostering innovation, and enabling strategic success in the rapidly evolving construction sector. The following section presents the final comprehensive definitions for each competency, as detailed in Figure 4.15: Next-Gen Digital PM Competency List for Construction, as a response to the digital transformation in the evolving construction era.

Skills

- **S1. Advanced Digital Technology Proficiency:** A key digital competency for construction PMs is the effective use of digital tools and software. Various studies provide multiple definitions of this competency. For example, some research emphasises BIM skills, highlighting the use of BIM systems for smart buildings (Rodrigues et al., 2023); while others stress proficiency in digital tools such as AutoCAD and BIM software to drive project performance (Liu et al., 2022). Additional definitions focus on technology design, encompassing BIM application development, equipment management, and the coordination of supporting digital tools (Uhm et al., 2017), whereas others underscore the importance of general project management software skills and project design capabilities (Mesaros et al., 2020; Mandičák et al., 2020). Further perspectives argue that advanced software skills are critical, as leaders must excel at managing digital databases and monitoring project progress from inception to handover (Omer et al., 2022). Specific aspects such as the ability to define levels of detail (LOD), object attributes, and effective BIM library management are also highlighted as essential (Hosseini et al., 2018; Lee et al., 2021).

Synthesising these perspectives, the final comprehensive definition can be defined *as the expertise required to effectively utilise digital tools, software, and technologies in construction project management. This includes proficiency in BIM systems, project management software, and digital design tools such as AutoCAD and Navisworks. Key competencies involve managing BIM libraries, defining levels of detail (LOD) and object attributes, and coordinating digital tools for enhanced project planning and execution. Additionally, leaders must excel in both software and construction technical skills to monitor progress from inception to completion, ensuring project outcomes meet client specifications. These skills enable efficient information retrieval, data management, and the seamless integration of technology into smart building practices.*

- **S2. Digital Technology Integration:** Various studies have provided multiple definitions of this competency. For instance, some authors highlight the importance of operating and integrating IoT systems in construction projects to enable real-time data collection and efficient oversight (Rodrigues et al., 2023). Others emphasise the leader's ability to combine digital resources, build and manage teams, and guide them through complex environments of technological innovation (Liu et al., 2022). Additional definitions focus on the role of digital collaboration with technology providers for capturing and managing construction data via service agreements (Atuahene et al., 2023), while yet others underscore proficiency in using BIM software for model viewing, analysis, and integration (Inguva et al., 2014). These perspectives collectively illustrate that effective digital technology integration encompasses a broad range of technical and managerial skills essential for modern construction project management.

  Synthesising these perspectives, the final comprehensive definition can be drawn as *the ability to effectively integrate and utilise digital tools, systems, and resources in construction projects to enhance efficiency and innovation. This includes operating IoT systems, collaborating with technology providers for data capture and management, and leading digital teams through complex systems of digital innovation. It also involves proficiency in BIM model viewing, analysis, and integration software to optimise project workflows and ensure seamless collaboration in technology-driven environments.*

- **S3. Digital Building Performance Optimisation:** Various studies have offered multiple perspectives on the use of BIM for performance simulation and maintenance in construction. Some definitions emphasise the use of BIM models to simulate various scenarios, evaluate performance, and explore different design alternatives, including 3D modelling, visualisation, and clash detection (Waqar et al., 2023). Others focus on the post-construction phase, highlighting how BIM can be used to analyse building performance, detect interferences, and assist in continuous maintenance planning (Waqar et al., 2023; Lee et al., 2021). Additionally, certain definitions underscore the importance of design reviews within BIM for quality assurance and efficient project coordination (Lee et al., 2021).

  Integrating these perspectives, the final comprehensive definition can be articulated as *the use of digital tools like BIM to simulate, monitor, and optimise building systems throughout their lifecycle. This includes analysing performance,* *scheduling maintenance activities, identifying and addressing repair needs, and managing resources effectively. By ensuring continuous performance, sustainability, and longevity, these practices enhance the functionality and resilience of buildings and infrastructure.*

- **S4. Digital Communication and Interaction Strategies:** Effective interaction through digital technologies is essential for facilitating communication, collaboration, and knowledge exchange in construction projects. One perspective highlights the importance of engaging with stakeholders through digital platforms to streamline communication and decision-making (Lukianov et al., 2021). Another emphasises the need for professionals to understand and adapt their communication strategies based on the digital context, ensuring clarity and appropriateness for different audiences (Vuorikari et al., 2022). Additionally, the ability to explain the functionalities and benefits of advanced technologies, such as BIM and IoT, to non-technical stakeholders is crucial in fostering adoption and integration within project teams (Rodrigues et al., 2023). Furthermore, articulating complex digital concepts in a clear and structured manner enhances collaboration and ensures that all project participants, regardless of technical expertise, can engage effectively (Kissi et al., 2025).

  Integrating these perspectives, the final comprehensive definition can be formulated as *the ability to engage effectively with stakeholders, teams, and non-technical audiences through various digital platforms and technologies. This competency involves adapting communication methods and tools to suit different contexts, clearly explaining the functionalities and benefits of advanced technologies, and fostering collaboration in virtual, hybrid, and in-person environments. It emphasises bridging the gap between technical and non-technical perspectives to ensure efficient and meaningful interactions.*

  S5. Real-Time Digital Information Exchange: The ability to share digital content effectively is fundamental to ensuring collaboration, knowledge transfer, and decision-making efficiency in construction projects. One perspective emphasises the role of digital technologies in enabling seamless sharing of data, information, and digital content among teams and stakeholders while maintaining proper referencing practices (Vuorikari et al., 2022). Another highlights the importance of disseminating digital information efficiently to facilitate project coordination and team engagement (Lukianov et al., 2021). The use of BIM is also noted for its ability to enhance real-time data exchange, streamline decision-making, and improve interoperability across digital platforms (Waqar et al., 2023; Lee et al., 2021). Additionally, structured project documentation plays a vital role in coordinating knowledge-sharing efforts and ensuring information consistency throughout the project lifecycle (Hosseini et al., 2018; Mandičák et al., 2020). Furthermore, fostering cooperative learning experiences and leveraging advanced IT systems supports continuous knowledge transfer and enhances team collaboration (Kissi et al., 2025).

  Synthesising these perspectives, the final comprehensive definition of this competency is *the ability to efficiently share data, information, and digital content using appropriate digital technologies to facilitate collaboration and decision-making. This competency includes leveraging tools such as BIM and DTs to enable real-time information exchange among diverse teams and stakeholders, ensuring interoperability across platforms for seamless collaboration. It also involves acting as an intermediary to ensure effective documentation, referencing, and knowledge* *transfer, while promoting cooperative learning experiences through advanced IT systems to enhance project outcomes.*

- **S6. Digital Collaboration and Knowledge Retention:** The ability to collaborate effectively through digital technologies is essential for modern construction project management. One perspective emphasises the role of digital tools in facilitating collaborative processes, co-creation, and co-construction of data, resources, and knowledge (Vuorikari et al., 2022). Another highlights the importance of shared digital platforms in enabling teamwork and coordination across project stakeholders (Lukianov et al., 2021). The use of BIM is particularly noted for its role as a unified collaboration platform, ensuring seamless information exchange and alignment among all parties involved in design and construction (Waqar et al., 2023). Additionally, structured project documentation supports coordination and knowledge-sharing efforts, enhancing communication and decision-making among project participants (Hosseini et al., 2018). Furthermore, documenting lessons learned throughout the construction process is crucial for institutional knowledge retention, allowing teams to continuously improve and refine future project workflows (Atuahene et al., 2023).
  Synthesising these perspectives, the final comprehensive definition can be articulated as *the use of digital tools and platforms to document, share, and apply insights, challenges, and solutions encountered during construction projects. This competency facilitates learning and collaborative knowledge retention by preserving institutional knowledge, encouraging team learning, and driving continuous improvement. By integrating lessons learned into digital collaboration processes, teams can make informed decisions, avoid repeated mistakes, and enhance overall project outcomes.*
- **S7. Digital Data Evaluation and Analytics:** A range of definitions address this competency. Some sources focus on evaluating digital content by analysing, comparing, and critically assessing the credibility and reliability of data and digital information (Vuorikari et al., 2022; Lukianov et al., 2021). Other definitions underscore the importance of data analytic expertise and the ability to employ visual data analysis techniques to derive actionable insights from visual data like images and videos in the construction process (Atuahene et al., 2023). Additional perspectives emphasise the need for ensuring accurate and adequate data capture, as well as maintaining and updating BIM data consistently throughout the project lifecycle to ensure its accuracy and suitability for decision-making (Mandičák et al., 2020; Lee et al., 2021).
  Building on these perspectives, the final comprehensive definition can be articulated as *the ability to critically assess the quality, relevance, and reliability of digital content, data, and information to support informed decision-making and project success. This competency includes analysing, comparing, and validating data sources, ensuring accurate and adequate data capture, and maintaining up-to-date project information throughout the lifecycle. Proficiency in evaluating digital data for accuracy and project suitability, updating models to reflect ongoing changes, and employing advanced techniques such as visual data analysis enables actionable insights. These competencies ensure efficiency, enhance project outcomes, and improve overall data management practices.*
- **S8. Cloud-Based Digital Content Management:** A key digital competency for construction PM is the effective organisation, storage, retrieval, and processing of digital data and content. Some definitions focus on the need to manage digital content by systematically organising, storing, and retrieving data in digital

environments to ensure efficient access and use (Vuorikari et al., 2022; Lukianov et al., 2021). Other perspectives emphasise data process management, which involves formulating robust data storage and processing guidelines as well as establishing electronic database systems to handle high volumes of data (Atuahene et al., 2023). Additional definitions highlight the role of digital management platforms, such as intranets, in streamlining data reporting and facilitating collaboration. Furthermore, competencies in data filing, exporting reports from BIM data for clear project communication (Lee et al., 2021), managing digital identities to protect reputations, and ensuring compliance with copyright and licensing regulations are also stressed.

Drawing from these perspectives, the final comprehensive definition can be defined as *the ability to organise, store, retrieve, and process digital data, information, and content in a structured and efficient manner. This competency encompasses creating and maintaining electronic database systems, formulating data storage and processing guidelines, and utilising digital management platforms to streamline data reporting and collaboration. It also includes properly filing and organising data for easy access, managing digital identities to safeguard reputations and handle generated data responsibly, and ensuring adherence to copyright and licensing rules for content use and sharing. Additionally, these skills involve exporting accurate reports from digital technology tools to support effective project communication, informed decision-making, and robust analytics.*

- **S9. Digital Content Development Skills:** Multiple definitions have been provided for this competency. For instance, one perspective describes it as the ability to create and edit digital content in various formats, enabling individuals to express themselves effectively through digital media (Vuorikari et al., 2022). Another definition emphasises the importance of creating original digital content using modern tools and technologies (Lukianov et al., 2021). These viewpoints collectively highlight that digital content development involves both the creative process and technical proficiency in managing diverse digital outputs.

  Expanding on these perspectives, Digital Content Development Skills comprehensively refers to *the ability to create, edit, and manage digital content across various formats using modern tools and technologies. This competency enables individuals to effectively express ideas, communicate, and contribute to projects through innovative and original digital outputs. Proficiency in digital content development ensures clear communication, creative problem-solving, and the capacity to adapt content for diverse audiences and platforms, thereby enhancing collaboration and overall project success.*
- **S10. Advanced Digital Content Management:** Different studies have offered varied perspectives on this competency. One definition characterises it as the ability to modify, refine, and reuse existing digital resources to create new, original content (Vuorikari et al., 2022). Another perspective describes it as integrating and modifying existing digital content to suit specific project needs (Lukianov et al., 2021). These definitions collectively emphasise the importance of adaptability and creativity in leveraging available digital assets to meet evolving project requirements.

  Building on these perspectives, Advanced Digital Content Management can be defined as *the ability to refine, modify, and adapt existing digital content to create new, original resources tailored to specific project requirements. These skills enhance creativity and efficiency by integrating and leveraging available digital assets to produce innovative outputs. Proficiency in this area ensures the effective* *reuse of resources, optimising workflows and fostering originality in content development while meeting project objectives.*

- **S11. AI-Assisted Programming and Automation:** This competency is described through various perspectives in the literature. One definition emphasises the ability to create and understand simple programs or automated systems that facilitate everyday tasks (Vuorikari et al., 2022), while another underscores the importance of coding proficiency for interacting with digital tools, analysing project data, and developing customised solutions to overcome specific project challenges (Kissi et al., 2025). These definitions together highlight that effective programming in construction project management involves not only basic coding skills but also the capacity to automate processes and enhance workflow efficiency.
  Drawing on these perspectives, the final comprehensive definition can be articulated as *the ability to create, understand, and utilise programs or automated systems to enhance project workflows and efficiency. This includes proficiency in coding languages for interacting with digital tools, analysing project data, and developing customised solutions to address specific challenges. These skills enable the automation of repetitive tasks, the optimisation of processes, and the development of innovative approaches to improve construction and project management outcomes.*
- **S12. Smart Construction Digital Tool Utilisation:** Several definitions emphasise the importance of creatively leveraging digital technologies to enhance project outcomes. One perspective highlights the application of digital tools, such as CAD/BIM software, cloud platforms, and simulation technologies, to streamline workflows and improve efficiency (Lukianov et al., 2021). Other definitions stress the need for in-depth knowledge of BIM and Virtual Design and Construction (VDC) software, as well as proficiency in using industry-specific platforms like Autodesk and Trimble products. Furthermore, expertise in interacting with digital tools, managing project team software parameters, and utilising advanced modelling techniques, including HVAC load analysis and energy modelling, are cited as key competencies (Uhm et al., 2017). The ability to draft, design, and produce construction licensing documents ensures compliance with regulatory standards. Besides, software support and the application of IT-driven project management strategies further enhance digital collaboration and decision-making (Hosseini et al., 2018; Mandičák et al., 2020; Kissi et al., 2025; Lee et al., 2021).
  Drawing from these insights, the final comprehensive definition can be articulated as *the creative and effective application of digital technologies, including CAD/BIM software, cloud platforms, and simulation tools, to achieve project objectives. This competency encompasses designing, modelling, rendering, and drafting accurate project documentation while ensuring compliance with technical standards. It also involves leveraging advanced software for visual design, energy modelling, and sustainable construction practices, as well as supporting the implementation of digital tools across projects. Proficiency in utilising these tools fosters efficient project management, enhances collaboration, and promotes innovation to optimise project outcomes.*
- **S13. Digital Technologies Training and Development:** This competency centres on equipping construction professionals with the necessary skills and knowledge to effectively use digital tools for data capture, analysis, and project management. Some definitions focus on the provision of training to enhance the use of digital technologies in capturing and analysing project data (Atuahene et al., 2023), while others emphasise the role of BIM as a platform for delivering instructional

resources that build the competencies of construction professionals (Waqar et al., 2023). Additional perspectives highlight the importance of training and teaching team members in managing electronic construction information, including developing training materials and offering informal BIM education and support (Uhm et al., 2017). Other definitions stress the need for continuous professional development, noting that BIM managers require ongoing training in digital skills to maintain alignment with industry standards (Hosseini et al., 2018).

Building on these perspectives, the final comprehensive definition of Digital Technologies Training and Development can be drawn as *the process of equipping construction professionals with the skills and knowledge to effectively use digital tools and technologies, such as BIM, for data capture, analysis, and project management. This competency includes developing and delivering training materials, conducting instructional sessions, and providing ongoing education to ensure alignment with industry standards. It also involves fostering continuous professional development and supporting team members in managing electronic construction information, thereby enhancing overall project execution and collaboration.*

- **S14. Smart Digital Documentation and Archiving:** Several definitions underscore the importance of systematically organising and maintaining project documentation in digital construction environments. One perspective emphasises the need to maintain a CAD library and an effective file system, outlining strategies for producing documents and identifying planned sheets for each project stage (Uhm et al., 2017). Another viewpoint highlights the necessity of defining data files and BIM elements, coupled with electronically filing, organising, and keeping all drawings and related paperwork up to date.

  Drawing from these perspectives, the final comprehensive definition of Smart Digital Documentation and Archiving is defined as *the process of organising, maintaining, and updating electronic project files, including CAD and BIM data, throughout the project lifecycle. This competency involves defining file structures, creating and implementing documentation strategies, and ensuring that all drawings, data files, and project-related documents are accurately recorded, electronically filed, and readily accessible. It also includes managing version control, maintaining a CAD library and file system, and strategizing document production to support efficient project workflows and seamless collaboration.*
- **S15. Digital Problem Solving and Technical Support:** Various definitions describe this competency in different ways. Some sources define it as the ability to identify and resolve technical issues encountered while using digital tools and applications (Vuorikari et al., 2022). Other definitions emphasise the importance of making timely decisions based on sound judgment, while keeping appropriate stakeholders informed and addressing problems through effective model management (Uhm et al., 2017). In addition, several perspectives highlight that problem solving is an essential skill in construction, developed through experience and knowledge, to identify the source of issues and implement sustainable solutions, thereby strengthening team performance (Mesaros et al., 2020; Mandičák et al., 2020; Kissi et al., 2025; Omer et al., 2022). Moreover, some definitions extend this competency to include assessing both personal and organisational digital needs and using digital tools creatively to solve problems (Vuorikari et al., 2022).

  Building on these perspectives, the final comprehensive definition of Digital Problem Solving and Technical Support is *the ability to identify, evaluate, and* *resolve technical issues encountered during the use of digital tools and applications, ensuring smooth project execution and performance optimisation. This competency involves making timely, informed decisions based on sound judgment, auditing and managing digital models, and implementing research-driven solutions to complex challenges. It includes supporting teams in overcoming obstacles through proactive problem-solving assistance, fostering creativity in using digital technologies to address issues, and ensuring solutions are sustainable to prevent recurrence. Additionally, it encompasses assessing personal and organisational digital needs, identifying appropriate technology solutions, and enabling innovative approaches to problem-solving and creative expression, ultimately improving project outcomes and team effectiveness.*

- **S16. Digital Skills Gap Analysis and Development:** This competency involves understanding where an individual's or team's digital skills require enhancement to keep pace with technological advancements. Some definitions emphasise the need to recognise areas where one's own digital competence must be improved or updated, as well as the ability to support others in developing their digital skills and continuously seek self-development opportunities (Vuorikari et al., 2022). Other perspectives focus on the recognition of gaps within a team or project, highlighting the importance of identifying deficiencies in digital skills that may hinder overall performance (Lukianov et al., 2021). Additionally, there is an emphasis on engaging in digital citizenship, participating in public and private digital services to foster self-empowerment and broader societal engagement (Vuorikari et al., 2022).

  Building upon these insights, the final comprehensive definition of Digital Skills Gap Analysis and Development is *the ability to assess and identify areas where an individual's or team's digital skills require improvement to enhance performance and adapt to the evolving digital landscape. This competency involves understanding current digital proficiency levels, recognising skill gaps that impact project success, and actively pursuing opportunities for self-development and team growth. It also encompasses fostering digital citizenship by engaging with public and private digital services to promote continuous learning and organisational improvement.*
- **S17. Cybersecurity and Digital Device Protection:** Some definitions emphasise the need to protect personal and organisational devices from digital threats and risks (Vuorikari et al., 2022; Lukianov et al., 2021). Others focus on designing robust systems that safeguard sensitive construction data, employing advanced analytics for diagnostic, predictive, and prescriptive measures (Atuahene et al., 2023). Additionally, there is an emphasis on ensuring digital health and well-being by managing screen time, content exposure, and online interactions to support safe digital environments (Vuorikari et al., 2022).

  Drawing from these perspectives, the final comprehensive definition of Cybersecurity and Digital Device Protection is *the strategies and practices employed to safeguard personal and organisational devices and data from digital threats, ensuring integrity, confidentiality, and availability throughout the project lifecycle. This competency encompasses protecting devices against cyber risks, implementing robust security systems and risk mitigation protocols, and utilising advanced analytics to monitor, predict, and address potential vulnerabilities. Additionally, it involves promoting digital well-being by managing screen time, content exposure, and online interactions, thereby supporting a secure and balanced use of digital resources.*

- **S18. Digital Privacy and Data Protection Compliance:** Some sources define this competency as the ability to protect both personal and professional data and digital privacy (Vuorikari et al., 2022), while others emphasise the importance of maintaining compliance with data protection regulations and safeguarding sensitive information (Lukianov et al., 2021). In addition, there is a focus on ensuring data security within BIM environments, which is critical for protecting project information (Lee et al., 2021).
  Rooted in these perspectives, the final comprehensive definition of Digital Privacy and Data Protection Compliance is *the practices and strategies to ensure the security, confidentiality, and integrity of personal and professional data within digital platforms. This includes safeguarding sensitive information by complying with data protection regulations and implementing measures to prevent unauthorised access, breaches, and misuse of data. These efforts aim to protect the privacy of individuals and organisations while maintaining secure and efficient workflows throughout digital processes and project lifecycles.*
- **S19. Emerging Technologies Cost Management:** Several perspectives define this competency in different ways. For instance, one definition emphasises the need for effective budgeting and controlling the higher costs associated with materials, equipment, and training required for implementing new technologies in smart building projects (Rodrigues et al., 2023). Another perspective highlights the role of government and industry support, whereby workshops and training sessions sponsored by construction bodies help firms manage the financial challenges related to big data and digital transformations (Atuahene et al., 2023). These definitions underscore that effective cost management in technology-driven construction is not only about financial control but also about leveraging external support to mitigate increased expenditures.
  Grounded in these perspectives, the final comprehensive definition of Emerging Technologies Cost Management is *the ability to budget, monitor, and control the increased costs associated with implementing new technologies, materials, equipment, and training in smart building projects. This competency involves the strategic allocation of financial resources to ensure that advancements such as BIM and IoT are integrated efficiently without exceeding financial limits and is further supported by government and industry-led initiatives, such as workshops and training programs, aimed at enhancing cost management practices and fostering digital transformation in construction.*
- **S20. Real-Time Cost Optimisation and Digital Budgeting:** One perspective defines project cost management as the use of BIM, particularly through 5D models, to enable accurate cost estimation via automated quantity take-offs and real-time feedback on design changes, thereby enhancing budget monitoring and productivity (Raza et al., 2023). Other definitions emphasise the fundamental ability to manage costs and budgets, focusing on essential cost control measures that aid in budgeting and financial planning, as well as the skills needed for effective cost planning and review in BIM-based project plans (Mesaros et al., 2020; Lee et al., 2021). Additionally, some sources stress the importance of balancing project objectives and constraints through comprehensive cost and budget management strategies (Liu et al., 2022).
  Drawing from these perspectives, the final comprehensive definition of Real-Time Cost Optimisation and Digital Budgeting is *the ability to effectively manage project costs and budgets using digital tools like BIM, particularly through the integration of 5D models. This enables precise cost estimation, automated quantity take-offs,*

real-time feedback on design changes, and efficient cost planning and reviews. It enhances budget tracking, productivity, and financial planning while requiring adjustments to traditional workflows. This approach empowers project teams to balance costs with project objectives, ensuring alignment with financial goals throughout the project lifecycle.

- **S21. Automated Digital Procurement Management:** Various definitions outline the role of digital tools in streamlining procurement activities in construction projects. One definition emphasises how BIM, particularly through 5D models, enhances project procurement management by predicting material quantities, simulating schedules, and identifying collisions early to reduce rework and omissions (Raza et al., 2023). Another perspective focuses on the budgeting and accounting aspects, highlighting the need for precise cost estimation through automated quantity take-offs (Mesaros et al., 2020). Additionally, some definitions stress the importance of generating detailed bills of material and using BIM for accurate procurement planning (Lee et al., 2021).
  Framed by these perspectives, the final comprehensive definition of Automated Digital Procurement Management is *the process of optimising procurement activities through digital tools like BIM, particularly 5D models, to ensure accurate material quantity predictions, budget estimations, and schedule simulations. This competency enables efficient procurement planning by leveraging detailed, automated data to reduce errors, omissions, and rework. It includes generating precise bills of material and quantity take-offs to support budgeting, accounting, and resource allocation. By integrating e-procurement frameworks and automating information management, digital procurement management enhances the reliability, accuracy, and efficiency of project resource planning and execution.*
- **S22. Digital Scheduling Management:** Some definitions describe this competency as the ability to plan and control project schedules, particularly when new digital technologies disrupt traditional timelines (Rodrigues et al., 2023). Other perspectives emphasise that BIM streamlines project time management by integrating models with schedules, enabling progress tracking, visualising construction processes, and providing real-time feedback on design changes (Raza et al., 2023). Additional definitions focus on scheduling and coordination, noting that BIM can develop comprehensive construction schedules that integrate design, engineering, and construction operations (Waqar et al., 2023). Further viewpoints stress the importance of meeting deadlines, organising work, and efficiently managing tasks, ranging from overall project management and task allocation to specific skills like 4D scheduling that integrate time data with BIM models (Mesaros et al., 2020; Omer et al., 2022; Uhm et al., 2017; Lee et al., 2021).
  Grounded in these perspectives, the final comprehensive definition of Digital Scheduling Management is *the ability to plan, control, and optimise project schedules using digital technologies such as BIM, which synchronise project timelines with digital models. This competency includes 4D scheduling, linking time data with BIM models to integrate design, engineering, and construction activities into a cohesive timeline, while enabling PMs to track progress, visualise workflows, and assess the impact of design changes in real time. It also involves prioritising tasks, allocating resources efficiently, and adjusting timelines to meet deadlines in accordance with project standards, thereby supporting efficient, timely project delivery and enhanced coordination across teams.*
- **S23. Digital Resource Management:** Several definitions underscore the importance of efficiently allocating and coordinating resources in smart building

projects. Some perspectives focus on the general need to manage resources such as technology, materials, and skilled labour (Rodrigues et al., 2023), while others highlight that BIM can enhance resource management by fostering interdisciplinary collaboration, optimising manpower, and reducing waste through sustainable practices like the circular economy (Raza et al., 2023). Additional definitions emphasise the role of BIM in cost estimation by accurately predicting material and labour needs (Waqar et al., 2023), as well as managing personnel resources, such as overseeing CAD/Revit engineers and mentoring technical teams (Uhm et al., 2017). Other viewpoints stress the importance of administrative activities, including budgeting, scheduling, and organising documentation, and also emphasise human resource planning, supply management, and effective on-site management to ensure project success (Mesaros et al., 2020; Mandičák et al., 2020; Omer et al., 2022; Lee et al., 2021; Liu et al., 2022).

Synthesising these perspectives, the final comprehensive definition for Digital Resource Management is defined as *the ability to efficiently allocate, coordinate, and utilise resources, including technology, materials, skilled labour, and human capital, in construction projects to meet strategic objectives. Leveraging digital tools such as BIM, this competency enables precise cost estimation, material and labour forecasting, and seamless interdisciplinary collaboration. It optimises resource usage, reduces waste, and promotes sustainable practices, while also encompassing human resource planning, procurement, and on-site technical skills management. Moreover, it supports administrative tasks such as budgeting, scheduling, and documentation, thereby enhancing overall resource control and project efficiency.*

- **S24. Digital Quality Control:** Some sources describe quality control as ensuring that high standards are maintained across both traditional and technology-driven aspects of a project (Rodrigues et al., 2023). Other definitions emphasise that BIM enhances quality management by enabling real-time monitoring, detailed audits of structural and Mechanical, Electrical, and Plumbing (MEP) elements, and fostering transparent stakeholder collaboration through multidimensional models, with features like clash detection reducing errors and supporting continuous improvement (Raza et al., 2023). Additional perspectives focus on rigorous quality control analysis, evaluating as-built drawings and Operation and Maintenance (O&M) manuals, managing BIM output, and setting up effective model checking and coordination processes to maintain adherence to established tolerances (Uhm et al., 2017). Furthermore, the importance of comprehensive monitoring of quality-related data, ensuring sufficient oversight of BIM processes, and a strong commitment to delivering high-quality products through effective client liaison and attention to detail.

  Building on these perspectives, the final comprehensive definition of Digital Quality Control is *the process of integrating quality management practices throughout the project lifecycle using digital tools such as BIM, DT, and AI. This competency involves real-time monitoring and detailed audits of structural, electrical, and mechanical elements, leveraging features like clash detection and comprehensive documentation of defects to support quality assurance. It ensures adherence to standards and tolerances, facilitates continuous improvement and conflict resolution, and enhances overall project efficiency by reducing waste and ensuring high-quality outcomes.*
- **S25. Digital Scope and Change Management:** Some definitions focus on the use of BIM to enhance project scope management by clarifying scope through 3D

modelling and visualising changes with 5D models, thereby improving communication among stakeholders and ensuring a shared understanding of project boundaries (Raza et al., 2023). Other perspectives emphasise the importance of flexibility, highlighting the need for adaptability in career, labour, and technological resources to respond to evolving project demands in a digital environment (Kissi et al., 2025).

Framed by these perspectives, the final comprehensive definition of Digital Scope and Change Management is *the ability to manage project scope and changes effectively using digital technologies such as BIM and DT. This competency involves clarifying project scope through 3D modelling, visualising changes with 5D models, and enhancing communication among stakeholders to foster a shared understanding. It also provides the flexibility needed to adapt to evolving project demands, accommodating changes in career requirements, labour resources, and technological innovations. By streamlining scope and change management, this approach minimises scope creep, enhances adaptability, and ensures that all stakeholders remain aligned with project goals, enabling efficient execution in a dynamic construction environment.*

- **S26. Innovation Management in Digital Construction:** Some definitions describe this competency as managing the integration of new technologies, such as AI and automation, into construction practices to drive operational improvements (Rodrigues et al., 2023). Other perspectives focus on fostering a data-driven culture that actively promotes the use of digital technologies throughout construction processes. Additionally, certain studies highlight the importance of investing in digital technologies and big data infrastructure as a means to enhance efficiency and spur innovation within construction firms (Atuahene et al., 2023). There is also an emphasis on the need for strategic decision-making to overcome financial and technical barriers associated with the adoption of smart building technologies (Rodrigues et al., 2023).

  Based on these viewpoints, the most comprehensive definition for Innovation Management in Digital Construction is defined as *the ability to manage the adoption and integration of emerging technologies, such as AI, automation, and big data infrastructure, into construction practices. This competency fosters a data-driven culture, promotes the use of digital tools, and emphasises strategic decision-making to overcome financial and technical barriers to technological implementation. It also involves investing in innovative technologies to enhance efficiency, decision-making, and overall project performance. By aligning with industry trends and organisational goals, this approach ensures construction firms remain competitive, adaptive, and at the forefront of technological advancements.*

Knowledge

- **K1: Advanced Digital Construction Knowledge:** Managing complex construction projects requires specialised expertise in advanced construction procedures and smart technologies. One perspective highlights the necessity of mastering technical knowledge and skills related to digital construction management, ensuring that professionals can efficiently handle intricate processes (Rodrigues et al., 2023; Liu et al., 2022). Additionally, expertise in construction process integration enables professionals to bridge technical data with actionable project deliverables, enhancing decision-making and execution (Atuahene et al., 2023). Besides, engineering and technological proficiency, including familiarity with BIM techniques and disciplines like HVAC, plumbing, and electrical systems, is essential for optimising modern construction workflows. Furthermore, extensive knowledge of building materials, construction methods, and the ability to interpret structural drawings further strengthens a construction manager's ability to oversee diverse project components (Uhm et al., 2017). Another key aspect is understanding construction complexity, grasping how different project elements interact and leveraging digital tools to enhance coordination (Mandičák et al., 2020). Lastly, staying updated with advancements such as nanomaterials, modular construction, and emerging smart building methods ensures that professionals remain at the forefront of industry innovation (Kissi et al., 2025).

Upon combining various perspectives, the final comprehensive definition for Advanced Digital Construction Knowledge is *the expertise required to manage complex construction processes, integrate technical data into actionable project deliverables, and apply advanced skills across various engineering and construction domains. This includes mastery of digital tools, such as BIM and DT techniques, comprehensive knowledge of building materials and systems such as HVAC, plumbing, and electrical, and familiarity with structural drawings and installation procedures. It also involves understanding the complexity of construction projects, including the interaction of various elements, and leveraging technology-driven workflows to evaluate, select, and apply advanced construction procedures for efficient and innovative project execution.*

- **K2: Emerging Technology Integration Knowledge:** Various studies provide multiple definitions of this competency. For example, one perspective emphasises the importance of understanding new technologies, such as IoT, AI, and VR, and their practical applications in construction (Liu et al., 2022). Another definition focuses on ensuring the availability of digital technologies, like drones and time-lapse cameras, within construction firms to support project activities (Atuahene et al., 2023). Additionally, some research highlights the need for proficiency in using BIM model viewing, analysis, and integration software as a critical element of digital competency (Inguva et al., 2014).

  Synthesising these perspectives, the final comprehensive definition for Emerging Technology Integration Knowledge is defined as *the understanding and application of cutting-edge technologies, such as IoT, AI, VR, drones, and time-lapse cameras, to enhance construction processes. This competency involves ensuring the availability and effective use of these technologies within construction firms, leveraging them for tasks in digital technologies like BIM model viewing, analysis, and integration. It emphasises practical knowledge of their applications to improve efficiency, drive innovation, and optimise project outcomes in technology-driven environments.*
- **K3: Smart Systems and Applications Knowledge:** Various studies offer multiple definitions for this competency. Some sources emphasise that BIM collects information about building components, materials, and systems to advise future developments (Waqar et al., 2023), while others highlight the importance of BIM-related work experience (Uhm et al., 2017). Additional definitions focus on the major functions of BIM software, specifically, knowledge of its core features and functions is seen as critical for optimised use (Lee et al., 2021). They also highlighted other perspectives stress the need for an understanding of object and BIM library classification systems, which is necessary for structured data usage, along with the capability to input correct attribute values to ensure data accuracy.

Furthermore, several studies underscore that technical knowledge, including the ability to effectively use digital technology, advanced materials, modern construction methods, and innovative applications, is fundamental (Kissi et al., 2025).

By incorporating various viewpoints, the final comprehensive definition for Smart Systems and Applications Knowledge is *the expertise and experience required to effectively utilise digital software and related technologies in construction. This includes proficiency in advanced digital technologies, such as BIM and DT systems, understanding their core functions, and managing libraries and classification systems for structured data usage. It also involves accurately inputting attribute values to maintain data integrity and leveraging digital technologies to collect and analyse information about building components, materials, and systems for future developments. Additionally, this competency encompasses technical knowledge of advanced materials, modern construction methods, and innovative applications, ensuring efficient project planning, development, and execution.*

- **K4. Digital Project Strategy and Goal Alignment:** Some sources describe this competency as ensuring that project objectives are in line with the broader strategic goals of the organisation (Rodrigues et al., 2023). Others emphasise that effective organisational management involves collaborating with top management and various departments to ensure projects support overall strategy (Liu et al., 2022). Additional perspectives highlight the importance of regular data strategy discussions to align team efforts and expectations (Atuahene et al., 2023), while other definitions stress the ability to formulate clear, actionable goals that direct project efforts toward success (Mesaros et al., 2020; Mandičák et al., 2020).

  The final comprehensive definition for Digital Project Strategy and Goal Alignment is *the ability to ensure that project objectives are aligned with the broader strategic goals of the organisation. This competency involves collaborating with top management and various departments to integrate projects with organisational strategy, engaging in regular data strategy discussions to guide team efforts, and establishing clear, actionable goals that direct project activities. By aligning project efforts with organisational expectations and fostering strategic collaboration, this competency drives successful project delivery and contributes to overall organisational success.*
- **K5. Digital Project Integrated Management:** Effective project integration is critical in the digital age of construction, and several definitions capture its multifaceted nature. One definition emphasises how BIM enhances project integration management by unifying multidisciplinary models into a cohesive system, thereby enabling efficient planning, analysis, and execution, and improving collaboration, communication, and documentation (Raza et al., 2023). Another definition underscores the importance of understanding and integrating interdisciplinary concepts, which facilitates the seamless combination of expertise from diverse fields (Inguva et al., 2014).

  The final comprehensive definition of Digital Project Integrated Management is defined as *the ability to unify and manage multidisciplinary aspects of a project to ensure efficient planning, execution, and delivery. This competency involves integrating various components, such as systems, teams, and processes, through collaborative technologies like BIM, which enhances project planning, analysis, communication, and documentation. By fostering collaboration and leveraging interdisciplinary concepts, these skills enable the seamless combination of expertise from diverse fields, ensuring cohesive and efficient project execution.*

- **K6. Digital Safety and Risk Mitigation:** This competency refers to the ability to manage safety throughout a project's lifecycle using digital tools. One definition emphasises the competence required to manage safety across all project phases (Liu et al., 2022). Another highlights how BIM enhances safety management by integrating safety standards with automated hazard identification and mitigation tools, thereby enabling early detection of hazards during preconstruction, improving communication, and streamlining safety processes through automated checks and simulations (Raza et al., 2023). Additionally, a further perspective focuses on the use of BIM to generate safety plans that proactively detect potential hazards and dangers in construction projects (Waqar et al., 2023).
  Building on these perspectives, the final comprehensive definition of Digital Safety and Risk Mitigation is *the ability to manage safety throughout the entire lifecycle of a project, from design to construction and handover. This includes integrating safety standards with digital tools such as BIM to enhance hazard identification and mitigation. By leveraging automated safety checks, simulations, and early hazard detection during the preconstruction phase, this competency ensures a proactive and systematic approach to safety. It also involves streamlining safety processes, improving communication, and ensuring compliance with safety regulations, thereby reducing risks and fostering a safe and efficient project environment.*
- **K7. Digital Quality Assurance and Lifecycle Management:** Quality management in construction involves overseeing quality control throughout every phase of a project, ensuring that project standards and specifications are consistently met (Liu et al., 2022). Additionally, some studies emphasise the role of BIM in lifecycle data management, where BIM models are used continuously during the building process to gather, track, and evaluate data, supporting informed decision-making and continuous quality monitoring (Waqar et al., 2023).
  Rooted in these perspectives, the final comprehensive definition of Digital Quality Assurance and Lifecycle Management is *the ability to oversee and manage quality control across all phases of a project, from initiation to completion. This competency ensures that project standards and specifications are consistently met by leveraging digital tools like BIM to gather, track, and analyse data throughout the building process. By integrating lifecycle data management, these skills enable continuous quality monitoring, facilitate informed decision-making, and support the long-term performance and sustainability of the built environment.*
- **K8. Contract and Negotiation Management:** Managing contracts and negotiations is a critical skill in construction project management, ensuring smooth stakeholder collaboration and legal compliance. One perspective highlights the necessity of overseeing contract negotiations, terms, and ongoing compliance throughout the project lifecycle (Liu et al., 2022). Another emphasises the ability to negotiate effectively, which plays a crucial role in securing favorable agreements and resolving disputes (Inguva et al., 2014). Additionally, strong negotiation skills are essential for mediating conflicts, facilitating agreements, and aligning stakeholder expectations to support successful project execution (Kissi et al., 2025).
  Combining these points of view, the last comprehensive definition for Contract and Negotiation Management is *the competency to manage all aspects of contract negotiations and administration throughout the project lifecycle. This includes negotiating favourable terms, ensuring compliance with contractual obligations, and addressing any necessary adjustments. These skills involve resolving disputes, mitigating risks, and fostering strong relationships with all parties to support*

successful project delivery. Effective contract management also ensures adherence to legal and regulatory standards, contributing to project efficiency and stakeholder satisfaction.

- **K9. Regulatory and Compliance:** This competency pertains to the knowledge and skills required to understand and adhere to the laws, regulations, and technical standards that govern construction projects. Some definitions focus on the basic familiarity with industry regulations, emphasising the need for an in-depth understanding of relevant laws, norms, and codes in construction (Liu et al., 2022). Others underscore the role of BIM in facilitating regulatory compliance by enabling automated hazard detection and conflict resolution, which streamlines adherence to established safety and quality standards (Waqar et al., 2023). Additional perspectives stress the importance of design knowledge and technical expertise, including the ability to navigate building design trends, code regulations, and production workflows, ensuring that projects align with legal and industry-specific requirements (Uhm et al., 2017). Moreover, certain studies highlight the competency in managing construction licensing documents and drawings as essential for upholding regulatory standards in BIM-based projects (Lee et al., 2021).

  The final comprehensive definition for Regulatory and Compliance can be drawn as *the knowledge and skills required to understand, apply, and adhere to industry laws, regulations, and standards throughout the project lifecycle. This includes familiarity with building codes, design regulations, and technical standards, as well as proficiency in creating and managing licensing documents to ensure regulatory adherence. It involves leveraging technologies to facilitate compliance, resolve conflicts, and align with national and international standards. Additionally, it encompasses mastery of design workflows, production cycles, and code procedures to ensure legal, safety, and quality standards are met, thereby supporting effective project execution within an evolving regulatory framework.*
- **K10. Language Proficiency:** A key competency for construction PMs is the effective use of language skills to facilitate clear and efficient communication. Some definitions stress that successful coordination in project management requires proficiency in languages such as English and Mandarin to ensure effective communication (Liu et al., 2022). Other definitions emphasise the importance of excellent writing skills, highlighting fluent written English, strong report writing, and the ability to communicate effectively in presentations and through written correspondence (Uhm et al., 2017). Additionally, several sources underline the need for robust speaking skills, including strong verbal communication, confident presentation abilities, and precise articulation in both small and large group settings (Uhm et al., 2017). They mentioned also the familiarity with foreign languages such as Mandarin (including Putonghua and Cantonese), Japanese, and German is also noted, supporting cross-cultural collaboration within diverse project teams.

  Based on these perspectives, the final definition for Language Proficiency can be summarised as *the ability to use language skills effectively, both spoken and written, to facilitate clear and efficient communication in project settings. This includes proficiency in common project languages such as English, as well as foreign languages such as Mandarin, Cantonese, Japanese, and German to support collaboration across diverse teams and cultures. It encompasses strong verbal communication, presentation, and writing abilities to ensure clarity in reports, speeches, and interpersonal exchanges, thereby fostering successful communication in both small and large group settings.*

- **K11. Digital Information and Data Literacy:** Various definitions highlight the importance of understanding how to identify, articulate, and address information needs in digital environments (Vuorikari et al., 2022). Some perspectives emphasise the necessity of comprehending effective methods for searching, browsing, and filtering data and digital content to locate and evaluate relevant resources (Lukianov et al., 2021). This knowledge ensures the ability to systematically access and manage digital information, supporting informed decision-making and digital competency in construction project management.
  Based on these viewpoints, the comprehensive definition of Digital Information and Data Literacy is *the foundational knowledge required to navigate, evaluate, and manage digital information effectively. This includes understanding methodologies for browsing, searching, and filtering data to ensure accurate access to relevant resources. By developing this knowledge, construction professionals can enhance digital collaboration, improve project outcomes, and make well-informed decisions within digital environments.*
- **K12. Digital Construction Risk Management:** Several definitions highlight the significance of managing construction risks through digital tools. Some perspectives emphasise risk management across various construction phases, particularly in innovative or untested projects where uncertainties are high (Rodrigues et al., 2023). Others focus on how BIM enhances risk management by enabling spatial visualisation and model-based analysis, helping identify and mitigate risks before they escalate. This approach improves communication, minimises change orders and rework, strengthens safety management, and ensures accurate cost and schedule forecasting throughout all project phases, from planning to demolition (Raza et al., 2023).
  Synthesising these perspectives, the final comprehensive definition for Digital Construction Risk Management is *the strategic use of digital tools to identify, assess, and mitigate risks throughout the construction project lifecycle. This competency involves leveraging technologies such as BIM and AI to provide a comprehensive view of potential risks, including safety hazards, cost overruns, and schedule disruptions. By integrating advanced risk forecasting, supporting real-time project updates, and enhancing stakeholder communication, it ensures a proactive approach to risk control, reduces rework, and improves overall project efficiency and safety.*
- **K13. Digital Technology Adoption Risk Mitigation:** This competency focuses on managing the challenges that arise from the adoption and integration of new digital technologies in construction projects. Some definitions emphasise managing risks associated with technologies such as BIM and IoT, particularly in the context of smart building projects (Rodrigues et al., 2023). Other perspectives highlight the need for developing cost models through research and development to assess the financial feasibility of adopting big data technologies in construction (Atuahene et al., 2023). Additional definitions underscore the importance of enforcing the use of digital tools and data applications within construction processes, while also noting that standardisation, such as that achieved through BIM, can reduce the likelihood of errors, delays, and cost overruns (Waqar et al., 2023; Atuahene et al., 2023).
  Based on these different viewpoints, the most comprehensive definition of Digital Technology Adoption Risk Mitigation is *the process of identifying, evaluating, and mitigating challenges associated with adopting and integrating new technologies, such as BIM and IoT, in construction projects. This includes assessing the financial feasibility of technology adoption through cost modelling, enforcing the use of*

digital tools, and leveraging standardisation to reduce errors, delays, and cost overruns. By addressing these risks, this competency ensures that technological integration enhances project outcomes while minimising uncertainties and potential disruptions.

- **K14. Financial Risk Management:** Some definitions highlight the importance of assessing and mitigating financial risks associated with the adoption of digital technologies in construction, particularly in areas such as budgeting, cost control, and resource allocation (Rodrigues et al., 2023). They emphasise that financial risk management, while overlapping with general risk management, specifically focuses on addressing budget uncertainties, cost overruns, and the fiscal impacts of integrating advanced digital tools like BIM and IoT.

  Based on these perspectives, the final comprehensive definition for Digital Financial Risk Management is *the process of evaluating and managing financial risks related to the implementation of digital technologies in construction projects. This competency includes assessing the financial feasibility of adopting digital tools, forecasting cost implications, and developing strategies to mitigate unexpected financial demands. By ensuring thorough cost control and addressing potential budget uncertainties, it supports project viability and enables the effective allocation of financial resources in digital construction environments.*
- **K15. AI-Powered Data-Driven Decision-Making:** Some sources describe this competency as the ability to utilise data and digital insights to guide project decisions, emphasising the importance of making informed, evidence-based choices (Lukianov et al., 2021). Other definitions highlight the development and use of industrial performance databases, created collaboratively with suppliers and subcontractors, to improve decision-making processes through comprehensive data integration (Atuahene et al., 2023). In addition, there is a focus on robust decision-making skills, which underpin the effective use of data to drive project outcomes (Inguva et al., 2014).

  The final comprehensive definition for AI-Powered Data-Driven Decision-Making can be summarised as *the ability to leverage digital insights, industrial performance databases, and analytical tools to inform and optimise project decisions. This competency involves effectively evaluating and utilising data to make precise, evidence-based choices that enhance project efficiency, outcomes, and overall performance. By integrating data-driven approaches, construction professionals can improve resource allocation, minimise risks, and ensure informed decision-making at every project stage.*
- **K16. Standardising Digital Technology Processes:** Some definitions emphasise the role of digital tools, such as BIM, in establishing standardised building procedures, highlighting their ability to simplify collaboration among construction teams while reducing errors and miscommunication (Waqar et al., 2023). Others focus on the consistent application of standards across project processes and documentation within BIM projects, ensuring clarity and uniformity throughout (Hosseini et al., 2018).

  Drawing from these perspectives, Standardising Digital Technology Processes refers to *the creation and implementation of uniform procedures and guidelines within digital environments to enhance collaboration, minimise errors, and streamline workflows. This competency ensures that standards are consistently applied across all project stages and documentation, facilitating clear communication among teams and reducing miscommunications. By standardising* *technology-driven processes, construction projects achieve greater efficiency, reliability, and alignment with industry best practices.*

- **K17. Energy Efficiency and Carbon Management:** Some definitions highlight the importance of managing energy-efficient solutions, such as smart HVAC systems and energy monitoring tools, to optimise energy consumption in construction projects (Rodrigues et al., 2023). Other perspectives indicate that BIM can be used to quantify the embodied energy and carbon footprint of a building by integrating information on materials, systems, and components. In addition, further definitions focus on the role of environmental impact simulation, where BIM is utilised to evaluate the effects of different design alternatives on a project's environmental performance (Waqar et al., 2023).

  Building on these insights, Energy Efficiency and Carbon Management encompasses *the implementation of energy-efficient systems, such as smart HVAC and energy monitoring tools, to optimise energy consumption and promote sustainability in construction projects. This competency leverages digital technologies like BIM and Digital Twins to quantify and reduce the embodied energy and carbon footprint of buildings. By simulating multiple scenarios and evaluating design alternatives, it supports informed decisions on materials, systems, and components to minimise environmental impact. These practices ensure that construction projects align with sustainability goals while enhancing efficiency and reducing carbon emissions.*
- **K18. Sustainability Reporting and Monitoring:** Some definitions highlight the importance of tracking and reporting on the sustainability aspects of smart building projects to ensure environmental accountability (Rodrigues et al., 2023). Other perspectives focus on the need to be aware of the environmental impacts of digital technologies and their use, thereby emphasising the importance of protecting the environment (Vuorikari et al., 2022). These views collectively stress that effective sustainability reporting not only involves monitoring a project's ecological footprint but also communicating these impacts to inform decision-making.

  Based on these views, Sustainability Reporting and Monitoring includes *the process of tracking, analysing, and documenting the environmental performance of smart building projects to ensure transparency and alignment with sustainability goals. This competency includes assessing and reporting on the environmental impact of digital technologies and their use, as well as identifying opportunities to enhance sustainable practices. By fostering awareness of a project's ecological footprint, it supports informed decision-making and continuous improvement in achieving environmental and sustainability objectives.*
- **K19. Sustainable Construction Strategies:** Some sources emphasise the importance of being aware of sustainability concepts, highlighting that PMs must possess a solid understanding of environmental principles (Inguva et al., 2014). Others focus on the selection of sustainable materials for smart building construction, stressing that environmentally friendly material choices are essential to reduce the ecological footprint of projects (Rodrigues et al., 2023). These definitions together underscore that effective sustainability in construction requires both conceptual awareness and practical application of sustainable practices.

  Refining these perspectives, Sustainable Construction Strategies encompass *the ability to promote environmentally responsible practices and achieve long-term ecological balance in construction projects. This competency includes awareness of sustainability principles and the selection of environmentally friendly materials to minimise environmental impact. By integrating sustainable practices into design* *and construction processes, this competency supports the creation of smart buildings that align with ecological and sustainability goals.*

- **K20. Qualifications and Professional Development:** Several definitions highlight the importance of combining academic credentials and professional experience for effective project management. For instance, one perspective emphasises that this competency includes the attainment of formal education, such as a college degree, bachelor's, or advanced degrees like an MS, MA, or Ph.D., as well as professional certifications and qualifications (Uhm et al., 2017; Liu et al., 2022). Other definitions point to the significance of obtaining industry-specific credentials, such as BIM management certifications, Leadership in Energy and Environmental Design Accredited Professional (LEED AP), or the Royal Institute of British Architects (RIBA) Part I, and fulfilling licensing requirements that ensure compliance with construction standards (Uhm et al., 2017; Lee et al., 2021). Additionally, the requirement for substantial project experience, including years of hands-on involvement in construction projects, is noted as a key element for BIM managers and construction professionals (Hosseini et al., 2018).

  Based on these views, Qualifications and Professional Development refer to *the education, certifications, and professional licensing required to effectively manage construction projects. It includes formal academic degrees (bachelor's, master's, or doctoral qualifications), industry credentials such as BIM management, LEED AP, or RIBA certifications, and adherence to construction standards and regulatory frameworks. Furthermore, it emphasises the importance of practical project experience, ensuring that professionals meet industry standards and maintain competency throughout their careers while adapting to evolving construction practices.*
- **K21. Curriculum Development:** Some definitions highlight the importance of collaborating with academic institutions to develop specialised curricula, particularly focusing on data management, for students in construction-related programs (Atuahene et al., 2023). Other perspectives emphasise technical vocational education, outlining the need for robust training in disciplines such as architecture, civil engineering, mechanical, electrical, plumbing, HVAC, and drainage to prepare future professionals for the challenges of modern construction (Uhm et al., 2017).

  Drawing on these opinions, Curriculum Development can be comprehensively defined as *the process of collaborating with academic institutions to create and refine curricula tailored to the construction industry, with a focus on data management and technical skills. This involves designing courses that integrate industry best practices, hands-on training, and technical knowledge in disciplines such as architecture, civil engineering, mechanical, electrical, and plumbing systems, as well as HVAC and drainage. The goal is to equip students with the competencies needed to address modern construction challenges, fostering a workforce that is prepared for the evolving demands of the industry.*

Core Personality

- **CP1: Team Leadership in Digital Construction:** Various studies offer multiple perspectives on what constitutes effective team leadership in digital construction project management. Some definitions emphasise the capacity to manage multidisciplinary teams and align them with project goals (Liu et al., 2022;

Rodrigues et al., 2023), while others focus on the ability to lead, influence, and inspire people at all levels to foster team development and effectiveness (Uhm et al., 2017). Additional perspectives stress the importance of mentoring junior team members and providing guidance and support, as well as the ability to inspire a shared vision, challenge existing processes, and enable others to act (Inguva et al., 2014). Other definitions underscore the necessity for leaders to build and manage interdisciplinary teams, organise tasks equitably, and resolve conflicts effectively (Mesaros et al., 2020; Mandičák et al., 2020; Omer et al., 2022), with some also noting that traits such as fairness and an openness to new ideas can enhance team dynamics and overall project performance.

In line with these ideas, Team Leadership in Digital Construction incorporates *the ability to lead, inspire, and manage multidisciplinary teams to achieve project goals in a collaborative and inclusive digital work environment. This involves fostering trust, fairness, and open communication, enabling team members to contribute optimally while aligning with project objectives. Key aspects include building and managing effective interdisciplinary teams, mentoring and supporting junior team members, organising tasks equitably, and motivating individuals at all levels. Effective team leadership also requires resolving conflicts, inspiring a shared vision, challenging existing processes, and driving team development through clear standards and processes that enhance overall project performance.*

- **CP2: Stakeholder Leadership in Digital Construction:** Effective stakeholder management is a critical competency for construction PMs. Some definitions describe this competency as managing relationships with stakeholders, including users, government bodies, and owners, to ensure project success (Rodrigues et al., 2023). Other perspectives emphasise stakeholder relationship management by focusing on building strong, productive ties with external parties such as clients, owners, and government entities (Liu et al., 2022). Additionally, some studies highlight that BIM-based stakeholder management fosters collaboration among various stakeholders, enhances communication, reduces conflicts, and ultimately improves productivity, quality, and client satisfaction (Raza et al., 2023).

  The final comprehensive definition of Stakeholder Leadership in Digital Construction is *the ability to effectively manage relationships with diverse stakeholders, including clients, owners, government entities, and end users, to drive project success in a digital environment. This competency leverages digital technologies such as BIM to enhance collaboration, streamline communication, and integrate stakeholder roles, ultimately improving productivity, quality, and client satisfaction. It emphasises conflict resolution, fostering a collaborative culture, and ensuring transparent information sharing, thereby aligning all stakeholders with project goals and outcomes.*
- **CP3. Digital Self-Leadership and Emotional Agility:** Maintaining self-discipline, motivation, and emotional resilience is essential for construction PMs to navigate high-pressure digital environments. One perspective highlights the importance of self-motivation, emphasising the ability to take independent initiative, manage multiple projects autonomously, and work independently with sound judgment (Uhm et al., 2017). Another underscores adaptability, which allows professionals to respond effectively to evolving challenges and handle various situations flexibly. Additionally, stress management is a key factor in ensuring that individuals remain composed under pressure, enabling them to make objective and informed decisions (Inguva et al., 2014). Commitment to tasks fosters accountability and consistency in project execution, ensuring that all stakeholders

adhere to agreed-upon objectives. Furthermore, resilience plays a crucial role in maintaining mental well-being despite encountering challenges, promoting stability within project teams. Coping mechanisms such as emotional regulation and stress adaptation help individuals navigate complex project environments with confidence (Omer et al., 2022). Leaders must also demonstrate emotional intelligence, including the ability to appraise, express, and regulate emotions strategically to improve collaboration and team dynamics. Moreover, effective utilisation of emotional intelligence enhances communication, supports team cohesion, and strengthens problem-solving abilities in high-stress scenarios (Kissi et al., 2025).

Digital Self-Leadership and Emotional Agility can comprehensively define as *the ability to work independently, remain focused, and maintain composure in challenging situations while fostering a positive and digital productive work environment. This competency encompasses self-motivation, adaptability, and effective stress management to handle pressure and make sound decisions. It includes a strong commitment to work, resilience in overcoming adversity, and the employment of robust coping mechanisms to navigate complex projects. Furthermore, emotional intelligence plays a critical role in fostering collaboration, managing interpersonal dynamics, and leading with calmness, patience, and focus, ensuring consistent progress and balanced mental health.*

- **CP4. Decision-Making and Accountability:** Effective decision-making and a strong sense of responsibility are essential traits for successful leadership in construction project management. One perspective emphasises the fundamental ability to make decisions and take responsibility for outcomes within a project (Mesaros et al., 2020). Another highlights the concept of self-determination, where individuals who feel in control of their choices can lead effectively, improve their skills, and foster development within their teams (Omer et al., 2022). Additionally, making sound decisions that align with project goals and requirements is crucial for guiding a project to success. Furthermore, accepting accountability for these decisions ensures that leaders take ownership of both positive and challenging project outcomes (Mandičák et al., 2020). Moreover, the ability to tolerate ambiguity and navigate uncertainty allows leaders to make informed choices even when project information is incomplete or evolving (Kissi et al., 2025).

  By incorporating these perspectives, the final comprehensive definition of Decision-Making and Accountability is *the ability to make effective, timely decisions that align with project goals and requirements while taking accountability for outcomes. This competency includes demonstrating determination, accepting responsibility for actions, and fostering a sense of control over choices. A determined and responsible leader not only guides the project toward success but also inspires team members to improve, take ownership, and contribute to a positive and goal-oriented digital work environment.*
- **CP5. Team Well-Being Leadership:** Creating a supportive and psychologically safe work environment is a fundamental leadership competency, ensuring that team members feel valued, motivated, and resilient in the face of challenges. Research highlights that effective leaders promote well-being by demonstrating tolerance, minimising undue pressure, and fostering optimism within the team (Omer et al., 2022). Leaders must also show genuine concern for employees' mental and physical health, recognising that a balanced and healthy workforce contributes to project success. Furthermore, mutual understanding and empathetic communication play a crucial role in conflict resolution and maintaining a positive

team atmosphere, helping leaders create an inclusive and collaborative work culture.

By incorporating these perspectives, the final comprehensive definition of Digital Team Well-Being Leadership is *the ability of a leader to create a positive and supportive work environment that prioritises the mental, physical, and emotional health of team members. This includes fostering optimism by reducing undue pressure, showing concern for employee well-being, and encouraging open and empathetic communication to resolve conflicts. Leaders must also remain aware of team safety and workplace conditions, proactively addressing factors that influence morale and productivity. By doing so, they cultivate an environment where employees feel valued, engaged, and motivated, leading to improved team resilience and overall project success.*

- **CP6. Digital Team Communication and Collaboration:** Effective team communication and collaboration are fundamental competencies in construction project management, particularly in the context of digital environments. Some studies highlight the importance of coordinated communication between multidisciplinary teams to ensure seamless project execution (Rodrigues et al., 2023). Others emphasise the role of structured communication in project coordination, ensuring that tasks align with overall project objectives through clear information-sharing mechanisms (Liu et al., 2022). Additionally, fostering collaboration between construction professionals and data analytics experts has been identified as crucial for integrating BIM-based processes with decision-making frameworks (Atuahene et al., 2023). Further perspectives underscore the role of continual interaction with supervisors, peers, and clients in managing BIM logistics and tracking project progress effectively (Mandičák et al., 2020; Uhm et al., 2017). Moreover, communication is regarded as an essential leadership skill, facilitating cooperation, ensuring transparency, and enabling efficient information flow across all project levels (Mesaros et al., 2020; Omer et al., 2022).

  Drawing from these perspectives, Digital Team Communication and Collaboration is defined as *the ability to utilise digital collaboration tools to facilitate seamless communication among multidisciplinary teams, ensuring real-time coordination and transparency in construction projects. This competency involves managing digital tools, such as BIM-based communication workflows, coordinating project logistics digitally, and integrating structured reporting mechanisms that enhance efficiency. Furthermore, it supports effective collaboration between construction professionals and data-driven decision-makers, ensuring that project stakeholders remain aligned throughout the construction lifecycle. By leveraging digital tools as a centralised communication platform, this competency enhances project coordination, reduces miscommunication, and fosters a more cohesive and data-driven approach to teamwork.*
- **CP7. Digital Stakeholder Communication and Collaboration:** Effective stakeholder communication and collaboration are crucial for ensuring construction project success. One perspective highlights the importance of engaging with clients, government agencies, and owners to align project objectives with stakeholder expectations (Rodrigues et al., 2023). Another emphasises how BIM enhances project communication management by providing centralised, data-rich models that enable real-time information sharing, reducing ambiguities and conflicts (Raza et al., 2023). Additionally, strong interpersonal skills are essential for continuous interaction with stakeholders, allowing professionals to liaise directly with clients, coordinate project logistics, and report critical updates to

senior teams (Uhm et al., 2017). Establishing and maintaining professional relationships strengthens collaboration, facilitates document sharing, and ensures smooth project execution across different disciplines. Beyond technical capabilities, fostering social and interpersonal skills enhances teamwork, strengthens engagement, and builds productive working relationships (Kissi et al., 2025).

The final comprehensive definition for Digital Stakeholder Communication and Collaboration can be drawn as *the ability to establish and maintain strong, professional relationships with internal and external stakeholders, including clients, government agencies, owners, and project partners, to manage expectations and ensure project success. This competency leverages digital tools such as BIM to facilitate real-time information sharing, enhance collaborative decision-making, and streamline project coordination. Additionally, it encompasses fostering productive interpersonal relationships, ensuring trust, and creating a seamless communication flow across multidisciplinary teams, both digitally and in person.*

- **CP8. Digital Innovation and Creativity in Smart Construction:** A number of definitions outline this competency from different angles. One perspective emphasises the development of innovation strategies, focusing on creating frameworks that enable smart building projects to leverage cutting-edge tools (Rodrigues et al., 2023). Another highlights innovative thinking, where creative solutions are generated to overcome project challenges using digital technologies (Lukianov et al., 2021). Additional definitions stress the importance of developing new products, services, and procedures to strengthen business continuity and track BIM efforts, thereby enhancing overall project efficiency (Uhm et al., 2017). Furthermore, some studies underscore that creativity skills, characterised by the ability to innovate, generate novel solutions, and view challenges from fresh perspectives, are crucial for improving project outcomes (Kissi et al., 2025).

  Leveraging these viewpoints, Digital Innovation and Creativity in Smart Construction encompasses *the ability to develop strategies and cultivate a mindset within project teams that fosters creative problem-solving and the adoption of cutting-edge digital technologies. This competency involves leveraging tools like BIM to enhance efficiency, optimise workflows, and improve project outcomes, particularly within smart construction environments. It includes designing and implementing innovative products, services, and procedures that streamline operations, strengthen business continuity, and drive continuous improvement. By promoting innovative thinking and creative solutions, this skill enables construction professionals to advance modern practices and integrate digital technologies seamlessly into project workflows.*

In summary, the comprehensive digital competencies have been rigorously identified, classified, defined, and expert-validated through a SLR, thematic analysis, and LLM-based synthesis. These competencies have been categorised into three fundamental categories, Skills, Knowledge, and Core Personality, which together encapsulate the digital competencies essential for modern construction PM. Synthesising these insights, the next section presents the Next-Gen Digital PM Competency List for Construction, which integrates and organises all identified competencies into a cohesive model. This framework serves as a practical tool to assess and develop the digital proficiency required to navigate the evolving construction landscape successfully.

4.7 The Next-Gen Digital PM Competency List for Construction

Building on the comprehensive definitions and systematic categorisation of digital competencies developed in the previous sections, this section presents the Next-Gen Digital PM Competency List for Construction, as illustrated in Figure 4.15. This validated list integrates all identified and expert-validated competencies into a cohesive model, structured around three primary categories: Skills, Knowledge, and Core Personality. By providing a structured and evidence-based approach, the validated list serves as a practical tool for assessing and developing the digital competencies essential for construction PMs in today's technology-driven environment.

The list is designed to bridge the gap between traditional project management expertise and the evolving demands of digital transformation, ensuring that PMs are equipped with the necessary technical proficiency, strategic knowledge, and leadership attributes. Figure 4.15 visually represents the validated list, mapping each competency within its respective category and demonstrating its relevance to the digital competency development of PMs. This structured model not only supports the evaluation of existing competencies among PMs but also provides a foundation for targeted training programs, industry-wide competency development, and future research in digital construction project management.

NEXT-GEN Digital PM Competency List for Construction

Skills

- S1. Advanced Digital Technology Proficiency
- S2. Digital Technology Integration
- S3. Digital Building Performance Optimisation
- S4. Digital Communication and Interaction Strategies
- S5. Real-Time Digital Information Exchange
- S6. Digital Collaboration and Knowledge Retention
- S7. Digital Data Evaluation and Analytics
- S8. Cloud-Based Digital Content Management
- S9. Digital Content Development Skills
- S10. Advanced Digital Content Management
- S11. AI-Assisted Programming and Automation
- S12. Smart Construction Digital Tool Utilisation
- S13. Digital Technologies Training and Development
- S14. Smart Digital Documentation and Archiving
- S15. Digital Problem Solving and Technical Support
- S16. Digital Skills Gap Analysis and Development
- S17. Cybersecurity and Digital Device Protection
- S18. Digital Privacy and Data Protection Compliance
- S19. Emerging Technologies Cost Management
- S20. Real-Time Cost Optimisation and Digital Budgeting
- S21. Automated Digital Procurement Management
- S22. Digital Scheduling Management
- S23. Digital Resource Management
- S24. Digital Quality Control
- S25. Digital Scope and Change Management
- S26. Innovation Management in Digital Construction

Knowlادge

- K1: Advanced Digital Construction Knowledge
- K2: Emerging Technology Integration Knowledge
- K3: Smart Systems and Applications Knowledge
- K4. Digital Project Strategy and Goal Alignment
- K5. Digital Project Integrated Management
- K6. Digital Safety and Risk Mitigation
- K7. Digital Quality Assurance and Lifecycle Management
- K8. Contract and Negotiation Management
- K9. Regulatory and Compliance
- K10. Language Proficiency
- K11. Digital Information and Data Literacy
- K12. Digital Construction Risk Management
- K13. Digital Technology Adoption Risk Mitigation
- K14. Financial Risk Management
- K15. AI-Powered Data-Driven Decision-Making
- K16. Standardising Digital Technology Processes
- K17. Energy Efficiency and Carbon Management
- K18. Sustainability Reporting and Monitoring
- K19. Sustainable Construction Strategies
- K20. Qualifications and Professional Development
- K21. Curriculum Development

Core Personality

- CP1. Team Leadership in Digital Construction
- CP2. Stakeholder Leadership in Digital Construction
- CP3. Digital Self-Leadership and Emotional Agility
- CP4. Decision-Making and Accountability
- CP5. Team Well-Being Leadership
- CP6. Digital Team Communication and Collaboration
- CP7. Digital Stakeholder Communication and Collaboration
- CP8. Digital Innovation and Creativity in Smart Construction

Figure 4.15: Next-Gen Digital PM Competency List for Construction (Overview of the Three-Domain Model)

4.8 Limitations and Future Research Directions

This study is subject to several limitations that should be acknowledged. First, the SLR relied on a single database (Scopus), which, despite its extensive coverage, may have excluded relevant studies indexed in other databases such as Web of Science or domain-specific repositories. Second, the review was limited to English-language publications to ensure consistency in analysis and interpretation, which is common practice in SLR, although it may limit the inclusion of relevant studies published in other languages.

Third, although the SLR followed a rigorous and structured methodology, inherent limitations associated with literature reviews remain, including potential publication bias and reliance on previously published work. Fourth, the LLM-based synthesis process, although carefully controlled and restricted to literature-derived inputs, may still be influenced by model interpretation during the integration of multiple definitions. However, this risk was mitigated through strict prompt design, manual verification, and expert validation.

Additionally, the SLR was based on a relatively limited sample of 15 high-quality studies identified through the SLR, which, while ensuring depth and relevance, may not fully capture the breadth of digital competency perspectives across all construction contexts. Finally, the expert validation phase involved a limited number of domain experts, which, while sufficient for qualitative validation, may limit the generalisability of the findings. Furthermore, this chapter adopts a primarily conceptual and qualitative approach to competency identification and refinement; therefore, the findings require further empirical validation, which is undertaken in subsequent chapters using quantitative methods.

To address these limitations, future research should expand the scope of literature sources by incorporating multiple databases and non-English publications, where appropriate. Further studies are also recommended to validate the competency framework across different geographic regions, project types, and organisational contexts. In addition, expanding the expert validation process through a larger and more diverse panel would enhance the generalisability and robustness of the findings. Longitudinal and quantitative studies, including the use of SEM, are encouraged to assess the impact of digital competencies on project performance and organisational outcomes.

4.9 Conclusion

The digital transformation of the construction industry is redefining the role of Project Managers (PMs), requiring the integration of advanced digital tools, strategic leadership, and data-driven decision-making. This study developed a comprehensive validated list of digital competencies that bridges the gap between traditional project management expertise and emerging digital demands. Using a three-phase methodological approach, the research systematically identified, classified, and refined competencies essential for digital project management in the evolving construction sector. The Systematic Literature Review (SLR) extracted competencies from 15 high-quality academic sources, providing an evidence-based foundation. NVivo-assisted thematic analysis then structured these competencies into Skills, Knowledge, and Core Personality traits, aligning them with established competency models. In the final phase, Large Language Model (LLM)-based synthesis using GPT-4 consolidated and refined the definitions, resulting in a practical, expert-validated competency list.

All LLM-generated definitions underwent independent review by two domain experts in construction project management and digital transformation. This expert validation ensured clarity, accuracy, and industry relevance, with most definitions requiring only minor adjustments to improve specificity and applicability. The combination of AI-driven synthesis and human expertise produced a robust, industry-aligned list with strong credibility and practical utility. Figure 4.15 presents the Next-Gen Digital PM Competency List for Construction, consisting of 55 critical competencies that serve as a structured reference for enhancing digital capabilities in both industry and academia. In addressing RQ2, "*What are the emerging digital competencies required for project managers to excel in the evolving construction sector?*", this chapter has systematically identified, classified, and validated a comprehensive set of 55 digital competencies, thematically organised into the three domains of Skills, Knowledge, and Core Personality Traits. These outcomes directly inform the taxonomy classification in Chapter 5 and provide the empirical basis for quantitative testing in Chapter 6 and Chapter 7.

The findings show that digital transformation in construction extends beyond adopting technology; it represents a fundamental shift in how PMs manage projects, lead teams, and engage with stakeholders. The identified competencies highlight the importance of digital literacy, AI-assisted decision-making, data analytics, and automation expertise, alongside soft skills such as adaptive leadership, resilience, and change management. This balance of technical capabilities and leadership attributes reflects the multi-dimensional demands of digital project management and positions the validated list as a practical tool for guiding competency development in the sector.

This research contributes to the evolving discourse on digital transformation in construction project management by presenting a validated, industry-relevant competency list that is both actionable and adaptable. It emphasises the emergence of a new generation of digitally capable PMs able to lead transformation, integrate automation, and drive innovation. By aligning traditional competencies with digital transformation needs, the validated list provides a foundation for competency development, workforce training, and policy formulation. As digitalisation continues to reshape construction, ensuring that PMs possess the right blend of technical skills, strategic vision, and leadership capabilities will be critical to achieving sustainable growth, maintaining competitive advantage, and improving project performance in the digital era.

Overall, this chapter establishes a validated and structured foundation for advancing digital competency development in construction project management, supporting both academic inquiry and industry application.

Chapter 5 Integrating Rather Than Replacing: A Taxonomy of Project Manager Competencies for Construction's Digital Transformation

This chapter is extended from:

- Owais, O. A., Poshdar, M., Ghaffarian Hoseini, A., Ghaffarian Hoseini, A., & Kineber, A. F. (in press). *Digitally ready, competently aligned: A novel taxonomy classification of the next-gen digital project manager competency for construction*. *Proceedings of the Global Digital Innovation Conference (GDI 2025)*.

5.1 Abstract

As digital transformation accelerates across the construction industry, the competencies required of project managers (PMs) are undergoing profound restructuring. This chapter develops a taxonomy-based classification and integration of competencies that capture this shift, offering a structured model for digitally enabled PMs. Competencies were categorised into three overarching domains, Skills, Knowledge, and Core Personality Traits, creating a taxonomy that also served as a semi-validation of the Next-Gen Digital PM Competency List developed earlier.

Following the taxonomy construction, a conceptual comparative analysis was conducted to integrate traditional and digital competencies. The integration process identified three key outcomes: digitally enhanced competencies, newly emerged digital competencies, and the re-contextualisation of traditional competencies, with none remaining fully unchanged. The findings reveal that while many foundational PM competencies, such as communication, risk management, and leadership, continue to be vital, they now demand augmentation through digital technologies like BIM, AI, and cloud-based collaboration systems. In parallel, a new set of digital competencies has emerged, including cybersecurity management, AI-powered decision-making, and sustainability analytics, which have no traditional equivalents.

These outcomes affirm that although technological contexts are evolving rapidly, human-centric attributes such as ethical leadership, emotional agility, and stakeholder engagement remain irreplaceable. The taxonomy-based integration presented in this chapter provides both a conceptual and practical foundation for future empirical validation, offering critical insights for workforce development, digital upskilling, and competency framework design to meet the demands of the evolving digital construction sector.

5.2 Introduction

The construction industry is undergoing an unprecedented shift driven by digital transformation, fundamentally altering project management practices. Unlike digitalisation, which focuses on the application of digital tools to enhance workflows, such as Building Information Modelling (BIM), project management software, and automation technologies (Parviainen et al., 2017), digital transformation represents a systemic change that integrates advanced technologies into all aspects of project execution, stakeholder collaboration, and decision-making (Vial, 2021). This shift extends beyond process optimisation, requiring a fundamental rethinking of strategic leadership, competency development, and organisational culture to accommodate emerging innovations such as Artificial Intelligence (AI), the Internet of Things (IoT), robotics, and Digital Twin (DT) technologies (Sacks et al., 2020; Whyte, 2019). Consequently, construction Project Managers (PMs) must expand their competencies beyond conventional project management knowledge to effectively navigate digital transformation in the Architecture, Engineering, and Construction (AEC) industry.

Competency models in construction project management have traditionally followed structured classifications that segment competencies into technical skills, knowledge domains, and behavioural or leadership attributes (IPMA, 2015b; PMI, 2021b). Taxonomy-based classification provides a structured framework for organising competencies into hierarchical, well-defined categories, enabling a logical and systematic approach to competency development (Nickerson et al., 2013). In competency research, taxonomies are widely used to classify skills, knowledge, and behavioural attributes, ensuring competencies are appropriately grouped for professional training, workforce development, and academic curricula (Winterton et al., 2006). In construction project management, established models such as the PMBOK Guide (PMI, 2021b), the IPMA Competency Framework (IPMA, 2015b), and the Project Manager Competency Development Framework (PMI, 2017b) categorise competencies into structured domains such as project execution, stakeholder engagement, cost management, and risk assessment. However, while these frameworks establish a foundational competency structure, they do not integrate emerging digital competencies necessary for managing smart construction environments (Rodrigues et al., 2023; Mandičák et al., 2020).

Despite significant advancements in construction technology and digitalisation, no prior research has systematically classified traditional and digital competencies into a unified taxonomy. Existing competency models typically focus on either traditional competencies or digital skill sets in isolation, rather than providing an integrated structure that reflects the demands of digital transformation in construction project management. While some studies have identified key competencies required for digital PMs (Liu et al., 2022; Atuahene et al., 2023), these works primarily highlight individual competencies rather than classifying them into a structured taxonomy that aligns with traditional PM competencies. Additionally, prior research, such as “Towards a Taxonomy for Project Management Competences,” has established taxonomies for traditional project management competencies but does not incorporate digital competencies (Nijhuis et al., 2015). Similarly, research like “Digital Era and Project Manager’s Competences” highlights competencies essential for managing projects in the digital era but does not integrate them with traditional competencies into a single taxonomy (Obradović et al., 2018).

Furthermore, prior studies such as Merschbrock and Munkvold (2015) demonstrate how BIM and digital tools can enhance collaboration in construction projects, particularly through case-based implementations. However, broader digital transformation models like the Avanti Project and Integrated Project Delivery (IPD) frameworks (e.g., Papadonikolaki & Morgan (2020)) have primarily focused on process optimisation rather than systematically categorising the competencies required for PMs. Likewise, studies on competency development in smart construction (Kissi et al., 2025; Rodrigues et al., 2023) outline essential digital skill requirements but do not systematically integrate them with traditional PM competencies within a unified taxonomy. Additionally, broader taxonomies of competence models, such as those discussed by Voogt and Roblin (2012), categorise general competence models but do not specifically address the integration of traditional and digital competencies for PMs in construction. Given these gaps, this research presents a first-of-its-kind taxonomy that systematically integrates traditional and digital PM competencies. Unlike previous studies that address traditional and digital competencies separately, this research emphasises integration rather than replacement, ensuring that digital advancements complement, rather than displace, conventional project management expertise (Atuahene et al., 2023; Rodrigues et al., 2023).

To address this research gap, this chapter focuses on the following Research Question 3 (RQ3): *How can traditional and emerging digital competencies be systematically integrated into a taxonomy-based classification that reflects construction's digital transformation needs?* To answer this question, this chapter builds upon previous research phases to establish a comprehensive taxonomy-based competency framework that integrates both traditional and digital competencies. The first research phase identified traditional PM competencies through an extensive literature review, drawing from industry standards such as PMI, PMBOK, and PMCD, as outlined in Chapter 3. The second phase identified Next-Gen Digital PM Competency List in construction through a Systematic Literature Review (SLR), Thematic Analysis, and Large Language Models (LLMs), highlighting newly emerging digital competencies relevant to digital transformation, as discussed in Chapter 4. The third phase, which is the focus of this chapter, systematically integrates traditional and digital competencies into a structured taxonomy, reflecting the evolving role of construction PMs in the digital era.

To achieve this integration, taxonomy-based classification is employed as the primary method for structuring competencies into a hierarchical framework, ensuring that competencies are categorised into Skills, Knowledge, and Core Personality Traits (Mikhridinova et al., 2024). The taxonomy-based approach allows for logical competency grouping, ensuring alignment with digital workflows and evolving project management methodologies (Nickerson et al., 2013). Additionally, comparative analysis is utilised to map traditional competencies against their digital adaptations, identifying integration points and ensuring a structured classification (Nijhuis et al., 2015; Mikhridinova et al., 2024). This structured approach ensures logical alignment based on criteria such as functionality, adaptability, and relevance to digital workflows (Mikhridinova et al., 2024; Voogt & Roblin, 2012).

The competency taxonomy developed in this study provides a practical model that serves multiple stakeholders. For PMs, it offers a structured roadmap for career progression and digital upskilling; for construction firms, it functions as a training and recruitment framework aligned with digital transformation initiatives; and for academia and policymakers, it presents a competency-driven educational and certification model that meets evolving industry needs (Mandičák et al., 2020). By integrating BIM-driven collaboration, AI-powered risk management, automation-based scheduling, and data-informed decision-making, this competency taxonomy equips PMs with the essential skills to navigate digital transformation in the construction sector. This structured integration ensures that PMs remain competitive in an industry increasingly driven by data, automation, and digital collaboration (Mesaros et al., 2020).

The following sections systematically build the chapter's contribution. Section 5.3 reviews the background of PM competency integration within the context of construction's digital transformation. Section 5.4 outlines the method for taxonomy development and the structured comparative analysis approach. Section 5.5 presents the taxonomy-based classification of Next-Gen Digital PM Competencies across three domains: Skills, Knowledge, and Core Personality Traits. Section 5.6 integrates traditional and digital competencies through a structured conceptual comparative analysis. Section 5.7 offers a broader interpretation of the integration outcomes, synthesised through a pyramid framework that highlights key findings. Section 5.8 discusses limitations and future research directions. Finally, Section 5.9 concludes the chapter by reinforcing the strategic and academic significance of the developed taxonomy for advancing competency development in the digital construction era.

5.3 Project Manager Competency Integration Background

The construction industry's digital transformation has significantly reshaped project management practices, necessitating an evolution in required competencies. Several studies have explored the competencies required for digital PM in construction, proposing various frameworks and models. However, a comprehensive taxonomy that systematically integrates both traditional and digital competencies specific to construction PMs remains underdeveloped.

Existing frameworks, such as those outlined by the Project Management Institute (PMI) and the Project Management Body of Knowledge (PMBOK), categorise competencies into technical, behavioural, and contextual domains (PMI, 2021b). Similarly, the International Project Management Association (IPMA) Competence Baseline offers a comprehensive set of competencies but does not fully address the integration of digital technologies into project management practices (IPMA, 2015b). While these models provide a structured approach to competency development, they do not define how traditional competencies should evolve in response to digital transformation (Samuelson & Stehn, 2023).

The rapid adoption of BIM, AI, and the IoT has transformed traditional construction practices. BIM enables collaborative project environments, improving coordination and minimising rework (Oesterreich & Teuteberg, 2016). However, despite the increasing reliance on digital tools, PMs often lack clearly defined digital competencies that align with traditional PM responsibilities. Without a structured competency taxonomy, PMs may struggle to adapt their existing skills to digital workflows.

Several studies have attempted to address this gap by proposing digital competency models for PMs in the construction sector. For instance, Liu et al. (2022) developed a competence model for digital PMs, aligning traditional competencies with the demands of digital transformation. Their study introduced the *"Diamond Model,"* which incorporates digital capability as an additional dimension alongside traditional competencies. This model categorises digital competencies into three levels: technology, knowledge, and management, emphasising the layered and multifaceted nature of digital expertise. However, while the Diamond Model enhances the understanding of digital PM capabilities, it does not establish a structured taxonomy that systematically integrates both traditional and digital competencies into a unified framework.

Recent research has attempted to classify digital competencies in construction, but these efforts remain isolated from traditional PM frameworks. For instance, Siddiqui et al. (2023) developed a taxonomy of 35 digital skills through a systematic literature review (SLR), categorising essential competencies into areas such as automation, coding, modelling, data acquisition, and digital literacy. However, this taxonomy focuses broadly on digital skills across various construction roles rather than providing a structured competency framework specifically tailored to PMs. Similarly, a study by Obradović et al. (2018) discusses the growing need for digital skills integration in project management but does not provide a taxonomy-based classification that systematically merges traditional and digital PM competencies into a unified structure.

Another study by Zulu and Khosrowshahi (2021) proposed a taxonomy of digital leadership approaches in construction, categorising leadership competencies into six themes: proactive, reactive, innovative, integrative, adaptive, and supportive. This taxonomy provides a structured classification of leadership strategies in digital environments but does not map traditional PM leadership competencies to digital leadership in a unified competency taxonomy.

A SLR by Rodrigues et al. (2023) evaluated the impact of PMs' competencies on project success, emphasising the need for a balanced skill set combining technical expertise, managerial competencies, communication skills, leadership qualities, and technological proficiencies. However, this study did not develop a structured taxonomy that unifies traditional and digital competencies into a cohesive classification.

Although some taxonomies related to digital skills in construction exist, they do not integrate traditional PM competencies into a unified framework. The lack of an integrated taxonomy creates challenges for both practitioners and educators. For practitioners, the absence of a clear, comprehensive competency framework makes it difficult to identify and develop the necessary skills for managing digitally enabled construction projects. For educators, the absence of an integrated model hinders the development of competency-based curricula that effectively prepare future PMs for the evolving demands of digital transformation.

Despite significant advancements in competency research, no existing study has developed a hierarchical taxonomy that systematically merges traditional and digital PM competencies within the construction sector. Most research either categorises traditional competencies or focuses solely on digital skills but fails to integrate both into a structured, unified taxonomy.

This study aims to fill this gap by developing a taxonomy-based classification that systematically integrates traditional and digital PM competencies for construction project management. By establishing a structured and coherent competency framework, this research provides PMs with the ability to better adapt to digital transformation, ensuring they possess a balanced skill set those merges foundational project management practices with emerging digital competencies.

5.4 Method

The ongoing digital transformation in the construction industry is reshaping the role of PMs, requiring an expanded and adaptive set of competencies. This chapter presents the methods used to develop a taxonomy-based classification and comparative integration that systematically merges traditional PM competencies with emerging digital competencies. The aim is to establish a structured, hierarchical taxonomy that reflects the evolving competency requirements of PMs operating in digitally enabled construction environments.

The competencies used in this classification are derived from the previous research phases. Traditional competencies were extracted from established industry standards, including PMI's A Guide to the Project Management Body of Knowledge (PMBOK) and the IPMA Individual Competence Baseline, as discussed in Chapter 3. Digital competencies were identified through a SLR, Thematic Analysis, and LLM refinement, as outlined in Chapter 4. Therefore, this chapter does not introduce new primary data but applies a two-phase method: (1) taxonomy-based classification to categorise the Next-Gen Digital PM Competency List into Skills, Knowledge, and Core Personality Traits, and (2) conceptual comparative analysis to align traditional PM competencies with their digital counterparts based on functionality, relevance, and adaptability. This methodological sequence is illustrated in Figure 5.1.

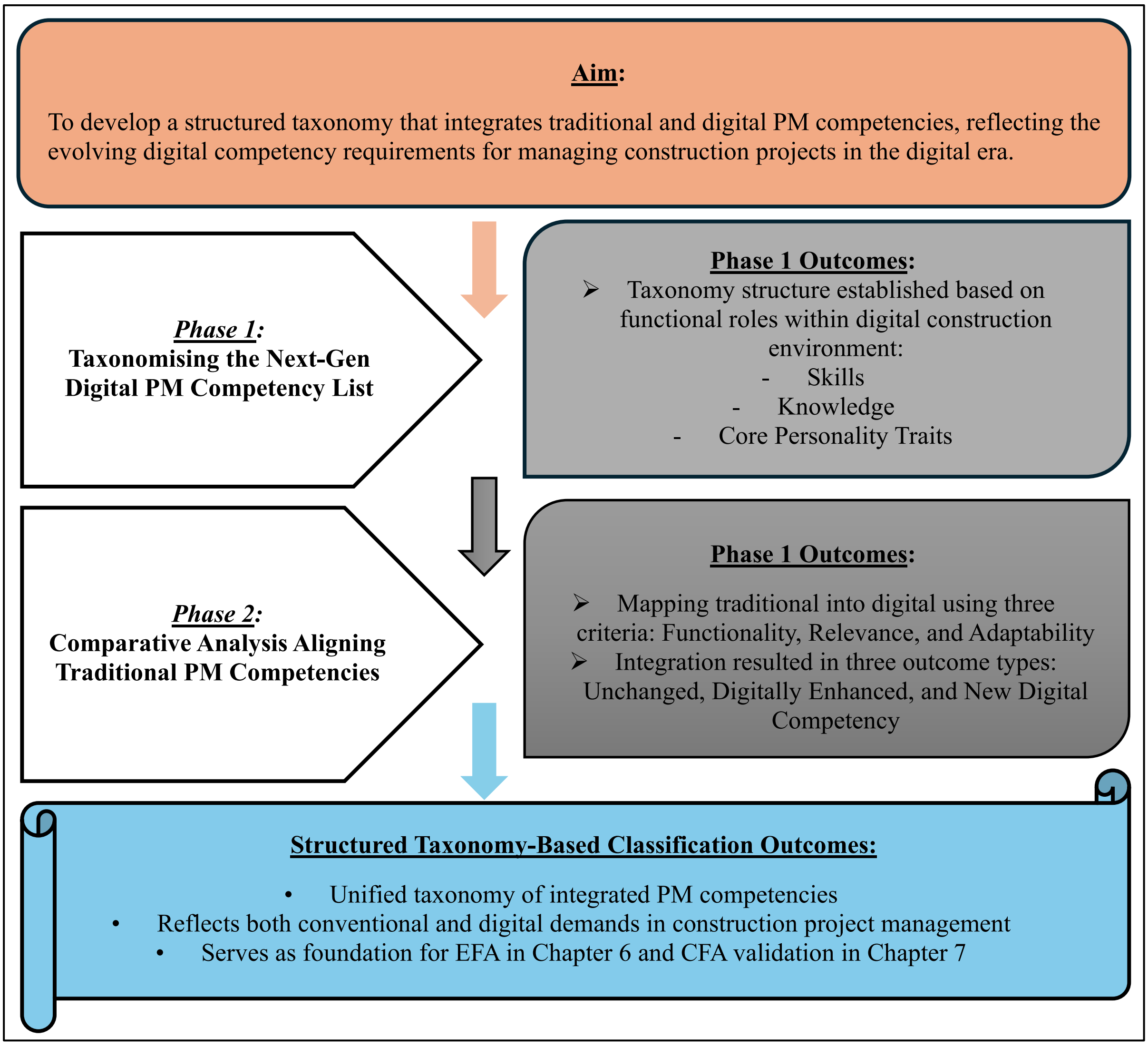


Figure 5.1: Two-Phase Method for Developing an Integrated Taxonomy of Digital PM Competencies

The *first phase* involves the taxonomy-based classification of digital PM competencies. A taxonomy, as defined by Nickerson et al. (2013), is a formal system for classifying entities into groups based on shared characteristics, typically organised hierarchically. In competency research, taxonomy-based classification provides a structured, consistent, and logical way to organise complex skill sets into categories that are easier to interpret, apply, and assess. This method has been widely used in workforce development and educational contexts to improve clarity and application in training design, certification, and professional development National Research Council, 2012). In this study, the taxonomy is first applied exclusively to the Next-Gen Digital PM Competency List identified in Chapter 4. These are organised into three overarching domains, as shown in Table 5.1.

Table 5.1: Digital Competency Functional Role Taxonomy Categorisation

Domain	**Definition**
Skills	Functional and technical abilities required to operate within digital project environments
Knowledge	Theoretical and domain-specific understanding of digital tools and systems

Core Personality Traits	Behavioural and leadership qualities needed to manage digitally enabled teams and processes

This classification ensures that digital competencies are grouped meaningfully based on their role in project management practices, allowing them to serve as the structural base for the integration that follows.

The *second phase* involves a comparative analysis to integrate the traditional PM competencies into the digital taxonomy developed in the first phase. Comparative analysis is an established method for identifying similarities, differences, and relationships between entities, in this case, between traditional and digital competencies (Hantrais, 2009). It allows for systematic mapping by assessing conceptual overlap, transformation, or distinction. The comparative process in this study is guided by the criteria and integration outcomes outlined in Table 5.2.

Table 5.2: Comparative Criteria and Integration Outcomes

Integration Outcome	**Definition**	**Guiding Criteria**	**Example**
Unchanged Competency	Traditional competencies that remain fully relevant without the need for digital adaptation	High relevance, no need for digital enhancement	Leadership, ethics, conflict resolution
Digitally Enhanced Competency	Traditional competencies that have been updated, expanded, or adapted through digital technologies and workflows	High functionality, high relevance, adaptability to digital contexts	Communication as BIM-enabled coordination; risk management as AI-based forecasting
New Digital Competency	Competencies that emerge solely from digital transformation, with no traditional equivalent	High functionality, no traditional predecessor	AI-based decision-making, cybersecurity, real-Time collaboration

By aligning competencies through comparative analysis, the resulting taxonomy maintains the relevance of traditional project management knowledge while embedding the new digital competencies required to manage construction projects in technologically advanced environments.

The output of this method, section 5.6, is a structured classification of integrated competencies that captures the transformation of PMs' practice. It is important to clarify that the result is a taxonomy, not a competency framework. The classification developed here does not establish interrelationships, performance indicators, or operational models. Instead, it serves as the foundation for the development of the measurement model in the next Chapter 6, where Exploratory Factor Analysis (EFA) will be applied to uncover underlying latent constructs. This will be followed by Confirmatory Factor Analysis (CFA) in Chapter 7, as part of the validation phase, to confirm the structure and assess the reliability and construct validity of the integrated competency taxonomy.

This chapter thus plays a critical transitional role, bridging the identification of competencies in Chapter 3 and Chapter 4 with the empirical modelling and validation stages in Chapter 6 and Chapter 7. Through the dual process of taxonomy-based classification and comparative integration, a unified and logically structured competency taxonomy is developed, reflecting the real-world challenges of PM in a digitally transformed construction industry.

5.5 Taxonomising the Next-Gen Digital PM Competency List

This section presents the taxonomy-based classification of the Next-Gen Digital PM competencies identified in the previous chapter. While Chapter 4 focused on synthesising and defining individual competencies through a SLR, Thematic Analysis, LLM-driven definition refinement, and expert validation, the current section shifts the focus to organising these competencies within a structured taxonomy. The goal is to classify the competencies into three overarching domains, Skills, Knowledge, and Core Personality Traits, based on their functional roles in digital project management practice. This phase also serves as a semi-validation of the Next-Gen Digital PM Competency List by providing a logical structure that reinforces its conceptual clarity and domain relevance.

To ensure methodological rigour, the classification process follows established taxonomy development frameworks (Nickerson et al., 2013; Mikhridinova et al., 2024). A content-driven classification approach was used to assess each competency according to the taxonomy criteria outlined in Table 5.1: Digital Competency Functional Role Taxonomy Categorisation. These criteria differentiate between operational or functional capabilities (Skills), cognitive or conceptual understanding (Knowledge), and behavioural or interpersonal attributes (Core Personality Traits).

Each competency was evaluated based on its primary descriptive focus, whether action-oriented, theoretical, or behavioural, and mapped accordingly to its respective domain. This ensures transparency, internal consistency, and alignment with research conventions in digital transformation and project management (Zulu & Khosrowshahi, 2021; Obradović et al., 2018). While interrelationships between competencies will be empirically tested in Chapter 6 through EFA, the current taxonomy provides a structured foundation by delineating the distinct roles these competencies play in the evolving digital construction landscape.

The classification results are presented in Tables 5.3, 5.4, and 5.5. Each table contains two columns: Competency Name and Justification for Categorisation. The justification explains how each competency aligns with one of the three domains based on the taxonomy definitions introduced in Table 5.1. This section does not reproduce the full competency definitions presented in Chapter 4, but instead offers a structured lens to support interpretation, application, and further model development.

For the Skills domain, competencies are classified based on their functional and technical contributions to digital project environments. These include digital tool proficiency, automation, collaborative technology usage, and task execution in smart workflows, as illustrated in Table 5.3.

Table 5.3: Skills – Functional and Technical Abilities

Competency Name	**Justification for Categorisation**
S1. Advanced Digital Technology Proficiency	Emphasises the application of digital tools such as BIM, AutoCAD, and PM platforms to execute project tasks, clearly reflecting operational and technical capacity.
S2. Digital Technology Integration	Involves the coordination and deployment of digital technologies like IoT and BIM in project environments, directly serving functional roles in digital workflows.
S3. Digital Building Performance Optimisation	Utilises tools to assess and optimise building systems and performance, supporting digital construction through hands-on technical functions.
S4. Digital Communication and Interaction Strategies	Relies on digital platforms to facilitate stakeholder communication and team interaction, indicating a practical execution-focused skill.

S5. Real-Time Digital Information Exchange	Enables data and content sharing using collaborative digital systems, reinforcing operational collaboration in digital projects.
S6. Digital Collaboration and Knowledge Retention	Supports co-creation and sharing through digital tools such as BIM or cloud platforms, representing an actionable coordination competency.
S7. Digital Data Evaluation and Analytics	Focuses on data validation and interpretation for digital decision-making, demanding technical skill in managing digital datasets.
S8. Cloud-Based Digital Content Management	Centres on the management and access of structured content in shared environments, a function-critical digital skill.
S9. Digital Content Development Skills	Includes content creation using modern digital tools, indicating hands-on engagement with project materials and communication content.
S10. Advanced Digital Content Management	Involves revising and adapting existing content for project-specific needs, showcasing process-oriented technical skills.
S11. AI-Assisted Programming and Automation	Applies programming to automate tasks and processes in construction, clearly rooted in technical execution.
S12. Smart Construction Digital Tool Utilisation	Focuses on the functional use of specialised digital tools and platforms, such as CAD and BIM, for simulation, modelling, and project visualisation in construction environments.
S13. Digital Technologies Training and Development	Involves delivering training and coaching through digital systems, contributing directly to technical skill dissemination.
S14. Smart Digital Documentation and Archiving	Manages documentation digitally with structured systems, reflecting a procedural, tool-based competency.
S15. Digital Problem Solving and Technical Support	Addresses digital system errors and task obstacles, requiring functional troubleshooting abilities.
S16. Digital Skills Gap Analysis and Development	Identifies and addresses team digital proficiency needs, a task-specific application of digital development.
S17. Cybersecurity and Digital Device Protection	Implements tools to protect devices and systems from threats, functionally grounded in digital security execution.
S18. Digital Privacy and Data Protection Compliance	Applies data governance rules in digital environments, involving regulatory tools and protocols.
S19. Emerging Technologies Cost Management	Manages budgeting for high-tech construction tools, reflecting applied cost control functionality.
S20. Real-Time Cost Optimisation and Digital Budgeting	Employs advanced digital tools like 5D BIM for budgeting and planning, highlighting live digital control of costs.
S21. Automated Digital Procurement Management	Uses automation tools to plan and manage procurement operations, showing technical workflow control.
S22. Digital Scheduling Management	Synchronises project activities using digital tools such as BIM for timeline control, grounded in digital coordination practices.
S23. Digital Resource Management	Allocates and monitors resource usage using digital platforms, aligned with operational workforce and material control.
S24. Digital Quality Control	Audits quality using digital simulations and monitoring, functionally linked to defect reduction and real-time checks.
S25. Digital Scope and Change Management	Tracks scope modifications digitally, integrating change controls into ongoing workflows.
S26. Innovation Management in Digital Construction	Implements and coordinates innovation through emerging tools, a competency executed in project systems.

For the Knowledge domain, competencies reflect cognitive, theoretical, or domain-specific expertise in digital systems, integration strategies, and data management. These capabilities underpin strategic thinking, compliance, risk mitigation, and technology planning, as presented in Table 5.4.

Table 5.4: Knowledge – Theoretical and Domain-Specific Understanding

Competency Name	**Justification for Categorisation**
K1. Advanced Digital Construction Knowledge	Involves conceptual understanding of smart technologies and construction practices.
K2. Emerging Technology Integration Knowledge	Requires theoretical insight into how new technologies can be applied.
K3. Smart Systems and Applications Knowledge	Represents domain-specific knowledge of advanced software systems such as BIM and DT, including their core functions and application in digital construction workflows.
K4. Digital Project Strategy and Goal Alignment	Strategic knowledge aligning project tasks with organisational goals.
K5. Digital Project Integrated Management	Understanding of how to unify multidisciplinary inputs using technology.
K6. Digital Safety and Risk Mitigation	Involves theoretical knowledge of safety frameworks and digital tools for risk control.
K7. Digital Quality Assurance and Lifecycle Management	Conceptual management of lifecycle data and quality performance.
K8. Contract and Negotiation Management	Relates to procedural and legal knowledge for managing project agreements.
K9. Regulatory and Compliance	Involves awareness of laws, technical codes, and regulatory requirements.
K10. Language Proficiency	Cognitive and linguistic knowledge required for stakeholder communication.
K11. Digital Information and Data Literacy	Understanding of how to access, filter, and interpret digital content.
K12. Digital Construction Risk Management	Conceptual frameworks for anticipating and mitigating construction risks.
K13. Digital Technology Adoption Risk Mitigation	Strategic awareness of challenges with emerging tech adoption.
K14. Financial Risk Management	Knowledge of how digital adoption affects budgeting and financial planning.
K15. AI-Powered Data-Driven Decision-Making	Involves interpreting data to inform strategic and technical decisions.
K16. Standardising Digital Technology Processes	Theoretical focus on procedural consistency and workflow standardisation.
K17. Energy Efficiency and Carbon Management	Conceptual knowledge of energy systems and sustainability targets.
K18. Sustainability Reporting and Monitoring	Understanding of how to monitor and communicate environmental data.
K19. Sustainable Construction Strategies	Strategic knowledge for applying green building practices.
K20. Qualifications and Professional Development	Knowledge about professional standards and learning pathways.
K21. Curriculum Development	Involves designing knowledge-driven educational content for training.

For the Core Personality Traits domain, competencies relate to behavioural qualities and leadership competencies that influence team performance, interpersonal engagement, and resilience in dynamic digital environments, as outlined in Table 5.5.

Table 5.5: Core Personality Traits – Behavioural and Leadership Qualities

Competency Name	**Justification for Categorisation**
CP1. Team Leadership in Digital Construction	Emphasises behavioural leadership capacity to inspire, manage, and align interdisciplinary teams in digital contexts.
CP2. Stakeholder Leadership in Digital Construction	Involves interpersonal leadership and relationship management with diverse external stakeholders using digital platforms.
CP3. Digital Self-Leadership and Emotional Agility	Focuses on internal behavioural regulation, emotional resilience, and independent decision-making under digital pressures.
CP4. Decision-Making and Accountability	Represents behavioural responsibility and ethical judgement in navigating complex digital environments and decisions.
CP5. Team Well-Being Leadership	Demonstrates psychological safety, empathy, and inclusive leadership, ensuring mental and emotional health in teams.
CP6. Digital Team Communication and Collaboration	Reflects interpersonal effectiveness and behavioural skills required to manage digital communication and collaboration within teams.
CP7. Digital Stakeholder Communication and Collaboration	Captures relational and emotional intelligence for managing digital communication with external partners and stakeholders.
CP8. Digital Innovation and Creativity in Smart Construction	Reflects behavioural adaptability and creative leadership required to foster innovation, generate novel solutions, and lead digital transformation in construction environments.

This taxonomy-based classification supports and extends the comprehensive Next-Gen Digital PM Competencies developed earlier by offering a structured, interpretable model for practical use. Categorising competencies by their functional role provides a foundation for training programs, recruitment strategies, digital upskilling initiatives, and curriculum development in construction project management.

Finally, this taxonomy phase functions as a semi-validation step for the competency list by confirming the internal consistency and logical alignment of each item within its domain. It ensures that each competency meaningfully contributes to the broader model and lays the groundwork for empirical testing through EFA in Chapter 6.

5.6 Integrating Traditional and Digital Competencies

This section presents the integration of traditional PM competencies with the Next-Gen Digital PM Competencies through a structured conceptual comparative analysis. Building upon the taxonomy-based classification developed in Section 5.5, the goal is to identify logical intersections, enhancements, and new additions that reflect the evolving role of PMs in digitally enabled construction environments. This integration clarifies how core competencies from traditional PM practice remain relevant, are digitally enhanced, or are complemented with newly emerged digital competencies arising from technological advancements in the construction sector.

The integration process draws on the outcomes from earlier competency identification stages and applies the comparative method introduced in the Method section. Rather than duplicating full definitions, this section uses a structured integration framework to map traditional PM competencies to their digital counterparts and categorise them based on conceptual relevance and functional role. This approach goes beyond textual similarity and instead considers the operational, cognitive, or behavioural focus of each competency.

This study adopts a conceptual comparative analysis approach, defined as the systematic evaluation of two or more sets of constructs (in this case, traditional and digital PM competencies) based not solely on surface-level similarities, but on their functional role, thematic focus, and relevance within a given operational context. This ensures integration outcomes are grounded in both practical relevance and theoretical coherence (Ridder, 2014; Hantrais, 2009).

Each traditional competency was assessed according to its role in digitally enabled construction workflows and matched, where applicable, to a digital counterpart. Based on this comparative process, three integration outcomes were defined, as outlined in Table 5.2:

- Unchanged Competency: Traditional competencies that remain fully relevant in the digital era.
- Digitally Enhanced Competency: Traditional competencies that have been updated or enhanced through digital tools or platforms.
- New Digital Competency: Competencies that emerge exclusively from digital transformation and have no traditional equivalent.

The integration outcomes are presented in Tables 5.6, 5.7 and 5.8 corresponding to the taxonomy domains introduced in Section 5.5 as Skills, Knowledge, and Core Personality Traits. Each table includes four columns: Traditional Competency, Digital Competency, Integration Outcome, and Justification. Where no traditional counterpart exists, the entry under Traditional Competency is marked as Not Applicable (N/A), indicating a newly emerged digital competency introduced by digital transformation in the construction sector. The integration analysis reveals key trends across the competency domains.

The integration analysis reveals key trends across the competency domains. The comparative mapping process also revealed several key misalignments between traditional and digital competencies. First, many traditional competencies lacked explicit digital context, particularly in areas such as communication, coordination, and decision-making, which are increasingly mediated through digital platforms (e.g., BIM, cloud systems, and AI tools). Second, digital competencies identified in earlier phases were often fragmented and technically oriented, lacking integration with core project management functions. Third, several critical competencies, including AI-assisted decision-making, cybersecurity, data governance, and digital privacy, were entirely absent from traditional frameworks, as evidenced in Tables 5.6, 5.7, and 5.8, where these are classified as newly emerged competencies (N/A). These misalignments were systematically addressed through the taxonomy by categorising competencies as digitally enhanced or newly emerged, ensuring that traditional competencies were contextually extended while incorporating new competencies required for digitally enabled construction practice.

The integration of Skills competencies focuses on functional and technical abilities related to digital project execution, including software use, modelling, automation, and real-time collaboration. This mapping reveals how certain traditional competencies retain operational value, others evolve through the use of digital tools, and some digital skills emerge entirely anew in response to advanced technologies. Table 5.6 illustrates how these Skills competencies are aligned within the integrated taxonomy.

Table 5.6: Skills Integration

Technical Competency	**Digital Competency**	**Integration Outcome**	**Justification**
Computer Proficiency in Project Management	S1. Advanced Digital Technology Proficiency	Digitally Enhanced	While the foundational computer proficiency is still relevant, the digital competency elevates the skill to an advanced, construction-specific, and integrated digital environment.
Tool and Technique Application	S2. Digital Technology Integration	Digitally Enhanced	The competency evolves from simply applying individual tools to orchestrating digital ecosystems that enhance project workflows, performance, and innovation.
N/A	S3. Digital Building Performance Optimisation	Newly Emerged	A novel digital capability focused on lifecycle-based performance monitoring and maintenance using simulation and BIM tools.
N/A	S4. Digital Communication and Interaction Strategies	Newly Emerged	Addresses communication across virtual platforms with emphasis on bridging technical and non-technical stakeholders, absent in traditional competencies.
Project Information Management	S5. Real-Time Digital Information Exchange	Digitally Enhanced	The traditional practices of information management are preserved but amplified through dynamic real-time digital environments, offering superior efficiency, accessibility, and collaboration capabilities.
N/A	S6. Digital Collaboration and Knowledge Retention	Newly Emerged	Focuses on preserving institutional knowledge and lessons learned via digital platforms, an emerging concern in digital PM environments.
Cognitive Analysis, Data Gathering, and Information Synthesis	S7. Digital Data Evaluation and Analytics	Digitally Enhanced	The traditional competency remains foundational, but it is significantly empowered by digital capabilities, providing higher speed, accuracy, and depth of cognitive analysis through technology.
N/A	S8. Cloud-Based Digital Content Management	Newly Emerged	Reflects current need for structured digital repositories, cloud systems, and real-time reporting, absent in conventional PM frameworks.
N/A	S9. Digital Content Development Skills	Newly Emerged	A new competency targeting creative output across digital formats, essential for communication and design in smart environments.
N/A	S10. Advanced Digital Content Management	Newly Emerged	Introduces skillsets for editing, adapting, and refining digital content, critical in evolving project needs and iterative workflows.
N/A	S11. AI-Assisted Programming and Automation	Newly Emerged	A newly developed competency focusing on creating and utilising automated systems and coding to streamline project workflows, without a direct traditional PM equivalent.
N/A	S12. Smart Construction	Newly Emerged	A newly emerged competency reflecting specialised functional applications and tools such

	Digital Tool Utilisation		as CAD/BIM software, simulation tools, and advanced platforms for digital project execution.
Team Training and Skill Development	S13. Digital Technologies Training and Development	Digitally Enhanced	The foundation of providing training and fostering professional growth remains, but it is significantly strengthened by incorporating digital tools, platform-specific training, and AI-driven development strategies.
Information Management	S14. Smart Digital Documentation and Archiving	Digitally Enhanced	The competency retains the original purpose as managing information but significantly improves execution, traceability, accuracy, and collaboration through advanced digital workflows.
Strategic and Innovative Problem Solving	S15. Digital Problem Solving and Technical Support	Digitally Enhanced	The traditional ability to solve complex problems remains crucial, but it is now amplified through the use of digital technologies, technical auditing, and data-supported decisions in construction environments.
N/A	S16. Digital Skills Gap Analysis and Development	Newly Emerged	A newly created competency targeting the identification and strategic development of individual and team digital skills to meet the evolving demands of digital construction environments.
N/A	S17. Cybersecurity and Digital Device Protection	Newly Emerged	New competency focusing on securing digital devices and infrastructure from cyber threats, supporting the safe operation of projects, without a direct traditional counterpart.
N/A	S18. Digital Privacy and Data Protection Compliance	Newly Emerged	A newly emerged competency ensuring digital privacy, regulatory compliance, and data protection strategies, without a traditional PM equivalent.
N/A	S19. Emerging Technologies Cost Management	Newly Emerged	Focuses on budgeting for emerging technology adoption, such as BIM/IoT, with no direct traditional PM competency equivalent identified.
Financial Management and Performance Control	S20. Real-Time Cost Optimisation and Digital Budgeting	Digitally Enhanced	The foundation of traditional financial management remains intact, but it is significantly amplified through digital tools that allow real-time cost tracking, forecasting, and proactive budgeting.
Procurement Management and Resource Planning	S21. Automated Digital Procurement Management	Digitally Enhanced	The core procurement management practices remain vital but are substantially upgraded through automation, predictive analytics, and integration into digital platforms.
Project Scheduling and Time Management	S22. Digital Scheduling Management	Digitally Enhanced	The traditional fundamentals of planning and time control are preserved but significantly strengthened by real-time digital tools, visual simulation, and adaptive schedule optimisation.
Project Resource Management	S23. Digital Resource Management	Digitally Enhanced	The traditional responsibility of coordinating resources remains essential, but is significantly strengthened through smart technologies, predictive digital tools, and sustainability-focused digital strategies.

Project Quality Assurance	S24. Digital Quality Control	Digitally Enhanced	Traditional quality assurance principles remain, but digital technologies dramatically increase speed, accuracy, collaboration, and predictive quality management, creating a far more dynamic and responsive quality control system.
Scope, Requirements, and Change Management	S25. Digital Scope and Change Management	Digitally Enhanced	The traditional principles are still essential but greatly strengthened by real-time, model-based communication, dynamic change visualisation, and digital adaptability.
Agility, Transformation, and Market Responsiveness	S26. Innovation Management in Digital Construction	Digitally Enhanced	The fundamental need for adaptability and market responsiveness remains, but the digital expansion makes it proactive, data-informed, and strategically driven by technology.

The integration of Knowledge competencies addresses domain-specific understanding, strategic thinking, and theoretical mastery of digital systems, processes, and risk management. This layer of integration shows how traditional knowledge areas adapt to support digital workflows or are extended through the acquisition of digital insights. Table 5.7 presents the integrated classification of these competencies within the Knowledge domain.

Table 5.7: Knowledge Integration

Technical Competency	**Digital Competency**	**Integration Outcome**	**Justification**
Industry and Project Domain Knowledge	K1: Advanced Digital Construction Knowledge	Digitally Enhanced	While the traditional domain knowledge remains critical, it is significantly expanded by the technical fluency and innovation awareness required in digitally transformed construction settings.
Technology Required	K2: Emerging Technology Integration Knowledge	Digitally Enhanced	The traditional understanding of essential technology serves as a base, but the digital competency broadens the requirement into advanced digital environments, requiring higher technological fluency and strategic integration capabilities.
N/A	K3: Smart Systems and Applications Knowledge	Newly Emerged	Focuses on domain-specific knowledge about advanced software such as BIM/DT systems, classification systems, and attribute management, competencies not found in traditional lists.
Strategic Planning, Business Case, Benefits Realisation	K4: Digital Project Strategy and Goal Alignment	Digitally Enhanced	Traditional strategic alignment skills remain vital but are amplified by real-time data-driven collaboration, digital monitoring, and adaptive strategy revision based on continuous digital feedback.
Project Integration, Managing, and Executing	K5: Digital Project Integrated Management	Digitally Enhanced	The traditional integration and management principles are preserved, but real-time data integration, digital visibility, and dynamic team collaboration using BIM and related technologies significantly expand the competency's operational and strategic reach.
Health, Safety, and	K6: Digital Safety and Risk Mitigation	Digitally Enhanced	The core principles of health, safety, and environmental responsibility remain intact, but the

Environmental Management			tools, processes, and foresight enabled by digital innovation significantly enhance the competency.
N/A	K7: Digital Quality Assurance and Lifecycle Management	Newly Emerged	Introduces digital lifecycle quality management across project phases through digital tools such as BIM, enabling continuous quality control and sustainability alignment.
Contract and Negotiation	K8: Contract and Negotiation Management	Digitally Enhanced	The traditional negotiation and contract management skills remain central but are expanded and strengthened by digital systems that improve speed, accuracy, and transparency.
Legal and Regulatory Compliance	K9: Regulatory and Compliance	Digitally Enhanced	The core role of governance and compliance remains unchanged, but it is significantly strengthened by automation, real-time monitoring, and digital governance support mechanisms.
N/A	K10: Language Proficiency	Newly Emerged	Introduces multilingual communication in digital contexts, focusing on verbal, written, and presentation skills critical for global, tech-enabled teams.
N/A	K11. Digital Information and Data Literacy	Newly Emerged	Focuses on foundational knowledge for navigating, filtering, and managing digital content in project settings, a core digital literacy does not present in traditional PM models.
Project Risk Management	K12. Digital Construction Risk Management	Digitally Enhanced	Traditional risk management capabilities remain central, but digital technologies greatly enhance precision, foresight, and real-time responsiveness.
N/A	K13. Digital Technology Adoption Risk Mitigation	Newly Emerged	Addresses emerging challenges in adopting technologies like BIM/IoT, involving cost modelling and standardisation, a distinct need in digital transformation not captured in traditional PM.
N/A	K14. Financial Risk Management	Newly Emerged	Introduces strategic oversight of digital-related financial risk, such as tech adoption costs and their budget forecasting, absent in traditional financial risk scopes.
N/A	K15. AI-Powered Data-Driven Decision-Making	Newly Emerged	Represents the use of analytics and industrial databases to support evidence-based decision-making, a new domain beyond traditional PM judgment.
Understanding Methods, Processes, and Procedures	K16. Standardising Digital Technology Processes	Digitally Enhanced	The traditional competency remains relevant but is augmented and expanded through digital process management, structured digital collaboration, and technology-driven consistency.
N/A	K17. Energy Efficiency and Carbon Management	Newly Emerged	Focuses on energy optimisation and carbon tracking using digital tools like BIM/DTs, a sustainability-driven digital capability missing from traditional models.
N/A	K18. Sustainability Reporting and Monitoring	Newly Emerged	Introduces the digital collection, analysis, and communication of sustainability data, not traditionally included in PM roles.

N/A	K19. Sustainable Construction Strategies	Newly Emerged	Reflects theoretical understanding of ecological balance, green materials, and climate-aligned practices, not embedded in conventional competencies.
N/A	K20. Qualifications and Professional Development	Newly Emerged	Captures knowledge of advanced certifications (e.g., BIM, LEED) and pathways for digital upskilling, reflecting evolving industry requirements.
N/A	K21. Curriculum Development	Newly Emerged	Encompasses collaborative curriculum design for digital construction education, a domain linked to workforce development beyond traditional PM training.

The integration of Core Personality Traits competencies reflects behavioural, emotional, and leadership-oriented attributes essential for guiding teams and stakeholders in complex digital environments. These competencies are not necessarily replaced but are digitally contextualised to address the nuances of communication, leadership, and collaboration in technology-enabled project settings. Table 5.8 details the alignment of these traits within the integrated taxonomy.

Table 5.8: Core Personality Integration

Technical Competency	**Digital Competency**	**Integration Outcome**	**Justification**
Team Leadership	CP1: Team Leadership in Digital Construction	Digitally Enhanced	Core leadership skills are preserved, but enhanced significantly by the tools, platforms, and data-driven collaboration demanded in digital construction environments.
Stakeholder Leadership	CP2: Stakeholder Leadership in Digital Construction	Digitally Enhanced	Core stakeholder leadership skills are preserved, but the competency is significantly expanded by digital tools and networked communication strategies required in technologically complex environments.
Self-Management and Emotional Regulation	CP3. Digital Self-Leadership and Emotional Agility	Digitally Enhanced	The underlying behavioural skills remain crucial but expanded to manage higher-intensity digital pressures (e.g., constant tech evolution, hybrid work stress) and to support mental resilience in digitally enabled projects.
Decision-Making and Ethics	CP4. Decision-Making and Accountability	Digitally Enhanced	The ethical principles stay core and unchanged, but now PMs must augment their judgement with real-time digital data interpretation, act quicker, and manage accountability through digital channels.
Cultural Sensitivity and Team Support	CP5. Team Well-Being Leadership	Digitally Enhanced	The core values remain, but digital settings have introduced new leadership demands around remote well-being, emotional resilience, and maintaining culture over digital platforms.

Communication and Interpersonal Skills	CP6. Digital Team Communication and Collaboration	Digitally Enhanced	Traditional communication skills remain essential, but the added technological adaptation and data interpretation for virtual collaboration enhances the competency for the digital construction context.
Client Engagement and Relationship Management	CP7. Digital Stakeholder Communication and Collaboration	Digitally Enhanced	The relational foundation remains but is augmented by the ability to leverage digital platforms for faster, more transparent, and broader stakeholder engagement.
Creative Problem-Solving and Design Thinking	CP8. Digital Innovation and Creativity in Smart Construction	Digitally Enhanced	The foundational creativity and design thinking principles remain, but the use of digital tools greatly expands the possibilities for innovation, efficiency, and scalability in construction contexts.

The integration of traditional and Next-Gen Digital PM competencies reveals critical insights into how the construction sector is evolving under the influence of digital transformation. Through the conceptual comparative analysis approach, this section highlighted the ongoing relevance of many traditional competencies, which remain essential but increasingly require enhancement through digital technologies. For instance, core competencies such as communication, risk management, scheduling, and procurement now leverage advanced tools like BIM, AI, and 5D modelling, signifying an expansion of traditional roles rather than their replacement. These digitally enhanced competencies underscore the continuity of foundational PM practices within a modernised context.

Simultaneously, the integration process also identified a distinct set of newly emerged digital competencies that have no traditional counterparts. These include AI-powered decision-making, cybersecurity, automated procurement, and data privacy compliance, competencies that have surfaced exclusively in response to digital innovation within construction environments. This shift is driven by the rapid advancement and integration of digital technologies in construction, including BIM, AI, IoT, and Digital Twins, which introduce new functional, analytical, and governance requirements not previously captured in traditional project management frameworks. Additionally, the growing reliance on data-driven decision-making, automation, and interconnected digital systems has expanded the scope of the PM role, necessitating new competencies related to cybersecurity, data governance, and digital integration. Their emergence reinforces the necessity for PMs to acquire new technical proficiencies to navigate increasingly complex digital ecosystems.

Furthermore, the analysis demonstrates that behavioural and leadership competencies, encapsulated in the Core Personality Traits domain, continue to play a pivotal role. Traits such as emotional agility, team leadership, and stakeholder communication remain unchanged in essence, though they now demand additional sensitivity to virtual collaboration, digital communication norms, and hybrid working environments. These findings reinforce the idea that while technologies are evolving rapidly, the human aspects of leadership, accountability, and team well-being remain irreplaceable.

Importantly, the integration process revealed that no traditional competencies were classified as "Unchanged." Every traditional competency that remains relevant has undergone some form of digital enhancement or re-contextualisation to align with the demands of digitally enabled construction environments. This outcome confirms the pervasive and comprehensive impact of digital transformation across the entire competency landscape, demonstrating that traditional PM competencies must evolve to remain effective.

Overall, this integration process confirms the value of taxonomy-based classification and conceptual comparative analysis as a methodological bridge between traditional and digital competencies. By mapping competencies across three distinct domains: Skills, Knowledge, and Core Personality Traits, through structured comparative evaluation, the taxonomy offers a coherent framework that supports workforce development, digital upskilling, and systematic adaptation within the construction industry. Moreover, the taxonomy serves as a semi-validation of the Next-Gen Digital PM Competency List developed earlier, reinforcing its internal coherence, domain alignment, and practical applicability to the evolving construction project management landscape.

5.7 Broader Interpretation of Integration Outcomes

The integration of traditional and Next-Gen Digital PM competencies, as outlined in Section 5.6, provided a critical foundation for understanding the transformation of PM roles within the digitally enabled construction sector. Building on this integration, this section moves beyond table-based results to offer broader interpretations, key findings, and strategic implications arising from the taxonomy-based classification. These interpretations are structured using a pyramid model that visually prioritises the emerging trends from the most fundamental to the most specialised outcomes.

To visually synthesise the key findings from the integration process, Figure 5.2 presents a pyramid model that captures the five core insights derived from the taxonomy-based comparative analysis.

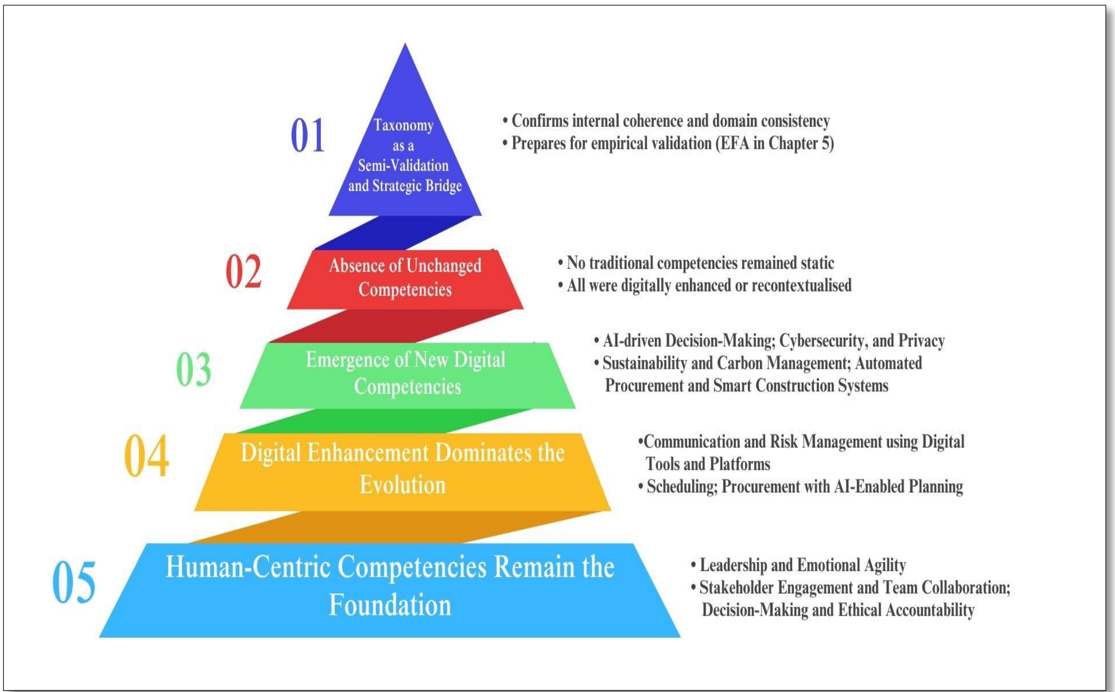


Figure 5.2: Pyramid of Key Findings from Traditional and Digital PM Competency Integration

1. **Human-Centric Competencies Remain the Foundation:** Despite rapid technological advancements, the integration revealed that human-centric competencies, such as leadership, emotional agility, accountability, and team well-

being, remain the irreplaceable foundation of project management practice. These Core Personality Traits have been digitally contextualised, managing virtual teams, adapting to remote collaboration, but their fundamental behavioural and relational essence remains unchanged. Technology acts as an enabler, not a substitute, for these human-centric capabilities, reinforcing that successful digital transformation in construction is equally about preserving and strengthening interpersonal leadership alongside technical advancement.

2. **Digital Enhancement Dominates the Evolution:** Beyond human-centric traits, the integration demonstrated that traditional functional competencies, including project scheduling, procurement, risk management, and stakeholder communication, have been significantly amplified and transformed by digital tools such as BIM, AI, real-time data analytics, and cloud collaboration platforms. These evolutions represent a shift from manual, sequential processes to dynamic, data-driven project environments. Digital enhancement dominates how core project functions are executed, requiring PMs to integrate technical proficiency into their traditional workflows to remain competitive and effective in modern construction environments.
3. **Emergence of New Digital Competencies:** The integration process also revealed a new category of competencies that have no equivalent in traditional PM models. Competencies such as AI-powered decision-making, cybersecurity, real-time cost optimisation, and digital content development emerged as novel requirements for managing smart construction projects. These newly emerged competencies demonstrate that the construction sector is not only adapting to technological change but is also actively innovating. PMs now need to master competencies rooted in emerging technologies to maintain relevance, competitiveness, and resilience in increasingly digitised and technology-driven project environments.
4. **Absence of Unchanged Competencies:** A striking observation from the integration is that no traditional competencies remained unchanged. Even foundational competencies like leadership, scheduling, and contract management have been digitally redefined, requiring adaptation to new workflows, digital platforms, and data-driven decision-making models. This underscores the pervasive and disruptive impact of digital transformation, signalling that PMs must continually evolve even their core skillsets to stay effective in the era of smart construction.
5. **Taxonomy as a Semi-Validation and Strategic Bridge:** Finally, the taxonomy-based classification served as a semi-validation of the Next-Gen Digital PM Competency List developed earlier in the research. By systematically mapping traditional and digital competencies across the domains of Skills, Knowledge, and Core Personality Traits, the taxonomy validated the internal coherence, structural alignment, and practical applicability of the Next-Gen model. Moreover, the taxonomy provides a strategic bridge to the next empirical phases of the study, EFA and CFA, supporting both academic validation and practical competency development strategies for the evolving construction sector.

The broader interpretation of integration outcomes affirms that while technologies drive construction forward, human-centric competencies remain the unshakable foundation. Digital enhancement dominates competency evolution, while the rise of entirely new digital competencies signals the need for strategic adaptation and lifelong learning among construction PMs. Importantly, the absence of unchanged competencies highlights that no aspect of traditional PM remains untouched by digital transformation.

By developing a taxonomy that merges traditional and digital competencies, this research provides a forward-looking structure that supports workforce planning, education, and professional development. The pyramid model introduced in this section offers a visual roadmap for understanding how PM roles are shifting and evolving, setting the stage for the next empirical stage of validation in Chapter 6 and Chapter 7. Therefore, this chapter bridging traditional and digital PM competencies is not simply an academic exercise, but a critical strategic pathway for enabling resilient, capable, and future-ready leadership in the construction industry's digital era.

5.8 Limitations and Future Research Directions

While this study offers a structured and original taxonomy-based classification of traditional and digital PM competencies for the construction sector, several limitations should be acknowledged. First, the integration process relied on a conceptual comparative analysis approach rather than empirical statistical methods at this stage. Although the mapping was grounded in rigorous definitions and logical evaluation, the absence of quantitative validation in this chapter means that further empirical testing is necessary to confirm latent relationships and dimensional structures among the competencies.

Second, the taxonomy development process focused on construction-specific contexts. While construction is experiencing rapid digital transformation, the applicability of the integrated taxonomy to adjacent industries such as infrastructure development, real estate, or large-scale engineering projects may require careful adaptation. Future studies could expand the taxonomy's scope and validate it across multiple sectors to assess its broader generalisability.

Third, the classification into Skills, Knowledge, and Core Personality Traits was based on expert-driven synthesis, thematic emphasis, and literature alignment. However, the dynamic nature of digital technologies and evolving industry practices suggests that competencies may continue to change over time. Therefore, the taxonomy presented here should be viewed as a foundation for ongoing refinement rather than a fixed model.

Future research should prioritise the empirical validation of the integrated competency framework through statistical techniques such as EFA and CFA. Such validation will help uncover underlying latent structures and strengthen the predictive power of the competency model. Longitudinal studies are also recommended to track how the relevance and weight of competencies evolve as digital transformation in the construction industry continues to accelerate. Moreover, expanding the research geographically, by testing the model in different regional, cultural, and technological contexts, could provide valuable insights into how digital PM competencies are influenced by diverse construction environments worldwide.

Ultimately, the taxonomy developed in this chapter provides a necessary step towards developing evidence-based, future-ready models for training, upskilling, and certifying PMs operating within digitally enabled construction environments.

5.9 Conclusion

This chapter systematically developed a taxonomy-based integration of traditional and Next-Gen Digital PM competencies to reflect the profound evolution of Project Manager (PM) roles in the construction sector under digital transformation. Beginning with the taxonomy-based classification of digital competencies, the chapter structured the Next-Gen list into three clear domains, Skills, Knowledge, and Core Personality Traits, thereby reinforcing the conceptual integrity of the competencies identified in earlier research phases. This classification process served not only to organise the competencies meaningfully but also to act as a semi-validation of the Next-Gen Digital PM Competency List by confirming logical domain alignment and internal coherence.

Building upon the established taxonomy, the chapter employed a conceptual comparative analysis approach to integrate traditional and digital competencies. This integration process revealed two major patterns: the digital enhancement of many foundational competencies and the emergence of entirely new digital competencies. Importantly, no traditional competencies remained strictly unchanged; rather, traditional competencies such as communication, risk management, scheduling, procurement, and leadership were found to have evolved significantly through the incorporation of digital technologies such as BIM, AI, and real-time collaboration platforms. This digital enhancement preserved the relevance of foundational practices while elevating their application to meet the demands of modern construction projects.

Simultaneously, a substantial set of newly emerged competencies was identified, including AI-powered decision-making, cybersecurity, data privacy management, and digital sustainability practices, areas not addressed by traditional PM frameworks. Their emergence underscores the growing need for PMs to acquire advanced skills, knowledge, and core personality proficiencies to successfully navigate complex, technology-driven construction environments.

Moreover, the analysis reaffirmed the pivotal role of behavioural and leadership attributes captured under the Core Personality Traits domain. Traits such as emotional agility, stakeholder leadership, and team communication retain their foundational importance but have been digitally contextualised to accommodate virtual collaboration, hybrid work models, and rapid technological innovation. This highlights that while technologies evolve, the human-centric dimension of leadership, accountability, and interpersonal effectiveness remains irreplaceable for the future success of PMs.

The integration outcomes are further encapsulated through a five-layered pyramid model, reflecting the hierarchical evolution of PM competencies in the digital construction era. At the base lies the enduring importance of human-centric competencies, highlighting leadership and emotional agility. This is followed by the dominance of digital enhancement, where traditional competencies have evolved through technology. The emergence of new digital competencies occupies the next layer, introducing novel skills essential for managing smart construction projects. Above this, the absence of unchanged competencies underscores the pervasive influence of digital transformation across all domains. Finally, at the summit, the taxonomy developed in this study serves as a semi-validation tool and strategic bridge, connecting traditional project management practices with the demands of the digital future.

While the taxonomy and integration process provide a robust conceptual foundation, it is important to acknowledge certain limitations. The classification and comparative analysis were based on theoretical alignment rather than empirical data; thus, the relationships between competencies and real-world performance outcomes require further quantitative validation. Additionally, the taxonomy reflects the current state of technological development and project management practices; ongoing updates will be necessary to keep pace with continuous innovation in the construction sector.

Future research should focus on empirical validation of the taxonomy through methods such as Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA), as outlined in the next chapters. Further studies could also explore cross-sectoral comparisons, longitudinal tracking of evolving competencies, and regional adaptations to capture global variations in digital construction practices.

Practically, the outcomes of this chapter offer immediate value for industry practitioners, educational institutions, and policymakers. The structured taxonomy provides a roadmap for workforce development, targeted upskilling initiatives, competency-based training programs, and curriculum design for construction management education. It also supports strategic human resource planning by identifying critical areas for digital competency development to future-proof the construction workforce.

Overall, this chapter confirms the effectiveness of taxonomy-based classification and conceptual comparative analysis as a methodological bridge between traditional PM competencies and the demands of the digital era. It provides a coherent and structured foundation that not only advances academic knowledge but also strengthens workforce adaptability and industry resilience. Furthermore, the taxonomy developed here lays a critical foundation for the empirical modelling stages that follow, ensuring that the integrated competencies are both theoretically robust and practically applicable. Thus, this chapter marks a pivotal transition from conceptual groundwork to empirical validation, bridging theory and practice in advancing construction project management into the digital future.

In addressing RQ3, *"How can traditional and emerging digital competencies be systematically integrated into a taxonomy-based classification that reflects construction's digital transformation needs?"*, this chapter has systematically integrated traditional and digital competencies into a taxonomy-based classification that reflects the evolving demands of digital construction. This taxonomy not only bridges past and present but also establishes the conceptual and structural foundation for empirical validation in the following chapters.

Chapter 6 From Taxonomy to Framework: Empirical Validation of the Next-Gen Digital Project Manager Competency Framework via Exploratory Factor Analysis

This chapter is extended from:

- Owais, O. A., Poshdar, M., Ghaffarian Hoseini, A., Jaafar, K., & Sarhan, S. (2026). *Empirical validation of the next-gen digital project manager competency framework through exploratory factor analysis*. *Smart and Sustainable Built Environment*. Advance online publication. https://doi.org/10.1108/SASBE-11-2025-0698.

6.1 Abstract

This chapter presents the results of an Exploratory Factor Analysis (EFA) undertaken to empirically validate a digital competency framework for next-gen PMs in the construction sector. While earlier chapters established a conceptually derived and taxonomy-based competency structure, the need for empirical validation to confirm its underlying latent structure necessitated the application of EFA. Drawing from a refined list of 55 digital competencies and informed by a taxonomy developed in earlier chapters, the analysis was based on responses from a purposively sampled professional cohort. Principal Axis Factoring with Promax rotation was applied, resulting in a seven-factor solution supported by scree plot, eigenvalue, and thematic interpretability criteria.

The final framework comprises 25 statistically retained competencies grouped into seven latent constructs: Digital Execution and Optimisation, Human-Centred Digital Leadership, Lifecycle Risk and Compliance Knowledge, Digital Sustainability Intelligence, Digital Tool Proficiency and Automation, Digital Content and Data Management, and Digital Transformation Enablement Skills. These factors reflect the multidimensional nature of digital PM in construction, integrating technical, behavioural, and cognitive capacities essential for navigating digital transformation.

The resulting framework offers a robust empirical foundation for defining and evaluating digital PM competencies. It establishes a structured basis for confirmatory analysis in the following chapter and supports the advancement of evidence-based competency development in the built environment.

6.2 Introduction

The construction industry is experiencing a profound shift through digital transformation, characterised by the integration of advanced technologies such as Building Information Modelling (BIM), Digital Twins (DTs), the Internet of Things (IoT), cloud computing, and Artificial Intelligence (AI) into all aspects of project delivery and organisational strategy (Paneru et al., 2024; Vial, 2021; Liu et al., 2022). This transformation extends beyond the adoption of digital tools; it reflects a fundamental reconfiguration in how construction firms operate, make decisions, manage data, and coordinate across disciplines. As a result, the role of the project manager (PM) is undergoing significant change. PMs are now expected to manage not only traditional domains such as cost, time, and quality but also to lead in digitally integrated environments, make data-driven decisions, coordinate dispersed digital teams, and drive innovation through the strategic use of technology (Aibinu & Venkatesh, 2014; Rodrigues et al., 2023; Whyte, 2019; Owais et al., 2025a).

This evolving role demands a new generation of PMs who possess capabilities that span technical fluency, systems thinking, leadership in virtual collaboration environments, and adaptability to fast-paced digital innovation cycles. While traditional competency models such as those developed by the Project Management Institute (PMI, 2021b) and the International Project Management Association (IPMA, 2015a) continue to offer valuable foundations, they do not fully address the strategic, behavioural, and digital literacy requirements emerging from digital transformation in construction. This gap is particularly evident in digitally transformed construction environments, where PMs are increasingly expected to act as integrators of digital workflows, stewards of data integrity, and facilitators of interdisciplinary collaboration across evolving platforms and technologies (Paneru et al., 2024; Rodrigues et al., 2023; Mandičák et al., 2020).

To address this competency gap, this thesis developed a theoretically grounded and systematically validated list of digital competencies for PMs working in digitally transformed construction contexts. As presented in Chapter 4, and submitted as , the Next-Gen Digital PM Competency List (Owais et al., 2025c) was developed using a three-phase methodology comprising a Systematic Literature Review (SLR), thematic analysis supported by NVivo software, and a synthesis phase powered by Large Language Models (LLMs). This process resulted in a list of 55 competencies, each mapped to one of three domains: skills, knowledge, or core personality traits. These domains reflect the cognitive, technical, and behavioural demands placed on PMs operating in digital environments. The list provides a foundational structure for identifying, developing, and assessing the core competencies needed to manage complex, technology-mediated construction projects.

Building on this list, Chapter 5 of the thesis applied a taxonomy-based classification approach to structure and semi-validate the digital competencies. It involved a conceptual comparative analysis that mapped and aligned traditional PM competencies, sourced from established frameworks such as the PMBOK Guide (PMI, 2021b), the IPMA ICB (IPMA, 2015a), and related academic models, to the digital taxonomy developed in Chapter 5. Using a conceptual comparative methodology (Hantrais, 2009; Miles & Huberman, 1994), the analysis categorised traditional competencies as either digitally enhanced or newly redefined digital functions. This ensured that the resulting taxonomy not only captured emergent digital skillsets but also retained the essential elements of traditional PM practice adapted to new technological realities. The final output of Chapter 5 was a three-domain taxonomy of digital competencies for PMs, conceptually integrating the traditional and digital perspectives into a single structured model.

While this taxonomy provides a robust conceptual integration of traditional and digital competencies, it remains theoretically derived and has not yet been empirically validated. Existing research in construction project management and digital competency modelling has largely relied on conceptual frameworks and qualitative synthesis, with limited application of quantitative techniques to uncover the underlying latent structure of competencies. This presents a critical gap in the literature, particularly in the context of digitally transformed construction environments, where validated competency structures are essential for reliable measurement, training, and application.

Crucially, the taxonomy presented in Chapter 5 is not a static listing of competencies, but a dynamic classification framework intended for empirical validation. Contemporary research in competency modelling highlights the importance of confirming theoretical structures through quantitative validation methods such as factor analysis and structural modelling (Costello & Osborne, 2005; Kline, 2023; Worthington & Whittaker, 2006). Accordingly, there is a clear need to empirically examine how these competencies group together and interact within real-world professional contexts. Accordingly, this chapter addresses Research Question 4 (RQ4): *How can the integrated taxonomy of traditional and digital competencies be empirically synthesised and modelled into an initial validated framework?*

To fulfil this objective, a four-phase empirical process was adopted. Phase One involved the design of a structured survey instrument to capture participant evaluations of 55 validated competencies from the Next-Gen list (Owais et al., 2025c), grouped into the domains of Skills, Knowledge, and Core Personality Traits, and rated using a five-point Likert scale. Although the survey targeted only digital competencies, the model remains comprehensive due to the prior integration of traditional competencies into the digital taxonomy through comparative analysis. Phase Two utilised purposive sampling to recruit experienced professionals actively engaged in digital project environments within the construction industry, ensuring targeted input aligned with the study's objectives. In Phase Three, the collected data were analysed using Exploratory Factor Analysis (EFA) in IBM SPSS Statistics (SPSS) to identify underlying latent constructs and assess the internal structure of the competency domains. EFA is particularly appropriate in this context as it enables the empirical identification of latent competency groupings, thereby transforming a conceptually derived taxonomy into a statistically grounded framework. EFA is widely used in scale development to determine factor groupings, reduce measurement noise, and refine item clusters (Costello & Osborne, 2005; Worthington & Whittaker, 2006). Phase Four presents the EFA-derived framework structure of the validated competency domains and explores the interrelationships among the latent constructs. These relationships will be further examined through Confirmatory Factor Analysis (CFA) in the next chapter to validate the theoretical framework via Structural Equation Modelling (SEM). SEM is a well-established technique for modelling relationships between latent constructs and validating theoretical frameworks in project management and organisational research (Aibinu & Papadonikolaki, 2020; Hair et al., 2010; Kline, 2023).

The significance of this chapter lies not only in empirically validating the digital competency taxonomy developed in Chapter 5 but also in synthesising these results into a functional, evidence-based framework. This framework is intended to serve as a tool for construction firms, project delivery teams, training institutions, and certification bodies seeking to advance digital leadership in project management. Rather than linking competencies to external success outcomes, the focus of this chapter is on validating the internal structure and interrelationships of the digital competencies themselves. It also provides a theoretical basis for future studies investigating the effects of digital competencies on measurable project outcomes in digitally transformed construction settings. Moreover, it sets the foundation for Chapter 7, which will confirm the structure of the model through CFA using the same dataset, in order to validate the factor structure identified in the EFA-derived model and assess the internal consistency and goodness-of-fit of the measurement model.

This chapter is structured to reflect the empirical progression of the research. Section 6.3 outlines the methodology used to design the survey instrument based on the validated Next-Gen Digital PM Competency List, detailing the survey design, sampling strategy, data collection, application of EFA, and the derivation of an empirically grounded competency structure to examine internal relationships between competency domains. Section 6.4 presents the conceptual framework developed from the taxonomy's domain structure, offering a theoretical rationale for the hypothesised interrelationships. Section 6.5 details the results and framework development process, including descriptive statistics of competency items, participant demographics, EFA outcomes, and the construction of the final competency structure. Section 6.6 synthesises these findings into a visual representation of the EFA-derived framework for digital PM competencies in construction. Section 6.7 addresses methodological and practical limitations while offering recommendations for future research and framework refinement. Finally, Section 6.8 concludes the chapter by summarising its contribution to the overall research objectives and establishing the foundation for model validation via CFA and SEM in Chapter 7.

6.3 Method

This section outlines the EFA-based approach in IBM SPSS used to empirically validate the Next-Gen Digital PM Competency List developed in Chapter 4 and subsequently structured into the taxonomy in Chapter 5, as also submitted in Owais et al. (2025c). The aim of this phase is to examine how the identified digital competencies, originally derived through literature synthesis, thematic analysis, and definition refinement using LLM, are statistically organised into latent structures via EFA, and how they interact to form an evidence-based framework for supporting digital PMs in construction. EFA is a statistical technique used to uncover the underlying structure of a relatively large set of observed variables by identifying clusters of interrelated items that reflect latent constructs (Fabrigar et al., 1999; Costello & Osborne, 2005). It is particularly useful in the early stages of scale development when the theoretical dimensionality of constructs is not yet confirmed (Worthington & Whittaker, 2006).

To achieve this, a four-phase empirical strategy was implemented, aligned with established best practices for quantitative scale validation and framework development (Costello & Osborne, 2005; Hair et al., 2010; Kline, 2023). Phase One involved the design of a structured survey instrument to capture participant evaluations of 55 digital competencies, grouped into the domains of Skills, Knowledge, and Core Personality Traits, and rated using a five-point Likert scale. Phase Two utilised purposive sampling strategy to recruit experienced construction professionals actively engaged in digital project environments. In Phase Three, the collected data were analysed using EFA to identify underlying latent constructs and assess the internal structure of the competency domains. Finally, Phase Four presents the empirically derived competency framework for digital PMs, modelling the internal structure of the validated domains and exploring the interrelationships among the latent constructs identified through EFA, as illustrated in Figure 6.1.

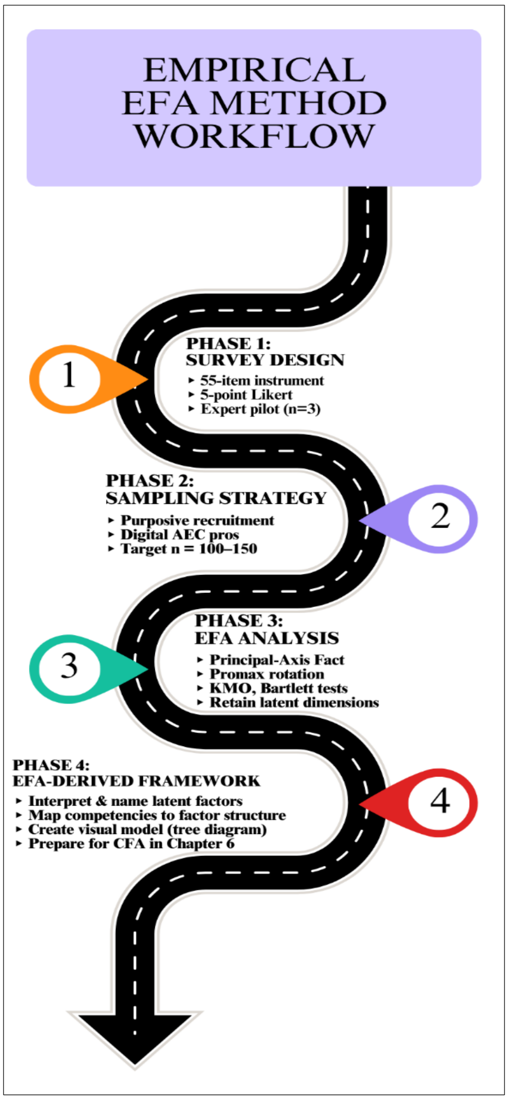


Figure 6.1: Empirical EFA Method Workflow

It is important to emphasise that this section is focused exclusively on outlining the academic procedures used for instrument development, participant sampling, and statistical modelling. No empirical findings or interpretations are presented here. Instead, the outcomes of each methodological phase are reported in Section 6.5. The subsections that follow correspond directly to the four-phase empirical strategy: Section 6.3.1 outlines Phase One: Survey Instrument and Design; Section 6.3.2 describes Phase Two: Sampling Strategy and Data Collection; Section 6.3.3 presents Phase Three: Exploratory Factor Analysis (EFA); and Section 6.3.4 explains Phase Four: Development of the EFA-Derived Competency Framework for Next-Gen Digital PMs.

6.3.1 Phase 1: Survey Instrument and Design

To operationalise the validated Next-Gen Digital PM Competency List developed in Chapter 4, a structured survey instrument was designed to quantitatively assess the perceived importance and structure of digital competencies among experienced professionals in the Architecture, Engineering, and Construction (AEC) sector. The survey items were directly derived from the final list of 55 digital competencies, categorised into three domains: Skills (26 items), Knowledge (21 items), and Core Personality Traits (8 items). These competencies were developed through a rigorous three-phase methodology comprising a SLR, NVivo-based

Thematic Analysis, and synthesis using LLMs, as documented in Chapter 4 and Owais et al. (2025c).

Each item in the survey was presented as a concise statement describing a specific competency. Participants were asked to rate the importance of each competency in relation to digital PM practice, using a five-point Likert scale ranging from 1 (Strongly agree) to 5 (Strongly Disagree). This format was selected for its psychometric robustness and compatibility with quantitative analysis methods such as EFA and SEM, while also minimising respondent fatigue. The design aligns with established guidelines in competency measurement and scale development (Worthington & Whittaker, 2006; DeVellis & Thorpe, 2021). A full justification of the survey's sample size and analytical suitability is provided in Section 6.3.2.

While the survey item pool was directly derived from the 55 fully defined digital competencies validated in Chapter 4, the integrated taxonomy developed in Chapter 5, which combined traditional and digital competencies into a unified classification, provided the structural foundation for organising these items into domains and guided the interpretation of latent constructs. Chapter 5 did not replace the validated competencies but integrated them with traditional competencies, ensuring that the quantitative validation in Chapter 6 was theoretically anchored in the taxonomy-based structure while remaining grounded in the full competency definitions established earlier

The survey was developed and distributed via Qualtrics, an online platform that ensured data security, anonymous participation, and compliance with academic research standards. The instrument began with a participant information sheet outlining the study's purpose, ethical compliance, and data confidentiality in accordance with Auckland University of Technology (AUT) ethics guidelines (AUT Ethics Approval No. 23/257; see Appendix A1). Demographic questions captured participant attributes such as age, gender, job role, education level, and years of experience in digital construction projects. These data were later used to validate the purposive sampling strategy by confirming alignment between the collected sample and the intended target population of digitally engaged AEC professionals.

To improve content validity and ensure item clarity, the survey underwent pilot testing with three domain experts, two senior academics and one industry-based digital PM, who provided feedback on item phrasing, relevance, and terminology. Based on their input, minor wording refinements were made to enhance clarity and ensure consistent interpretation across diverse professional backgrounds.

A representative subset of the survey items is shown in Table 6.1, providing a sample from each domain. The full instrument is included in Appendix A2: Qualtrics Survey Instrument to ensure transparency and enable future replication.

Table 6.1: Sample Survey Items by Competency Domain

Domain	**Sample Competency Item**	**Rating Scale**
Skills	Applying advanced digital tools (e.g., BIM, simulation tools) to design, model, and document deliverables	1 = Strongly Agree to 5 = Strongly Disagree
Knowledge	Understanding lifecycle data management and its role in digital project delivery and sustainability	1 = Strongly Agree to 5 = Strongly Disagree
Core Personality Traits	Demonstrating adaptability and emotional resilience under pressure in digitally dynamic environments	1 = Strongly Agree to 5 = Strongly Disagree

These items reflect the integration of technical fluency, contextual knowledge, and behavioural adaptability essential for PMs operating in digitally transformed construction environments. Rather than linking competencies to performance outcomes at this stage, the survey supports an internal framework-building strategy. This enables empirical identification of latent structures through EFA and the development of a theoretically coherent measurement framework, as explored in later sections.

6.3.2 Phase 2: Sampling Strategy and Data Collection

This study employed a purposive sampling strategy, widely used in competency validation and organisational research where the goal is not statistical generalisation but targeted expertise acquisition from information-rich cases (Etikan et al., 2016; Palinkas et al., 2015). The objective was to collect high-quality insights from construction professionals with demonstrable experience in digital project environments, as their evaluations were essential for assessing the structure and relevance of digital PM competencies. This sampling approach aligns with previous studies that required domain-specific knowledge for evaluating skills and behaviours in digitally enabled project settings (Obradović et al., 2018; Zulu & Khosrowshahi, 2021).

The target population included professionals from the AEC industry, with diverse roles including digital PMs, BIM/Virtual Design and Construction (VDC) coordinators, design and engineering leads, digital construction engineers, site managers, and senior executives overseeing technology-integrated projects across New Zealand and Australia. To ensure the relevance and rigour of the responses, two inclusion criteria were established:

1. A minimum of five years of professional experience in AEC-related disciplines; and
2. Active involvement in digitally mediated project delivery, such as through the use of BIM, cloud platforms, AI-enabled tools, DTs, or collaborative virtual environments.

Participants were recruited using a combination of professional networks, industry LinkedIn groups, digital construction associations, national engineering magazine, university–industry partnerships, and snowball sampling, wherein initial respondents were encouraged to refer colleagues who met the inclusion criteria. This multi-pronged recruitment strategy was designed to ensure diversity across roles, sectors (public/private), and geographic regions, and to capture a broad cross-section of the digitally evolving AEC landscape (Robinson, 2014; Palinkas et al., 2015).

The survey was deployed using Qualtrics, a secure online platform that allows anonymous participation, customisable design, and institutional compliance. Each participant received a unique invitation with a link to the survey, including an explanation outlining the study's purpose, voluntary nature, and confidentiality terms. The survey began with a digital informed consent form, aligned with protocols approved by the Auckland University of Technology Ethics Committee (AUTEC). Participants could withdraw at any time by exiting the browser, and no personal identifiers were collected.

The study aimed to collect between 100 and 150 valid responses, in alignment with established guidelines for EFA and SEM. Although larger samples are generally preferred, the use of smaller samples is acceptable when certain conditions are met, particularly when communalities are high ($\geq$0.5), factor loadings are strong ($\geq$0.4), and each construct is represented by multiple items (Costello & Osborne, 2005; Hair et al., 2010; Fabrigar et al., 1999). In such cases, EFA has been found to yield stable and interpretable factor structures with samples as small as 100. Because this study employed purposive sampling to target experienced digital construction professionals, it was not necessary to calculate the total population of AEC practitioners in New Zealand and Australia. Instead, sample adequacy was evaluated based on methodological standards for latent variable modelling and expert-based validation studies (Etikan et al., 2016). For SEM, simulation studies have shown that samples in this range can be sufficient for frameworks of moderate complexity and well-behaved data structures, particularly when factor-to-indicator ratios exceed 3:1 and estimation techniques such as maximum likelihood or robust estimators are used (Kline, 2023; Wolf et al., 2013).

In addition to the 55 competency items, the survey included a demographic section to collect participant data such as age group, gender, professional discipline, current role, years of experience, education level, and self-assessed familiarity with digital construction technologies. These data were used to evaluate the representativeness and diversity of the respondent pool and to confirm that the sample aligned with the study's objectives. A detailed analysis of these demographic characteristics is presented in Section 6.5.2, which precedes the statistical analysis of the competency data.

By focusing on qualified digital construction professionals and employing a rigorous yet flexible sampling approach, this study ensured that the resulting dataset was not only statistically viable but also theoretically meaningful for validating the digital competency taxonomy and developing the conceptual framework through EFA, with further structural validation planned through SEM in subsequent chapter.

6.3.3 Phase 3: Exploratory Factor Analysis (EFA)

EFA was employed as a key statistical technique to uncover the underlying latent structure of the 55-item digital PM competency dataset. This step was essential to empirically validate the taxonomy developed in Chapter 5 and to assess the coherence of the three conceptual domains, Skills, Knowledge, and Core Personality Traits, originally proposed in Chapter 4. EFA is widely recognised as a robust approach in the early phases of scale validation, particularly when the objective is to identify unobserved constructs (latent variables) that account for shared variance among a large set of interrelated observed variables (Costello & Osborne, 2005; Fabrigar et al., 1999; Worthington & Whittaker, 2006).

The EFA procedure in this study was designed to ensure both methodological rigour and theoretical alignment with the digital competency framework. Prior to conducting the analysis, the dataset was examined for completeness, distributional characteristics, and suitability for factor analysis. Responses with more than 15% missing values due to incomplete survey submission were excluded using listwise deletion to preserve data integrity, while item-level gaps were addressed using Expectation-Maximisation (EM) imputation. EM is a preferred method in social science research for handling missing-at-random data, as it has been shown to maintain structural relationships and minimise parameter bias (Enders, 2022; Schafer & Graham, 2002).

Before applying the Kaiser–Meyer–Olkin (KMO) and Bartlett's tests, item-level Standard Deviations (SDs) were assessed to ensure adequate variability in responses. Items with very low SD values ($SD < 0.25$) were flagged for potential review due to their limited discriminatory power. However, in line with the exploratory nature of the study, such items were retained if they were conceptually significant and aligned with the theoretical competency domains. Evaluating SDs is a standard preparatory step in psychometric assessments, ensuring that retained items exhibit meaningful variation across the sample (Morgado et al., 2017).

To evaluate the appropriateness of the dataset for EFA, two standard diagnostics were conducted: the KMO measure of sampling adequacy and Bartlett's Test of Sphericity. A KMO value > 0.60 was used as the minimum threshold for sampling adequacy, while a statistically significant Bartlett's test ($p < 0.05$) was required to confirm that the correlation matrix was sufficiently different from an identity matrix, suggesting that meaningful factor structures existed in the data (Hair et al., 2010; Field, 2024). Both tests are standard prerequisites for proceeding with EFA and are considered foundational for assessing factorability in multivariate social research.

The extraction method selected for this study was Principal Axis Factoring (PAF), which is more appropriate than Principal Component Analysis (PCA) when the goal is to identify latent constructs that explain shared variance, rather than simply reduce data dimensionality. PAF is also more robust to non-normal data distributions, a common characteristic in Likert-scale responses (Fabrigar et al., 1999; Field, 2024). This aligns with the study's objective to empirically determine the factor structure underlying the theoretical taxonomy of digital competencies, rather than merely summarise variance across items.

For the rotation method, Promax (oblique) rotation was chosen over orthogonal alternatives (e.g., Varimax) based on the theoretical expectation that latent factors, such as digital skills, behavioural traits, and knowledge areas, would likely be correlated. In digital project environments, competencies often work in tandem; for instance, a PM's knowledge of digital tools may enhance their ability to lead teams or solve problems collaboratively. Oblique rotation methods accommodate such realistic correlations and produce more accurate and conceptually meaningful factor solutions in social-behavioural sciences (Fabrigar et al., 1999; Costello & Osborne, 2005; Worthington & Whittaker, 2006).

The criteria for factor retention followed four-pronged approach to ensure both statistical robustness and theoretical interpretability. Specifically, factors were retained if they met the following conditions:

- An eigenvalue ≥ 1.0 based on the Kaiser criterion;
- A visible "elbow" in the scree plot suggesting inflection points in explained variance;
- Theoretical coherence with existing domain definitions from Chapter 4;
- A minimum of three items loading strongly (≥ 0.40) on each retained factor with minimal cross-loadings (i.e., secondary loadings < 0.30).

Items that failed to meet these criteria were either flagged for potential removal or examined for conceptual overlap. This process ensures the internal consistency and parsimony of the emerging factor structure, both of which are critical for developing valid measurement frameworks (DeVellis & Thorpe, 2021; Kline, 2023).

While EFA is inherently data-driven, the interpretability of emerging factor structures in this study was intended to be guided by the established taxonomy from the prior chapters. In line with best practices in scale development, decisions regarding item deletion or factor consolidation were not to be made purely on statistical grounds. Instead, each decision would be cross-referenced with the competency definitions and domain classifications developed in Chapter 4 (Owais et al., 2025c), and the taxonomy and comparative integration strategy applied in Chapter 5. This approach was designed to ensure that the resulting factor framework would retain fidelity to both the empirical structure of the data and the theoretical foundations of the competency taxonomy (DeVellis & Thorpe, 2021; Worthington & Whittaker, 2006).

The final factor structure derived from EFA provided the empirical foundation for developing the initial digital competency framework, as introduced in Section 6.3.4. The detailed outcomes of the EFA, including factor loadings, item groupings, percentage of variance explained, and retained competencies, are presented in Section 6.5.4. This framework will be further evaluated and validated through CFA/SEM in Chapter 7.

6.3.4 Phase 4: Empirically Derived Competency Structure for Digital PMs

Building on the factor structure extracted through EFA, this phase aimed to translate the empirical groupings of competencies into a structured conceptual framework that reflects the core dimensions of the Next-Gen Digital PM Competency List. This framework represents an intermediate, data-informed model, not yet statistically validated, that serves as a critical bridge between the latent constructs identified through EFA and the confirmatory modelling to be conducted in Chapter 7.

In this phase, each of the retained factors from EFA was examined for thematic coherence based on the competency items it grouped together. These thematic clusters were then assigned meaningful labels that reflect their underlying digital PM function (e.g., "AI-Driven Decision Skills," "Lifecycle Resilience Knowledge," or "Collaborative Digital Mindset"). The relationship between each factor and its associated competency items is presented in Section 6.5.3.4, where factor loadings and component classifications are detailed. This mapping enables a grounded interpretation of how digital PM competencies are structured in practice and how they can inform leadership, training, and capability-building efforts in the construction sector.

No statistical modelling software (e.g., Analysis of Moment Structures (AMOS)) was used in this chapter, nor were model fit indices assessed. Instead, this phase focuses on visualising the outcome of EFA as a preliminary structural framework, a first iteration of the Digital PM Competency Framework that will serve as the conceptual base for further empirical validation. The final version of this framework, including its formalised structural relationships and goodness-of-fit evaluation, will be presented and tested in Chapter 7 using CFA.

Thus, the outcomes of this phase are threefold:

I. The interpretation and thematic naming of each latent factor based on the conceptual coherence of its constituent competencies;
II. The systematic organisation of strongly loading items under their respective factors to reflect meaningful competency groupings;
III. The development of an initial structural representation that serves as the empirical foundation for the final model in Chapter 7.

This iterative, staged approach ensures that the resulting framework is not only empirically grounded in data-driven patterns, but also theoretically aligned and practically relevant for application in digital project management contexts.

6.4 **Conceptual Framework Development**

The conceptual framework developed in this study serves as the theoretical foundation for empirically validating the digital PM competencies introduced in earlier chapters. Building on the Next-Gen Digital PM Competency List presented in Chapter 4 and the taxonomy-based classification established in Chapter 5, this framework organises competencies into three overarching domains: Skills, Knowledge, and Core Personality Traits. These domains reflect distinct but interdependent dimensions of professional capability essential for digital construction environments.

The framework was initially constructed through a rigorous, multi-phase process involving SLR, thematic analysis using NVivo, and definition synthesis via LLMs. This process led to the identification of 55 validated competencies, structured across the tri-domain framework. The conceptual framework assumes that successful digital PM depends not only on applied technical proficiency (Skills), but also on cognitive understanding (Knowledge) and behavioural adaptability (Core Personality Traits).

Importantly, the framework posits that these domains function interactively rather than in isolation. This systemic view aligns with contemporary competency theories that advocate for the inclusion of emotional and behavioural traits alongside technical and cognitive abilities (Boyatzis, 2008; Draganidis & Mentzas, 2006).

This conceptual structure serves as the pre-empirical basis for the EFA presented in Section 6.5.3 of this chapter. EFA is employed to empirically examine how the 55 digital competencies group into latent constructs and whether the hypothesised domains are statistically supported. As illustrated in Figure 6.2, the initial conceptual framework groups the competencies under three hypothesised domains. The EFA results test these groupings and reveal new emergent factors that reflect how competencies cluster in practice.

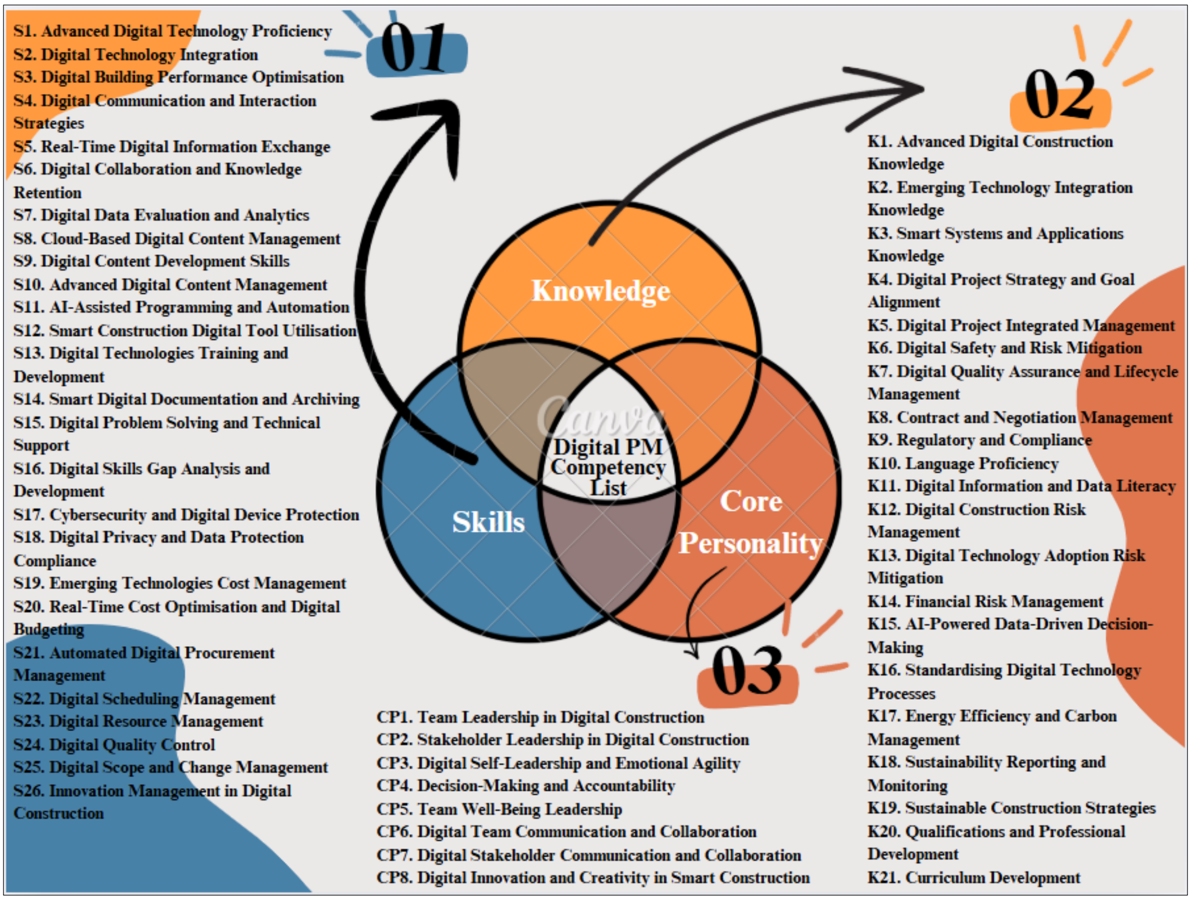


Figure 6.2: Conceptual Framework of Digital PM Competency Domains (Pre-Empirical Version)

The empirical outcomes of EFA, including factor extraction, item reduction, and structural interpretation, are presented in Sections 6.5.3 and 6.5.4. These sections culminate in the development of the Final EFA-Derived Competency Framework for Next-Gen Digital PMs, which serves as the input structure for confirmatory validation using SEM in Chapter 7.

6.5 Results and Framework Development

This section presents the empirical outcomes of the four-phase validation process outlined in Section 6.3. The primary objective is to test and refine the conceptual framework introduced in Section 6.4, thereby establishing an evidence-based competency framework for digital PMs operating within digitally transformed construction environments. The analysis follows a structured progression from descriptive statistics to latent structure identification and initial structural representation, in accordance with best practices in competency framework development and latent construct validation (Hair et al., 2010, Kline, 2023).

Section 6.5.1 provides descriptive statistics for all 55 competency items, including measures of central tendency, dispersion, and distribution shape, to assess the psychometric suitability of the dataset for factor analysis. Section 6.5.2 outlines the demographic and professional characteristics of the sampled participants, validating the appropriateness of the purposive sampling strategy employed and its alignment with the study's target population. Section 6.5.3 presents the results of the EFA, which was used to identify latent competency groupings and empirically assess their internal structure. Finally, Section 6.5.4 interprets the factor solution and introduces a preliminary structural framework, which will be further validated using CFA in Chapter 7.

Together, these results provide the empirical foundation for the validated Next-Gen Digital PM Competency Framework, which will be formally synthesised and tested in the next chapter.

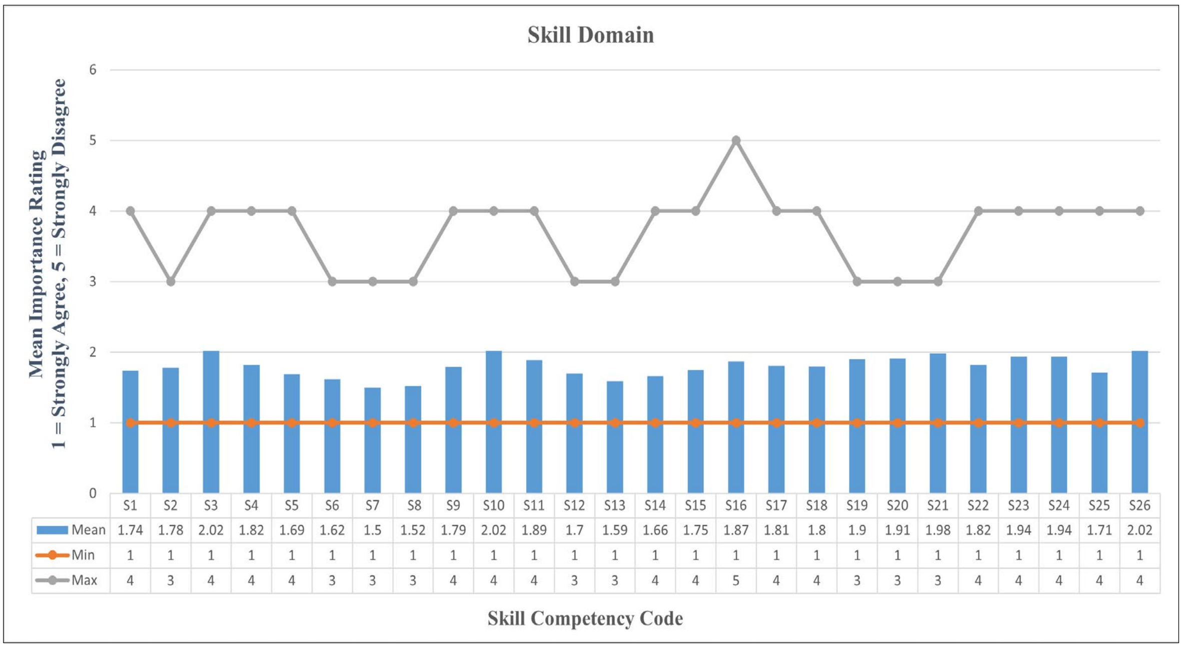
6.5.1 Phase One Outcome: Descriptive Statistics of Competency Items

This section presents descriptive statistics for the 55 competency items used to assess perceived agreement on Skills, Knowledge, and Core Personality Traits among digital PMs in the AEC sector. Each item was rated using a five-point Likert scale, where 1 indicates "Strongly Agree" and 5 indicates "Strongly Disagree." These statistics offer a preliminary evaluation of the dataset's psychometric properties and its readiness for latent variable analysis, including measures such as mean, standard deviation, range, skewness, and kurtosis.

6.5.1.1 Mean, Min, and Max

The mean, minimum, and maximum are fundamental descriptive statistics in psychometric analysis. The mean reflects the central tendency of responses, indicating the overall perceived importance or agreement level for each item. Minimum and maximum values provide insight into the spread of responses, identifying whether there is sufficient variance in the dataset to support factor extraction. A well-distributed range, particularly when paired with low means in a scale anchored at 1 = Strongly Agree, suggests strong endorsement and discriminative capacity across items (DeVellis & Thorpe, 2021; Field, 2024).

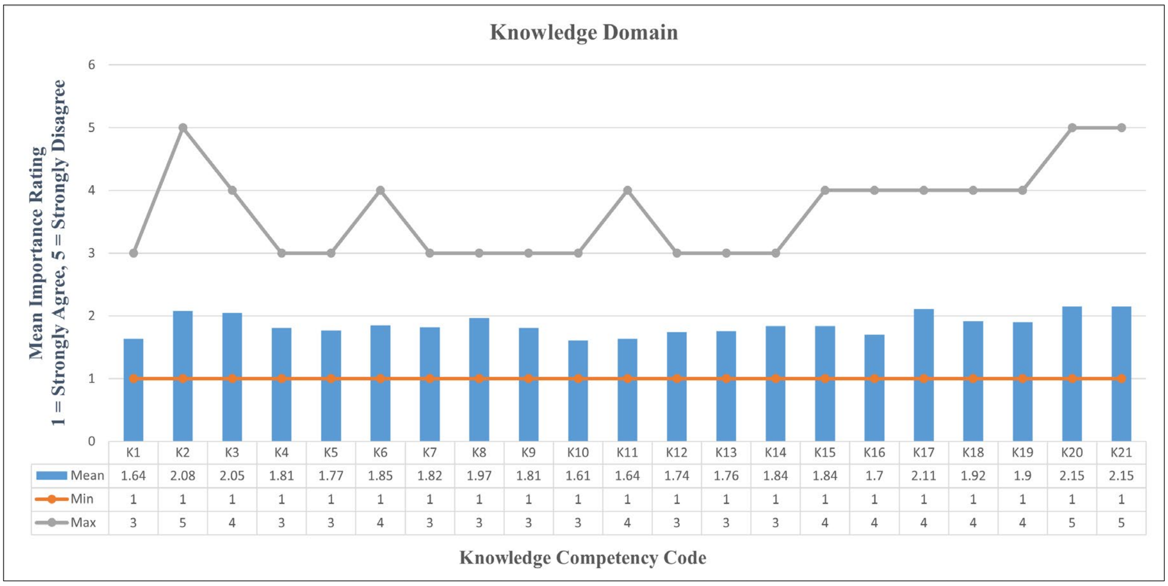
In the Skills domain, Figure 6.3 presents the descriptive statistics for the 26 skill-based competency items. Mean values mostly range from 1.50 to 2.02, with several items exceeding 1.90, indicating particularly valued skills such as S3. Digital Building Performance Optimisation, S10. Advanced Digital Content Management, and S21. Automated Digital Procurement Management. All items recorded a minimum value of 1, while the maximum values varied between 4 and 5. This spread confirms item-level variability and a strong discriminative range, supporting the psychometric integrity of the Skills domain.



	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	S26
Mean	1.74	1.78	2.02	1.82	1.69	1.62	1.5	1.52	1.79	2.02	1.89	1.7	1.59	1.66	1.75	1.87	1.81	1.8	1.9	1.91	1.98	1.82	1.94	1.94	1.71	2.02
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Max	4	3	4	4	4	3	3	3	4	4	4	3	3	4	4	5	4	4	3	3	3	4	4	4	4	4

Figure 6.3: Skills Competency Descriptive Statistics: Mean, Min, Max

In the Knowledge domain, Figure 6.4 displays the same set of descriptive metrics across 21 knowledge-based items. The mean ratings fall between 1.61 and 2.15, reflecting broad consensus on the high relevance of these competencies. Minimum ratings were consistently at 1, indicating that many participants rated these items as "Strongly Agree." Meanwhile, maximum ratings of 5 were observed for multiple items, affirming response variability and supporting the item set's suitability for latent structure analysis.



	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K14	K15	K16	K17	K18	K19	K20	K21
Mean	1.64	2.08	2.05	1.81	1.77	1.85	1.82	1.97	1.81	1.61	1.64	1.74	1.76	1.84	1.84	1.7	2.11	1.92	1.9	2.15	2.15
Min	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Max	3	5	4	3	3	4	3	3	3	3	4	3	3	3	4	4	4	4	4	5	5

Figure 6.4: Knowledge Competency Descriptive Statistics: Mean, Min, Max

For Core Personality Traits, Figure 6.5 presents the descriptive statistics for the 8 associated items. The mean ratings range from 1.43 to 1.99, suggesting strong consensus on the criticality of traits such as adaptability, team leadership, and resilience. Minimum values remained at 1 across all items, while maximum scores varied from 3 to 5, suggesting less dispersion but strong central agreement. The relatively tighter spread in this domain highlights more uniform perceptions, indicative of shared recognition of the importance of behavioural competencies in digital PM roles.

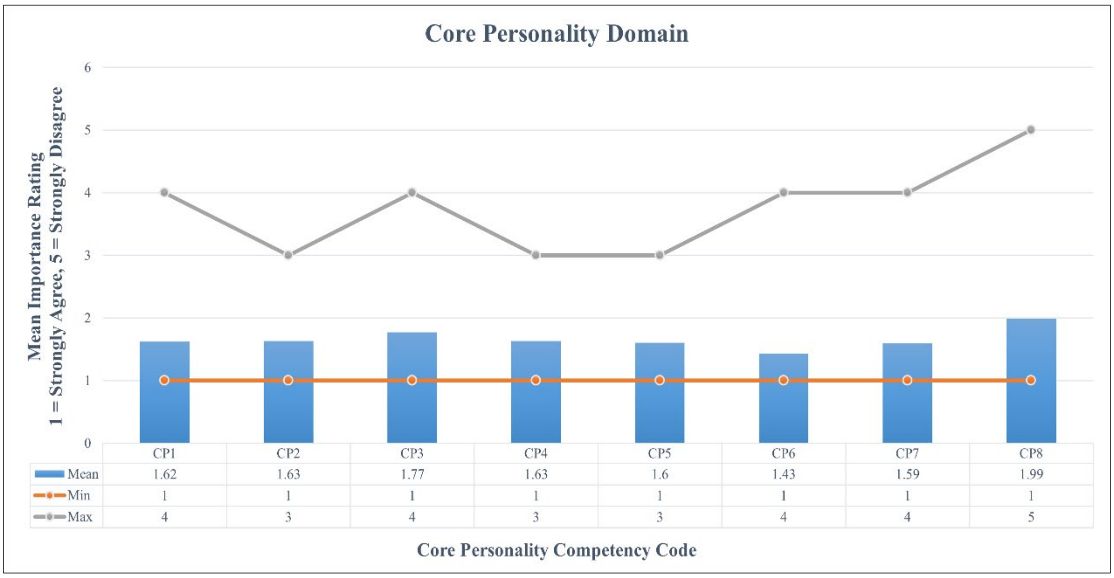


Figure 6.5: Core Personality Trait Descriptive Statistics: Mean, Min, Max

6.5.1.2 Standard Deviation and Response Variability Screening

As part of the preliminary data quality procedures, the SD was calculated using Excel for each individual respondent to assess overall response variability across all 55 survey items. This diagnostic step is commonly recommended in psychometric research to identify potentially inattentive or invalid respondents who may have provided uniform responses across items (e.g., selecting "1 – Strongly Agree" throughout), which can artificially inflate inter-item correlations and distort the outcomes of EFA (Clark & Watson, 2016; DeSimone et al., 2015; Meade & Craig, 2012).

A widely adopted screening threshold of SD < 0.25 was applied to flag cases exhibiting insufficient variability. This cut-off has been empirically supported in prior research as indicative of low engagement or lack of item discrimination and is commonly employed in scale development and validation studies (Curran, 2016; Huang et al., 2012). Responses falling below this threshold are typically excluded from EFA to prevent bias in the emergent factor structure and maintain psychometric integrity (Worthington & Whittaker, 2006).

In total, eight respondents were identified below the variability threshold, five with SD values ≥ 0.2328 and three with SD = 0. These responses were excluded from further analysis to uphold data quality standards. Notably, three of these five respondents may also have been among those excluded earlier for exceeding the 15% missing data threshold, as described in Section 6.3.3. This overlap reinforces the consistency of the exclusion process and supports the overall integrity of the cleaned dataset by addressing both response completeness and response variability through independent but complementary quality controls.

The remaining 103 valid cases demonstrated acceptable variability, with SD values ranging from approximately 0.2672 to 1.0899, reflecting meaningful differentiation in how participants rated the 55 competencies. A scatter plot of respondent-level SD values, sorted in descending order, is presented in Figure 6.6, with a visual threshold line at 0.25 demarcating excluded cases. This graphical representation provides further evidence of sufficient response engagement and confirms the dataset's appropriateness for latent structure exploration via EFA.

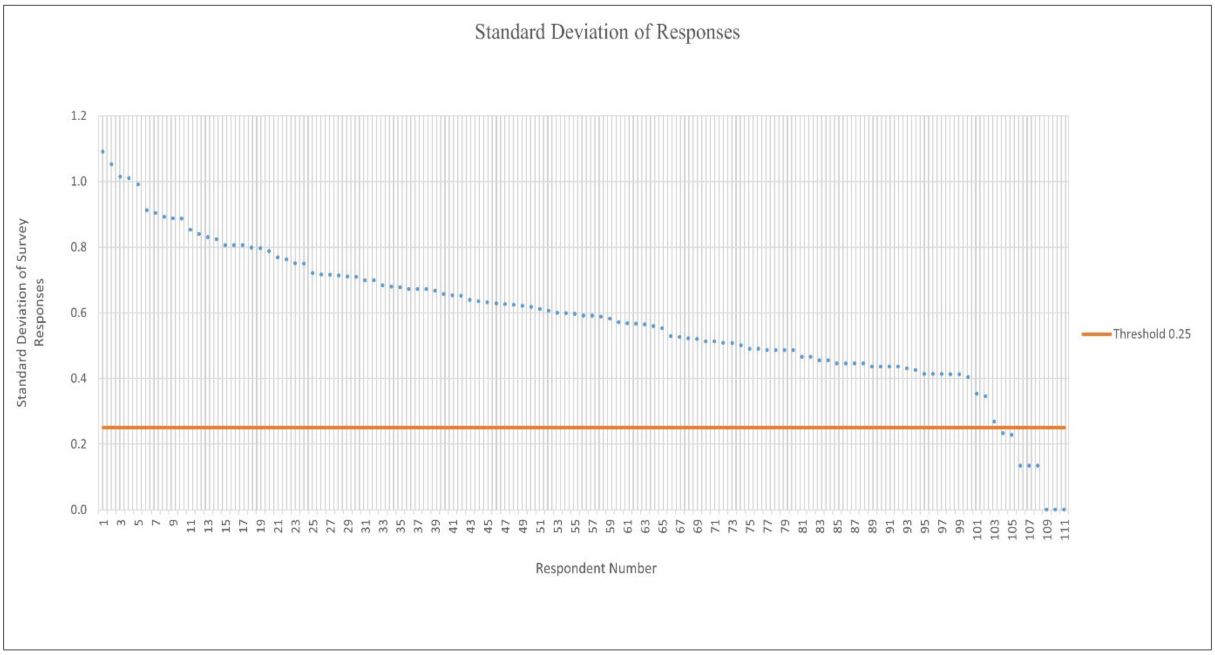


Figure 6.6: Standard Deviation Values per Respondent in Descending Order

6.5.1.3 Impermissible Value Screening and Range Validation

Following the SD screening, a secondary validation step was undertaken to identify any impermissible values, specifically, responses falling outside the designated Likert scale range of 1 (Strongly Agree) to 5 (Strongly Disagree). While such out-of-range entries are rare in established online platforms like Qualtrics, they may occasionally occur due to data entry errors, system glitches, or participant interference. If uncorrected, these values can distort statistical outputs and compromise the integrity of psychometric analysis (Hair et al., 2010; Byrne, 2016).

This screening was conducted on the final dataset of 103 valid responses, retained after applying the standard deviation threshold discussed earlier. The dataset was systematically examined using SPSS's descriptive statistics and frequency analysis tools. All 55 competency items were checked to ensure compliance with the valid scale boundaries. The analysis confirmed that every recorded value conformed to the specified range: no item exhibited values below 1 or above 5, as detailed in Appendix B: Impermissible Value Screening.

Some items showed a maximum score of less than 5 (e.g., maximum = 3 or 4). These instances were not classified as anomalies but were instead interpreted as natural variations in response distribution, indicating that no participants rated those specific items at the lowest level of agreement. This variability aligns with typical patterns of competency perception and does not compromise data quality.

These findings affirm the descriptive integrity of the dataset. A detailed item-level summary of minimum and maximum values is provided in Appendix B, supporting transparency and completeness in the data validation process.

6.5.1.4 Skewness and Kurtosis Analysis

To assess the distributional properties of the 55 competency items and confirm the dataset's suitability for factor-based parametric techniques, particularly PAF in EFA and Maximum Likelihood Estimation (MLE) for the planned SEM in Chapter 7, this study evaluated both skewness and kurtosis statistics. These metrics provide insight into the symmetry (skewness) and peakiness or tailedness (kurtosis) of item-level response distributions. Ensuring acceptable ranges for these values is an important prerequisite in psychometric research, as non-normal data may distort inter-item correlations and compromise model estimation (Kline, 2023; Hair et al., 2010; Byrne, 2016).

While the ideal range for normality is often set between ±1.0, for ordinal data such as five-point Likert-type items, a more flexible threshold of ±2.0 is commonly considered acceptable for EFA and SEM without requiring data transformation (Finney & DiStefano, 2006; DeCarlo, 1997). This reflects the practical robustness of estimation methods like PAF and MLE under real-world data conditions (Kyriazos, 2018; West et al., 1995).

The SPSS analysis revealed that skewness values across the 55 items ranged from 0.022 (S21) to 1.324 (CP6), and kurtosis values ranged from –1.369 (K8) to 2.334 (CP6). While the majority of items fell well within the recommended ±2.0 threshold, one item, CP6 (Core Personality Trait 6), slightly exceeded this limit, with a kurtosis value of 2.334. This mild leptokurtic shape is likely attributable to a strong consensus among participants about the critical importance of this trait. However, this deviation is marginal and does not violate the robustness assumptions of EFA or MLE-based SEM, especially given the adequate sample size (N = 103) and high communality expectations.

Accordingly, no data transformation was applied, and all items were retained for further analysis. A full summary table of skewness and kurtosis values is provided in Appendix C: Skewness and Kurtosis Screening, reinforcing transparency in the distributional assessment process.

6.5.2 Phase Two Outcome: Participant Demographics and Sample Characteristics

This section presents the demographic and professional characteristics of the survey participants, focusing on the final subset of 103 respondents whose data were retained for EFA and SEM. These respondents satisfied the initial inclusion criteria outlined in Section 6.3.2 and additionally met the descriptive and psychometric adequacy conditions detailed in Section 6.5.1, including minimum standard deviation thresholds, valid response ranges, and acceptable skewness and kurtosis parameters.

In total, 680 survey invitations were distributed, from which 111 responses were received (16.3%). Following data cleaning, 103 valid responses were retained, representing a final usable response rate of 15.1%. This aligns with the lower bound of the commonly reported benchmark of 15–30% for organisational surveys (Baruch & Holtom, 2008; Nulty, 2008).

A total of 111 responses were initially collected through purposive sampling. However, following SD screening and other data quality procedures (see Section 6.5.1.2), 8 responses were excluded due to insufficient response variability or failure to meet the minimum inclusion criteria. The remaining 103 valid cases represent a robust expert sample drawn from digitally engaged professionals within the AEC industry across New Zealand and Australia.

All retained participants satisfied the study's purposive sampling requirements, namely, a minimum of five years of professional experience in AEC-related disciplines and active involvement in digitally mediated project delivery. The diversity in roles, experience levels, and digital proficiency among these professionals demonstrates strong alignment with the study's target population and supports the methodological rationale for using expert-based sampling in competency validation research (Etikan et al., 2016; Palinkas et al., 2015).

As shown in Figure 6.7, the age profile of the 103 respondents was weighted toward mid-career professionals. The 30–39 age group accounted for the majority (55%), followed by the 40–49 age group (25%), and the 20–29 age group (13%). A small proportion of participants (7%) were aged 50 and over, while no participants or being excluded were under the age of 20. This distribution supports the inclusion criteria and affirms that the respondent pool reflects a professionally mature and experienced demographic with substantial exposure to digital construction practices.

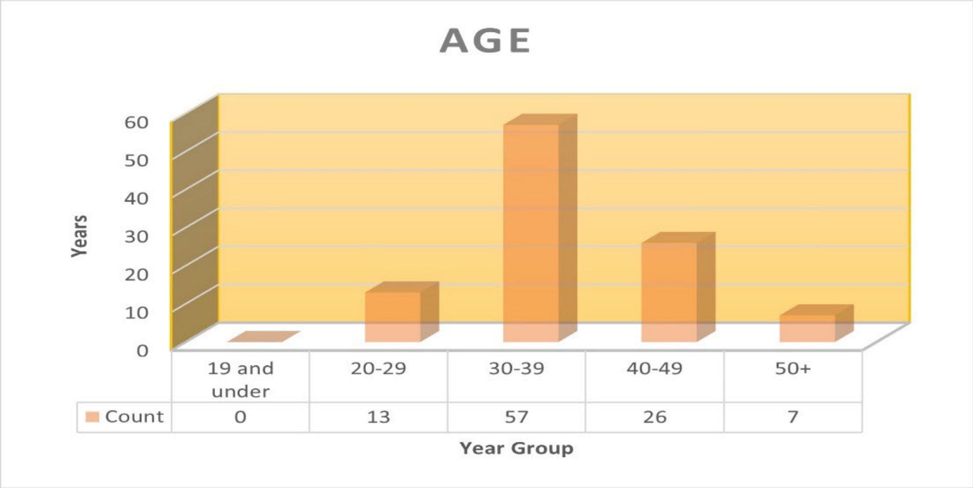


Figure 6.7: Age Distribution of Survey Participants

Also, Figure 6.8, illustrates that the respondent gender sample was predominantly male, with 76 participants (74%) identifying as male, and 26 participants (25%) identifying as female. One participant preferred not to disclose their gender, and no respondents identified as non-binary. This distribution reflects existing gender imbalances often observed in the construction sector, particularly in leadership and digital roles, and provides a realistic demographic context for interpreting competency expectations in the industry.

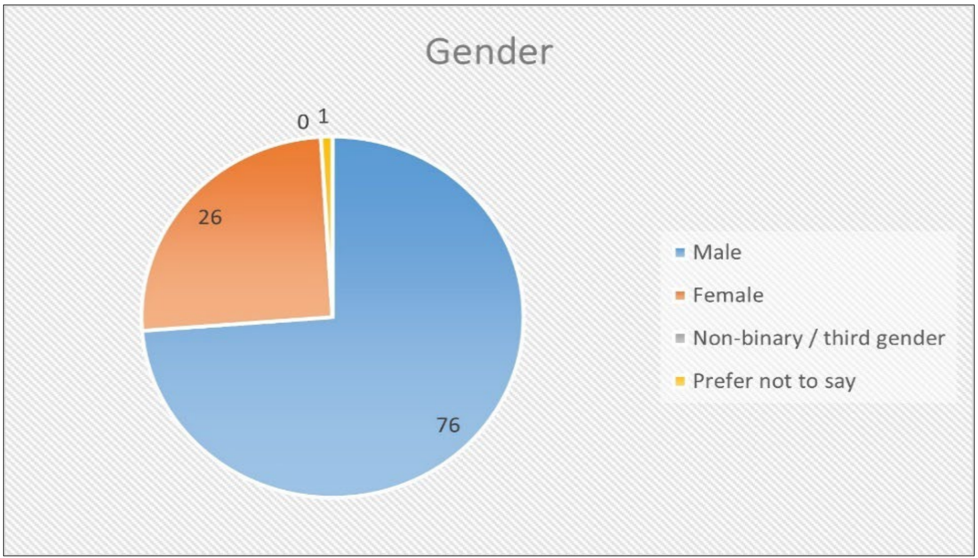


Figure 6.8: Gender Distribution of Survey Participants

Besides, all 103 respondents met the minimum inclusion criterion of having at least five years of professional experience in AEC-related fields. As shown in Figure 6.9, the largest subgroup (35%) reported between 5–10 years of experience, followed by 10–15 years (28%), 15–20 years (17%), and more than 20 years (19%). No respondents or have been excluded had less than five years of experience. This high level of professional maturity reinforces the credibility of the dataset and supports its use in validating a competency framework aimed at experienced digital PMs.

Figure 6.9: Years of Experience Among Respondents

The survey attracted a diverse range of participants from across the AEC industry. As shown in Figure 6.10, the most represented professional group was Digital and Technology roles (e.g., BIM/VDC specialists, digital engineers, data analysts), accounting for 34% of the total sample. This was followed by Project Management professionals (24%), and those in Construction Engineering (17%). A smaller proportion of respondents came from Design and Architecture (9%), while 16% selected "Other," indicating multidisciplinary roles such as academia, sustainability, or asset management. This disciplinary breadth reinforces the transdisciplinary relevance of the digital competencies being assessed.

Figure 6.10: Professional Field Distribution

Participants reported a broad range of current job positions, indicative of hierarchical diversity across the sector. As presented in Figure 6.11, the largest category (38%) included respondents in miscellaneous roles, such as consultants, academics, researchers, and specialists not explicitly covered by standard industry labels. These were followed by Managers (30%), Senior Managers (18%), and Directors (11%), while a small group of Quantity Surveyors (3%)

also participated. This mix of strategic and operational roles supports a balanced evaluation of competency relevance across project delivery tiers.

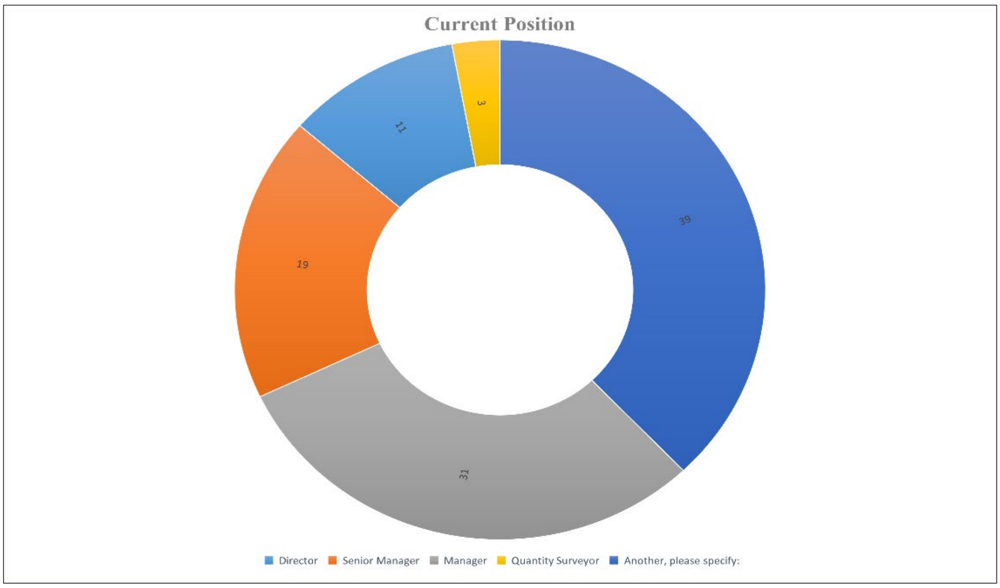


Figure 6.11: Current Position of Respondents

Furthermore, Figure 6.12 shown the educational attainment of respondents was high. 45 participants (44%) held a Master's degree, and 35 (34%) held a Bachelor's degree, indicating that the majority had advanced academic qualifications. A further 13 respondents (13%) reported holding a PhD, while smaller groups reported Diploma qualifications (3%) or selected "Other" (7%), which included postgraduate certificates or industry-specific training. This distribution reflects the increasingly academic nature of leadership roles in digital construction and supports the study's goal of establishing a theoretically grounded competency framework.

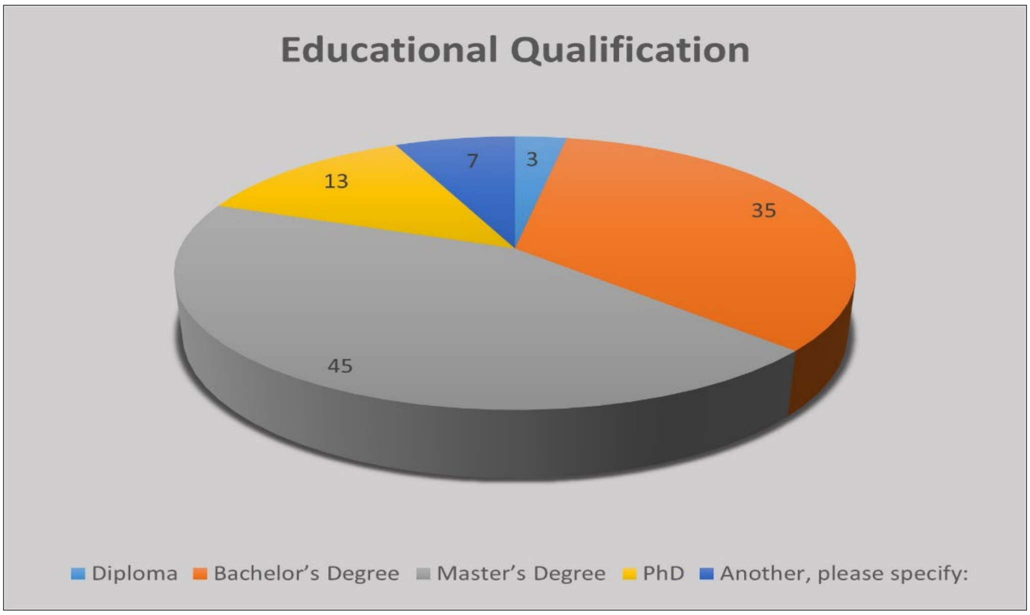


Figure 6.12: Educational Background of Respondents

In terms of self-reported familiarity with digital technologies, the sample demonstrated a strong orientation toward digital tools and systems. As illustrated in Figure 6.13, 37 participants (36%) identified as Very Familiar with digital construction technologies, while 47 (46%)

reported being Familiar. A further 18 respondents (17%) rated themselves as Moderately Familiar, and only one participant reported being Not Familiar. This distribution confirms that the respondent pool was digitally competent and well-positioned to evaluate the structure and relevance of the proposed digital PM competencies.

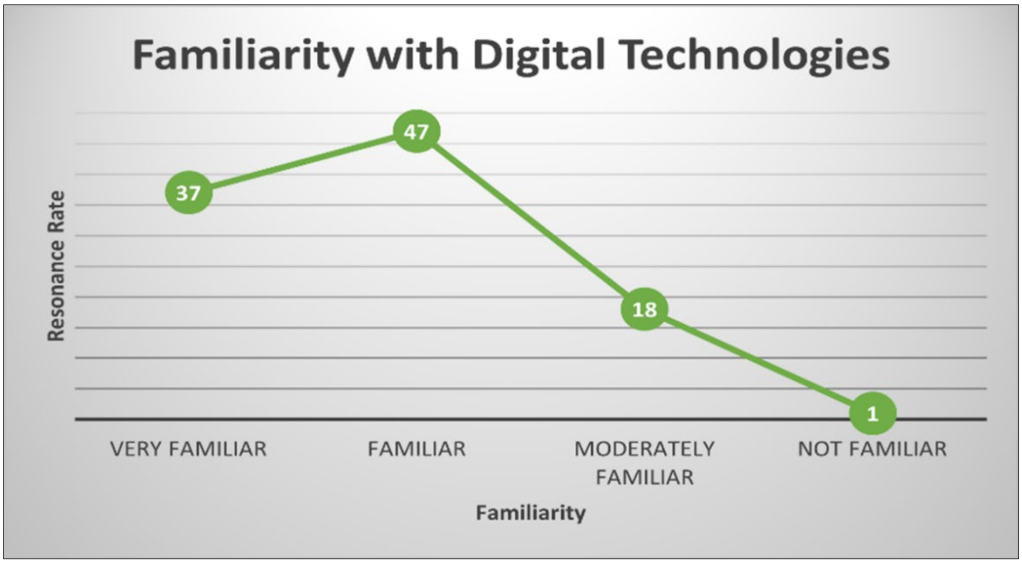


Figure 6.13: Familiarity with Digital Construction Technologies

In summary, the final dataset comprises 103 qualified respondents representing a diverse, experienced, and digitally engaged cross-section of the AEC sector across New Zealand and Australia. Their demographic and professional characteristics closely align with the target population identified in the study design, reinforcing the validity of the expert-based sampling strategy. Given the high level of digital familiarity and broad representation across roles and disciplines, this sample provides a robust foundation for EFA. The following section 6.5.3 presents the outcomes of Phase Three, where EFA was employed to empirically identify the latent competency structures underpinning the 55-item digital PM competency list.

6.5.3 Phase Three Outcome: EFA Results and Competency Factor Structure

This section presents the outcomes of the EFA conducted to empirically examine the latent structure of the 55 digital PM competencies. The primary aim is to validate and refine the theoretical competency taxonomy introduced in Chapter 5 by revealing statistically grounded latent dimensions across the Skills, Knowledge, and Core Personality Trait domains.

EFA is a robust multivariate technique used to identify patterns of interrelationships among variables and uncover underlying latent constructs (Fabrigar et al., 1999; Costello & Osborne, 2005). This phase employed PAF with Promax rotation to allow for correlated factors, consistent with theoretical expectations that competencies across domains are interdependent. Factor retention was based on a four-pronged approach incorporating the Kaiser criterion (eigenvalues ≥ 1.0), scree plot analysis, conceptual coherence with domain theory, and minimum item loading thresholds, as outlined in Section 6.3.3 (Worthington & Whittaker, 2006; Hair et al., 2010).

This section is structured into five subsections. Section 6.5.3.1 reports the results of the KMO Measure and Bartlett's Test for Sampling Adequacy. Section 6.5.3.2 explains the factor extraction and scree plot analysis. Section 6.5.3.3 examines communalities and item-level variance contributions. Section 6.5.3.4 presents the pattern matrix and interprets factor loadings. Section 6.5.3.5 addresses cross-loading diagnostics and item removal. The validated factor structure presented at the end of this phase forms the EFA-derived framework, which will be tested and validated through SEM in Chapter 7.

6.5.3.1 KMO and Bartlett's Test for Sampling Adequacy

Before conducting EFA, the dataset was evaluated for its suitability using two standard statistical diagnostics: the KMO Measure of Sampling Adequacy and Bartlett's Test of Sphericity. These tests assess whether the underlying data structure is appropriate for uncovering latent factors through EFA.

The KMO statistic quantifies the degree to which each variable in the dataset shares common variance with others. Values range from 0 to 1, with higher values indicating more compact and factorable correlation matrices. As recommended by Hair et al. (2010) and Field (2024), a KMO value ≥ 0.60 is considered acceptable for proceeding with factor analysis. Values between 0.70–0.80 indicate good adequacy, and those above 0.80 are deemed excellent. In this study, the overall KMO score was 0.736, confirming that the sampling adequacy is sufficient to justify factor extraction, as illustrated in Figure 6.14.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.736
Bartlett's Test of Sphericity	Approx. Chi-Square	3579.238
	df	1485
	Sig.	<.001

Figure 6.14: KMO and Bartlett's Test Output

The Bartlett's Test of Sphericity evaluates whether the correlation matrix significantly differs from an identity matrix, which would indicate no relationships among variables. A significant result suggests that sufficient inter-item correlations exist to support the use of EFA (Hair et al., 2010). In this case, the test produced a Chi-square value of 3579.238 with 1485 degrees of freedom and a p-value < 0.001, indicating that the matrix is suitable for factor analysis.

Together, these diagnostic tests confirm that the 103 retained survey responses meet the minimum statistical assumptions for factor analysis. The results validate the decision to proceed with the factor extraction procedures outlined in the following sections. A full summary table of the KMO and Bartlett's results is also included in Appendix D: KMO and Bartlett's Test results, ensuring transparency in the statistical validation process.

6.5.3.2 Factor Extraction and Scree Plot Analysis

Following confirmation of data suitability through the KMO and Bartlett's tests, the next step involved extracting the latent factor structure from the 55 digital PM competency items. The primary objective was to identify clusters of interrelated competencies that could represent underlying constructs within the broader domains of Skills, Knowledge, and Core Personality Traits.

As outlined in Section 6.3.3, PAF was employed as the extraction method due to its suitability for uncovering latent constructs that explain shared variance among observed variables, rather than merely reducing data dimensionality as in PCA. PAF is particularly well-suited to psychometric research where the aim is to model unobservable underlying traits (Costello & Osborne, 2005; Fabrigar et al., 1999; Field, 2024).

To determine the optimal number of factors to retain, the study employed a triangulated criterion: (1) eigenvalue ≥ 1.0 (Kaiser criterion), (2) visual inspection of the scree plot, and (3) theoretical alignment with the digital PM competency structure proposed in Chapters 3 and 4. According to DeVellis and Thorpe (2021), factors with eigenvalues greater than one are considered statistically meaningful, as they explain more variance than a single item. As shown in Figure 6.15, the data returned 15 factors with eigenvalues above 1.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings		
Factor	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	14.506	26.375	26.375	14.157	25.739	25.739
2	3.996	7.265	33.640	3.648	6.633	32.372
3	3.170	5.763	39.404	2.808	5.105	37.478
4	2.438	4.433	43.837	2.078	3.779	41.257
5	2.335	4.245	48.081	1.989	3.616	44.873
6	2.104	3.825	51.906	1.759	3.198	48.071
7	1.696	3.083	54.989	1.330	2.418	50.489
8	1.521	2.766	57.755	1.155	2.100	52.588
9	1.421	2.583	60.338	1.074	1.953	54.541
10	1.405	2.554	62.892	1.045	1.901	56.442
11	1.246	2.265	65.157	.910	1.655	58.097
12	1.193	2.169	67.326	.838	1.523	59.620
13	1.153	2.097	69.422	.801	1.456	61.077
14	1.081	1.965	71.388	.723	1.314	62.391
15	1.017	1.849	73.237	.663	1.206	63.597

Figure 6.15: Extracted Factors with Eigenvalues ≥ 1.0

However, statistical thresholds alone can be misleading when applied without visual and theoretical context (Costello & Osborne, 2005; Fabrigar et al., 1999). As illustrated in Figure 6.16, the scree plot shows an "elbow" at Factor 8, beyond which the eigenvalues flatten significantly. Notably, Factor 7 has lambda (λ) = 1.696, and Factor 8 has λ = 1.521, indicating a small decline of delta (Δ) = 0.175. Although both factors exceed the eigenvalue threshold of 1.0, this marginal drop suggests diminishing structural contribution. Following Auerswald and Moshagen (2019), very small eigenvalue differences between successive factors, typically around 0.17, are often interpreted as signs of weak explanatory gain. Although the observed difference between Factor 7 and Factor 8 slightly exceeded this threshold at 0.175, the minimal increase in explained variance suggested that Factor 8 contributed little additional conceptual value. As such, a seven-factor solution was adopted to preserve parsimony and theoretical coherence.

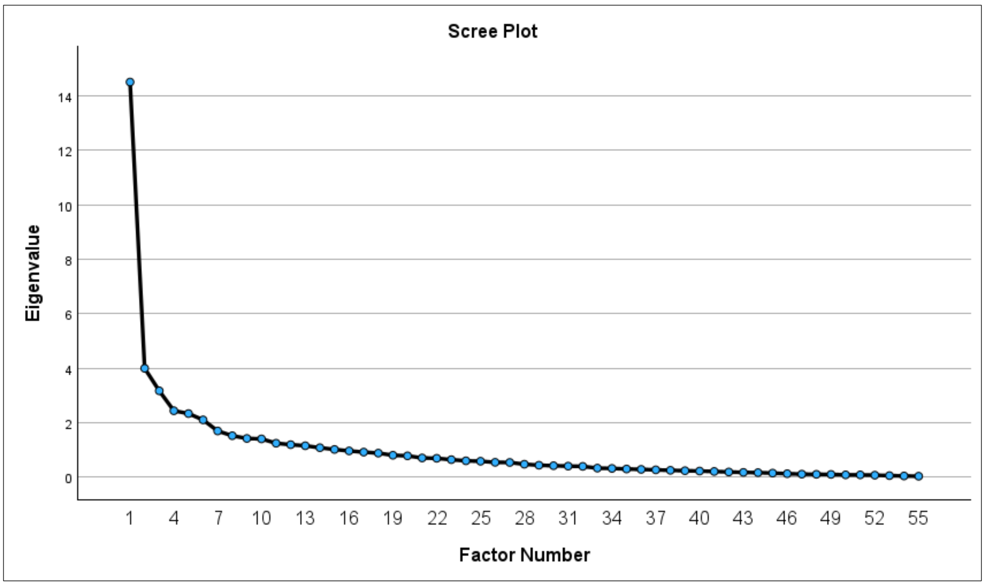


Figure 6.16: Scree Plot of Extracted Factors From EFA

The decision to retain seven factors was further supported by the theoretical framework underpinning this research. These factors mapped closely to sub-domains anticipated across the three major competency categories, Skills, Knowledge, and Core Personality Traits, with each factor predominantly comprising items from a single original domain. For example, several extracted factors consisted entirely of competencies drawn from the Skills domain, while others grouped items exclusively from the Knowledge or Core Personality categories. This domain-consistent clustering strengthens the theoretical validity of the initial taxonomy and demonstrates that the empirical structure reflects the conceptual distinctions established in earlier chapters. Such alignment not only confirms the coherence of the original domain classification but also affirms the integrity of the survey instrument and item development process.

As summarised in Table 6.2, all seven retained factors exceeded the Kaiser threshold and collectively explained 54.989% of the total variance, an acceptable range for social science exploratory factor models (Hair et al., 2010; Worthington & Whittaker, 2006). The full Total Variance Explained table is presented in Appendix E: Total Variance Explained – SPSS Outcome to support transparency and enable detailed inspection of eigenvalues and cumulative contributions across all extracted components.

Table 6.2: Total Variance Explained by the Seven Extracted Factors (Initial Extraction – Full Item Set)

Factor	Initial Eigenvalue	% of Variance	Cumulative %
1	14.506	26.375	26.375
2	3.996	7.265	33.640
3	3.170	5.763	39.404
4	2.438	4.433	43.837
5	2.335	4.245	48.081
6	2.104	3.825	51.906
7	1.696	3.083	54.989

The final decision to retain seven factors integrates empirical evidence with conceptual relevance. As emphasised by Worthington and Whittaker (2006), combining statistical indicators with theoretical justification enhances construct validity and ensures interpretability. The specific factor solution, including loadings, item composition, and alignment with the digital PM taxonomy, is presented in the following section (6.5.3.3).

6.5.3.3 Communalities and Item Adequacy

Following the decision to retain a seven-factor solution (as justified in Section 6.5.3.2), the communalities were recalculated using PAF with a fixed extraction of seven factors. This allowed for a more accurate estimation of each item's shared variance explained under the final factor framework.

Communality represents the proportion of an item's variance accounted for by the retained factors. Higher communalities indicate stronger associations between the item and the underlying latent constructs. According to Field (2024) and Hair et al. (2010), values above 0.30 are considered acceptable, while items with communalities below this threshold may require scrutiny for weak structural contribution or conceptual misalignment.

As shown in Appendix F: Communalities of Extracted Factors, the extracted SPSS communalities for the 55 digital PM competency items ranged from 0.264 to 0.681, confirming that the seven-factor framework captured meaningful shared variance across most items. Specifically:

- 28 items recorded communalities above 0.500, demonstrating strong explanatory power and clear alignment with latent factors.
- 23 items fell within the moderate range of 0.300–0.499, which remains acceptable for exploratory research, particularly when supported by strong theoretical foundations (Worthington & Whittaker, 2006).
- Four items, namely K21 (0.264), K10 (0.290), S21 (0.296), and S13 (0.292), recorded communalities slightly below the conventional 0.30 threshold.

Rather than excluding these four items outright, their theoretical importance and empirical behaviour were critically assessed:

- K21, the lowest-performing item by communality, was retained due to its conceptual significance in representing digital knowledge integration in construction. As discussed in Chapter 4, it captures domain-specific technical awareness vital to the digital competency taxonomy. Its removal would result in a meaningful gap in thematic coverage.
- K10 and S21, although statistically marginal, demonstrated acceptable pattern matrix loadings (see Section 6.5.3.4) and exhibited no problematic cross-loadings. Their content aligns with essential digital PM skillsets that may be context-sensitive but remain critical for comprehensive competency evaluation.
- S13, which focuses on Digital Technologies Training and Development, is central to enabling digital capability across teams. As defined in Chapter 4, this competency involves developing and delivering training programs, supporting ongoing digital education, and facilitating professional growth. While its communality was slightly low (0.292), this may reflect variation in training implementation across roles rather than weak conceptual coherence. Its retention ensures the framework adequately represents mechanisms of knowledge transfer and capacity-building crucial to digital transformation.

This approach is consistent with the recommendations of Costello and Osborne (2005), who argue that strict statistical cutoffs should not override theoretical relevance, particularly in construct development within the social sciences. Retaining these borderline items helps preserve the completeness, conceptual integrity, and practical relevance of the digital PM competency framework.

In summary, the communalities profile based on the seven-factor solution offers strong empirical support for item adequacy and factor coverage. These findings justify the retention of all 55 items in the rotated pattern matrix analysis and contribute to the robustness of the structural framework developed in the subsequent section (6.5.3.4).

6.5.3.4 Pattern Matrix and Factor Structure

This section presents the final rotated pattern matrix, which displays the loadings of each retained competency item on the seven extracted latent factors. In EFA, the pattern matrix shows the unique contribution of each item to a given factor after accounting for correlations among factors, offering a clearer interpretation of which items best represent each latent construct (Fabrigar et al., 1999; Hair et al., 2010).

Factor loadings in the matrix reflect the strength of association between an observed item and its corresponding latent factor. In line with established psychometric conventions, a minimum loading threshold of 0.40 was adopted to determine whether an item meaningfully contributes to its factor. Loadings below this threshold are typically considered too weak for reliable interpretation (Worthington & Whittaker, 2006; DeVellis & Thorpe, 2021).

Importantly, none of the retained items exhibited cross-loadings ≥ 0.30, ensuring a clean and well-defined factor structure. This clarity substantially enhances the discriminant validity of the framework and reinforces its structural integrity for CFA in Chapter 7 (Costello & Osborne, 2005; Kline, 2023). Clean factor loadings reduce the risk of model misspecification during CFA and contribute to stronger model fit indices.

While most retained items met the 0.40 threshold, two competencies, S10 (0.369) and S16 (0.378), displayed slightly lower loadings. These were deliberately retained due to their strong conceptual alignment with adjacent items, their established relevance in the literature, and their thematic coherence within their respective factors. As noted by Worthington and Whittaker (2006), slightly lower loadings may be justified when items add substantive value and enhance construct completeness.

The final matrix, presented in Table 6.3, illustrates the structure of the 25 retained digital PM competencies across the seven empirically derived factors. Competency codes and names are consistent with the validated Next-Gen Digital PM Competency List in Chapter 4.

Table 6.3: Rotated Pattern Matrix of Retained Competencies

Pattern Matrix[a]

	Factor						
	1	2	3	4	5	6	7
S3	.887						
S22	.745						
S20	.597						
S23	.546						
S15	.495						
CP5		.763					
CP1		.719					
CP3		.660					
CP2		.568					
K7			.766				
K8			.729				
K6			.448				
K19				.774			
K17				.689			
K18				.687			
S11					.690		
S12					.508		
S14					.477		
S7						.832	
S8						.543	
S10						.369	
S21							.621
S4							.599
S26							.438
S16							.378

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.
a. Rotation converged in 8 iterations.

It is important to note that the EFA process was conducted iteratively, whereby the removal of items resulted in recalculation of factor loadings and potential changes in the factor structure. As such, a single comprehensive pattern matrix including all initially considered items cannot be meaningfully presented, as loadings vary across successive refinement stages. The pattern matrix reported in this study therefore represents the final optimised solution following iterative item removal. Decisions regarding item retention and removal were based on cross-loadings, communalities, and theoretical alignment at each stage of the refinement process. Transparency of these decisions is provided through the retained item structure, Table 6.3, and the summary of removed items with justification, Table 6.4.

To interpret the pattern matrix shown above, the following points provide a detailed analysis of each empirically derived factor. For each factor, the associated competencies are listed, individually explained, and interpreted as a coherent thematic group. Based on the shared conceptual focus of the grouped items, a preliminary factor name is proposed to reflect the latent construct represented. Additionally, each factor is mapped back to the original Skills, Knowledge, or Core Personality Traits domains introduced in Chapters 3 and 4, allowing for a clear assessment of how the emergent factor structure aligns with the initial theoretical taxonomy.

- ❖ **Factor 1**

Factor 1 comprises five skill-based competencies related to digital project execution and optimisation: S3, S22, S20, S23, and S15. Each item demonstrates a strong focus on data-informed, systems-driven decision-making in complex construction environments.

- **S3. Digital Building Performance Optimisation**: This competency reflects the strategic use of technologies such as BIM to enhance operational and environmental performance throughout a building's lifecycle. It involves continuous monitoring and optimisation of systems to improve energy efficiency, durability, and long-term asset value. This skill is critical for aligning digital tools and frameworks with real-world sustainability and resilience goals.
- **S22. Digital Scheduling Management:** It addresses the synchronisation of time-related project data with digital construction workflows, particularly through advanced digital tools such as 4D BIM. It enables visualisation of sequencing, adjustment of project timelines in real time, and cross-team alignment. The competency is essential for proactive schedule control in digitally integrated project environments.
- **S20. Real-Time Cost Optimisation and Digital Budgeting:** This competency involves applying tools such as 5D BIM and cost-tracking technologies to ensure accurate budgeting and financial responsiveness throughout the project lifecycle. It supports financial governance through automated quantity take-offs, cost forecasting, and digitally enabled cost analysis, providing real-time decision support for project stakeholders.
- **S23. Digital Resource Management:** This competency focuses on coordinating labour, materials, and digital assets via centralised platforms. This includes aligning resource allocation with schedule and budget data, which contributes to improved project productivity, reduced waste, and enhanced sustainability. It also reflects the convergence of human and digital systems in resource optimisation.
- **S15. Digital Problem Solving and Technical Support:** This skill emphasises troubleshooting and adaptive thinking in digital contexts. It includes resolving technical issues in digital platforms, supporting software implementation, and guiding innovation during project delivery. It ensures teams are equipped to manage uncertainty and leverage technology for continuous improvement.

Together, these five competencies form a coherent cluster centred on the practical application of digital technologies to optimise core project constraints including cost, time, quality, and resources within dynamic environments. Each item reflects a competency to operate in data-rich, digitally enabled contexts while maintaining operational control and adaptability.

Based on the above analysis, a preliminary name for this factor is proposed as ***Digital Execution and Optimisation***. This factor grouping consists of five competencies, all of which originated from the Skills domain, as defined in Chapter 4 and Chapter 5 (Owais et al., 2025c). This confirms that the emergent factor structure is consistent with the original theoretical taxonomy, reinforcing the conceptual integrity of the Skills domain and validating its practical coherence through empirical grouping.

- ❖ **Factor 2**

Factor 2 includes four competency items drawn entirely from the CP Traits domain: CP1, CP2, CP3, and CP5. Each of these competencies reflects the behavioural, emotional, and interpersonal capacities required for leadership in collaborative, digitally enabled project environments.

- **CP1. Team Leadership in Digital Construction:** This competency highlights the ability to lead and manage multidisciplinary teams operating in virtual construction environments, such as BIM or DT-mediated settings. It encompasses building trust, equitable task coordination, mentoring, and conflict resolution. The emphasis is on empowering collaborative team dynamics and sustaining productivity in high-tech construction settings.
- **CP2. Stakeholder Leadership in Digital Construction:** This competency extends leadership beyond internal teams to encompass external relationships with clients, regulators, and end users. It focuses on leveraging digital tools to promote transparency, manage expectations, and facilitate engagement, making it essential for achieving collaborative stakeholder alignment in digitally enabled project delivery.
- **CP3. Digital Self-Leadership and Emotional Agility:** This competency reflects the internal capacity to regulate emotions, demonstrate resilience under pressure, and apply emotional intelligence in fast-paced, technology-driven projects. It supports personal effectiveness and enhances team influence by modelling adaptability and self-discipline during periods of uncertainty or disruption.
- **CP5. Team Well-Being Leadership:** This trait centres on promoting a psychologically safe and supportive team environment. It includes managing stress, morale, and health-related concerns in virtual or high-stakes digital teams. The competency reflects an emerging leadership role focused on sustainability in human capital, not just project outcomes.

Together, these competencies reflect a cohesive behavioural dimension of leadership suited for digitally mediated collaboration, where technical coordination must be supported by interpersonal insight, emotional intelligence, and stakeholder engagement. This cluster moves beyond operational efficiency and into human-centred digital project management, where people, wellbeing, and empathy are foundational to performance in virtual and hybrid teams.

Based on this interpretation, a preliminary name for Factor 2 is proposed as ***Human-Centred Digital Leadership***. The term captures both the interpersonal leadership aspect and the emotional self-regulation necessary for managing people within the evolving digital construction landscape. All four items originate from the CP Traits domain defined in previous chapters. This strong domain consistency supports the structural validity of the taxonomy and reinforces the relevance of behavioural and emotional competencies as an empirically distinct pillar of the Digital PM competency framework.

❖ **Factor 3**

Factor 3 consists of three knowledge-based competencies: K7, K8, and K6. Each item emphasises strategic and operational knowledge required to manage quality, contracts, and safety across the entire project lifecycle. These competencies reflect a knowledge-centric approach to ensuring performance, compliance, and risk mitigation through digital means.

- **K7. Digital Quality Assurance and Lifecycle Management:** This competency highlights the integration of quality control with lifecycle thinking using digital platforms like BIM. It involves tracking compliance with specifications, analysing performance data, and applying lifecycle information to ensure long-term value, sustainability, and continuous improvement. It supports a proactive approach to digital quality assurance that spans all phases of construction.

- **K8. Contract and Negotiation Management:** This knowledge trait focuses on the legal, regulatory, and strategic dimensions of contract administration. It includes negotiating terms, ensuring adherence to legal obligations, and managing conflict resolution. This knowledge area is essential for aligning digital workflows with contractual frameworks, ensuring transparency, accountability, and relationship management across stakeholders.
- **K6. Digital Safety and Risk Mitigation:** This competency reflects the application of digital tools to enhance safety planning and risk reduction throughout the project lifecycle. It includes BIM-enabled hazard detection, simulation of safety scenarios, and automated compliance monitoring. The emphasis is on anticipating and mitigating risk in a data-informed and systematic manner.

Together, these competencies reflect a cohesive knowledge dimension focused on governance, compliance, and risk assurance across the full construction lifecycle. Rather than representing isolated technical knowledge, this cluster underscores integrated oversight, where quality management, safety protocols, and legal contract administration converge within data-informed, digitally enabled environments. This grouping supports informed decision-making, enhances lifecycle performance, and embeds strategic governance responsibilities within the fabric of digital project delivery.

Based on this interpretation, a preliminary name for Factor 3 is proposed as ***Lifecycle Risk and Compliance Knowledge***. The term captures the unified oversight of risk, quality, and contractual control enabled by digital platforms and lifecycle thinking. All three competencies originate from the Knowledge domain as defined in previous chapters. This strong domain consistency reinforces the structural validity of the taxonomy and confirms the importance of governance-related knowledge as an empirically distinct cognitive pillar in the Digital PM competency framework.

❖ **Factor 4**

Factor 4 includes three competencies from the Knowledge domain: K19, K17, and K18. Collectively, these competencies focus on integrating sustainability goals into digital project delivery by leveraging smart systems, environmental analysis, and performance reporting. They reflect an evolving knowledge base in which digital PMs are expected not only to meet operational targets but also to advance ecological and environmental stewardship through data-informed decision-making.

- **K19. Sustainable Construction Strategies:** This competency highlights the importance of embedding sustainability principles into all aspects of project planning and execution. It includes awareness of environmentally responsible practices, such as selecting green materials and designing for ecological resilience. It positions the digital PM as a key contributor to long-term environmental goals within the built environment.
- **K17. Energy Efficiency and Carbon Management:** This knowledge trait focuses on optimising energy use and reducing embodied carbon through smart systems and simulation tools. It involves using digital platforms such as BIM and DTs to evaluate energy scenarios, select efficient systems, and monitor environmental impacts in real time. This competency enhances sustainability-driven decision-making during design and construction.

- **K18. Sustainability Reporting and Monitoring:** This competency relates to tracking, documenting, and communicating the environmental performance of construction projects. It includes analysing sustainability indicators, reporting carbon impact, and promoting transparency in environmental goals. By providing actionable data, this knowledge supports continuous improvement in digital sustainability performance.

Together, these competencies form a cohesive knowledge-based cluster focused on the integration of sustainability, energy intelligence, and environmental accountability in digital project delivery. They reflect a shift toward ecological responsibility within the PM's knowledge portfolio, where the digital environment becomes both a tool and a platform for promoting smart, sustainable construction.

Based on this interpretation, a preliminary name for Factor 4 is proposed as ***Digital Sustainability Intelligence***. This title reflects both the content (sustainability-focused knowledge) and the delivery mechanism (digital tools and platforms that support ecological performance). All three items originate from the Knowledge domain, as presented in Chapters 3 and 4. This consistency reinforces the integrity of the digital PM competency taxonomy and supports the classification of sustainability-related expertise as a discrete, empirically validated knowledge area.

❖ **Factor 5**

Factor 5 comprises three competencies from the Skills domain: S11, S12, and S14. Together, these competencies reflect the practical and technical capabilities required to engage with advanced digital systems, automate workflows, and manage project data environments. The cluster represents the digital PM's operational fluency in deploying, customising, and maintaining smart technologies that support efficient, scalable construction delivery.

- **S11. AI-Assisted Programming and Automation:** This competency relates to the ability to design and apply programmable or automated solutions that enhance construction processes. It includes proficiency in coding, data analysis, and the development of tailored software-based functions to automate repetitive tasks or solve domain-specific challenges. This skill set enables project teams to streamline workflows and embed innovation into core project functions.
- **S12. Smart Construction Digital Tool Utilisation:** This skill involves the creative and effective use of digital tools such as BIM, CAD, and simulation platforms to support visualisation, collaboration, and project accuracy. It reflects the digital PM's capacity to not only operate software effectively, but also to align tool outputs with technical standards, energy modelling requirements, and sustainability objectives. This competency supports the integration of digital tools into everyday construction practices.
- **S14. Smart Digital Documentation and Archiving:** This competency emphasises structured management of digital files, ensuring that all project documents, particularly those generated in CAD or BIM environments, are well organised, version-controlled, and accessible. It includes defining document protocols, establishing archiving systems, and ensuring long-term data usability across project phases and stakeholders.

Together, these competencies reflect a cohesive digital skillset centred on tool mastery, automation, and data environment management. They equip digital PMs with the technical fluency and operational discipline required to maximise the benefits of digital technologies across project lifecycles, ensuring reliability, repeatability, and innovation in practice.

Based on the above interpretation, a preliminary name for Factor 5 is proposed as ***Digital Tools Proficiency and Automation***. The title reflects both the practical application of digital systems, and the programming logic required to extend their impact. All three competencies originate from the Skills domain, as outlined previously, confirming a consistent structural alignment and supporting the taxonomy's integrity through empirical validation.

- ❖ **Factor 6**

Factor 6 comprises three competencies from the Skills domain: S7, S8, and S10. These competencies collectively reflect the digital PM's capacity to engage with data, content, and information ecosystems. The focus is on maintaining accuracy, integrity, and innovation within digital content workflows, ensuring that teams have access to validated data and adaptable digital resources throughout the construction lifecycle.

- **S7. Digital Data Evaluation and Analytics:** This competency focuses on validating and analysing digital project data to inform reliable, evidence-based decision-making. It includes verifying data accuracy, updating digital models in real time, and applying data visualisation techniques to derive insights. These skills ensure that project teams operate with relevant, high-quality data that reflects actual project conditions and changes.
- **S8. Cloud-Based Digital Content Management:** This trait emphasises the organisation and secure management of digital content in cloud-based environments. It includes setting up structured data repositories, applying data processing protocols, and maintaining responsible digital practices such as copyright compliance and secure information sharing. The competency is critical for facilitating collaboration and content integrity across distributed teams.
- **S10. Advanced Digital Content Management:** This skill extends beyond storage to the adaptive reuse and repurposing of digital content. It involves editing, refining, and synthesising digital assets to create new deliverables that meet evolving project needs. This fosters innovation, resource optimisation, and efficiency in content development across digitally enabled construction teams.

Together, these competencies form a skill-based cluster centred on data reliability, secure information exchange, and creative reuse of digital resources. They equip digital PMs with the tools to manage and transform digital content into actionable insights and tailored outputs, enhancing both collaboration and innovation across the project lifecycle.

Based on this interpretation, a preliminary name for Factor 6 is proposed as ***Digital Content and Data Management***. This name captures the integrated handling of both structured data and creative content in cloud-enabled construction workflows. All three competencies originate from the Skills domain, as defined in Chapter 4 and Chapter 5. Their domain consistency reinforces the structural validity of the taxonomy and confirms digital content and data governance as an essential, empirically distinct area of competency.

- ❖ **Factor 7**

Factor 7 includes four competencies from the Skills domain: S21, S4, S26, and S16. These competencies are unified by a strategic focus on digital transformation enablement, encompassing communication, procurement optimisation, innovation leadership, and workforce upskilling. They reflect a future-oriented skill set that equips the next generation of

PMs to adapt, lead, and empower teams for continuous improvement in digitally evolving environments.

- **S21. Automated Digital Procurement Management:** This competency relates to the integration of advanced digital tools, such as cost estimation and procurement management platforms, into construction workflows. It supports the generation of bills of quantity, links procurement activities to 5D cost and schedule simulations, and ensures timely, transparent, and data-driven material acquisition. This contributes to better alignment between design, budgeting, and supply chain operations.
- **S4. Digital Communication and Interaction Strategies:** This trait highlights the role of communication in bridging technical and non-technical perspectives in digital environments. It involves tailoring messages, tools, and strategies to different audiences while fostering collaboration across virtual, hybrid, and on-site teams. Effective communication ensures engagement with stakeholders and helps build trust in digitally enabled project settings.
- **S26. Innovation Management in Digital Construction:** This competency involves identifying, adopting, and leading the use of emerging technologies, including AI, automation, and big data, within the construction process. It supports cultural and strategic transformation by embedding innovation into the team's mindset and aligning technology adoption with broader project goals and industry trends.
- **S16. Digital Skills Gap Analysis and Development:** This competency focuses on evaluating digital proficiency at both individual and team levels. It includes identifying training needs, designing development pathways, and promoting digital maturity through active learning and upskilling. It also emphasises digital citizenship, encouraging engagement with broader digital services and frameworks.

Together, these competencies represent a transformation-oriented skill cluster focused on optimising operations, enabling innovation, strengthening digital communication, and fostering long-term digital capability. The group reflects the digital PM's evolving responsibility to lead not only projects but also people and processes into more advanced, adaptive, and future-ready states.

Based on this interpretation, a preliminary name for Factor 7 is proposed as ***Digital Transformation Enablement Skills***. This title encapsulates the dynamic and strategic nature of the competencies, emphasising innovation leadership, change communication, digital talent development, and procurement efficiency. All four items stem from the Skills domain, reinforcing the empirical coherence and domain alignment of this factor within the overall competency framework.

The rotated pattern matrix revealed a clean and well-defined factor structure, with all retained items demonstrating strong, singular loadings on their respective factors. This confirms the discriminant clarity of the extracted components and supports the conceptual alignment of competencies within the digital PM framework. The thematic cohesion of each factor, together with domain-level consistency, reinforces the empirical validity of the taxonomy developed in earlier chapters.

The next section examines potential cross-loadings and outlines the rationale for item removal. Although no problematic cross-loadings, commonly defined as secondary loadings exceeding 0.30, were identified in the final solution, the section discusses how such overlaps can compromise factor clarity and reduce model parsimony. A summary of the excluded items is also provided, with justifications based on thematic redundancy, conceptual overlap, or weak structural alignment, while acknowledging their continued relevance to broader digital PM practice.

6.5.3.5 Cross-Loadings and Item Removal

To ensure conceptual clarity and statistical robustness, this section presents the cross-loading assessment and item removal decisions undertaken during the EFA process. A central aim of this phase was to reinforce the discriminant validity of each extracted factor by removing items that exhibited ambiguous loading patterns, thematic redundancy, or insufficient contribution. These refinements enhance parsimony and improve the framework's readiness for subsequent validation through CFA.

In EFA, a cross-loading is typically defined as a secondary loading ≥ 0.30 on a non-primary factor (Costello & Osborne, 2005; Worthington & Whittaker, 2006). Such items may lack a clear conceptual home, compromise the interpretability of factors, and introduce redundancy across constructs. While the final rotated pattern matrix (Section 6.5.3.4) revealed no problematic cross-loadings, earlier extraction rounds identified a number of items that either:

- Cross-loadings ≥ 0.30 on multiple factors, which compromise discriminant validity;
- Insufficient loading strength, where the item failed to meet the recommended threshold of 0.40 on any single factor, thereby contributing limited explanatory value (Hair et al., 2010; Worthington & Whittaker, 2006);
- Conceptual redundancy with other items that better represented the factor structure;
- Or ambiguous thematic alignment, where items did not clearly map onto the emergent latent constructs.

Table 6.4 summarises the competencies removed during the iterative refinement process and provides brief justifications:

Table 6.4: Competencies Removed

Code	Competency Name	Reason for Removal
S1	**Advanced Digital Technology Proficiency**	Cross-loaded across multiple technical and strategic factors; lacked distinct thematic anchoring.
S2	**Digital Technology Integration**	Overlapped conceptually with several integration and execution items; reduced factor specificity.
S5	**Real-Time Digital Information Exchange**	Demonstrated ambiguous loadings; content overlapped with communication and data management clusters.
S6	**Digital Collaboration and Knowledge Retention**	Cross-loaded with both communication and innovation-related factors; weakened discriminant validity.
S9	**Digital Content Development Skills**	Shared variance with data handling and tool utilisation; lacked a clean loading path.
S13	**Digital Technologies Training and Development**	Diffused across upskilling and leadership factors; failed to stabilise on a single factor.
S17	**Cybersecurity and Digital Device Protection**	Cross-loaded across risk and IT clusters; remained statistically weak.
S18	**Digital Privacy and Data Protection Compliance**	Conceptually overlapped with legal and governance items; cross-loaded during analysis.
S19	**Emerging Technologies Cost Management**	Ambiguous loading between cost and innovation clusters; lacked unique conceptual identity.
S24	**Digital Quality Control**	Overlapped with broader lifecycle assurance items; diluted factor interpretability.
S25	**Digital Scope and Change Management**	Loaded across scheduling, planning, and execution clusters; created factor ambiguity.

K1	**Advanced Digital Construction Knowledge**	Broad theoretical scope resulted in diffuse loadings; insufficient specificity.
K2	**Emerging Technology Integration Knowledge**	Shared conceptual ground with innovation and technical domains; cross-loading prevented clean alignment.
K3	**Smart Systems and Applications Knowledge**	Cross-loaded with digital tools and automation competencies; lacked singular factor fit.
K4	**Digital Project Strategy and Goal Alignment**	Spread across leadership and governance domains; failed to anchor thematically.
K5	**Digital Project Integrated Management**	Statistically unstable; overlapped with multiple project execution constructs.
K9	**Regulatory and Compliance**	Cross-loaded with contract and governance factors; lacked distinct empirical support.
K10	**Language Proficiency**	Thematically relevant but isolated; weak factor convergence.
K11	**Digital Information and Data Literacy**	Distributed across multiple knowledge areas; lacked a coherent empirical grouping.
K12	**Digital Construction Risk Management**	Cross-loaded with safety, legal, and strategic knowledge domains; compromised clarity.
K13	**Digital Technology Adoption Risk Mitigation**	Shared conceptual ground with innovation and risk domains; failed to align cleanly.
K14	**Financial Risk Management**	Overlapped with budgeting and lifecycle management items; blurred loading pattern.
K15	**AI-Powered Data-Driven Decision-Making**	Cross-loaded across analytics and leadership factors; lacked statistical isolation.
K16	**Standardising Digital Technology Processes**	Overlapped with implementation and governance domains; failed to stabilise in one factor.
K20	**Qualifications and Professional Development**	Conceptually diffuse; weak empirical alignment with any emergent factor.
K21	**Curriculum Development**	Retained low communality and failed to cluster strongly; removed despite relevance.
CP4	**Decision-Making and Accountability**	Cross-loaded with leadership and governance traits; impaired construct clarity.
CP6	**Digital Team Communication and Collaboration**	Statistically unstable; overlapped with broader team coordination constructs.
CP7	**Digital Stakeholder Communication and Collaboration**	Cross-loaded between stakeholder management and digital communication factors.
CP8	**Digital Innovation and Creativity in Smart Construction**	Diffused across multiple innovation and personality factors; lacked clean empirical fit.

Although these items were excluded from the final factor structure, their relevance to digital project management remains significant. Each competency reflects a specialised domain that may not have emerged as a statistically distinct factor in this framework but still contributes meaningfully to broader professional practice. Their removal reflects a methodological focus on improving construct precision rather than questioning their importance. Future research may re-examine these competencies in more specialised sub-domains of digital construction or re-integrate them into extended competency frameworks as the digital landscape continues to evolve.

Although these 30 competencies were excluded from the final factor structure, their relevance to digital project management remains significant. Each competency reflects a specialised domain that may not have emerged as a statistically distinct factor within this study but still contributes meaningfully to broader professional practice. Their removal reflects a methodological focus on achieving parsimony, structural clarity, and discriminant validity, rather than questioning their conceptual importance. These competencies may therefore be re-examined in future research through larger or more diverse samples, role-specific frameworks (e.g., cybersecurity, AI integration, or training design), or qualitative validation methods such as Delphi studies.

The outcomes of this refinement process produced a parsimonious and statistically robust structure of 25 retained items across seven latent constructs, which together form the Next-Gen Digital PM Competency Framework. This framework represents the empirically validated foundation that will be further tested through confirmatory analysis in the next phase.

6.5.4 Phase Four Outcome: Empirically Derived Competency Structure for Digital PMs

This section presents the final outcome of Phase Four, which involved interpreting and consolidating the results of the EFA into a structured competency framework. Drawing on the validated pattern matrix and factor structure detailed in the preceding sections, seven latent factors were retained, comprising a total of 25 competency items. These groupings represent empirically derived clusters of digital PM competencies that converge around shared statistical patterns and thematic alignment, reflecting the underlying structure of digital competency requirements in the evolving construction sector.

Each factor was named according to the shared conceptual focus of its underlying competencies, as interpreted in Section 6.5.3.4. The resulting structure spans the full competency list developed in Chapter 4 and the taxonomy formalised in Chapter 5, encompassing the three core domains of Skills, Knowledge, and Core Personality Traits. This alignment confirms the theoretical relevance of the original framework and supports its empirical validity through factor-analytic evidence.

Table 6.5 summarises the final seven-factor solution, including each factor's label, associated competency codes, and the percentage of variance explained, based on the final output from Principal Axis Factoring with Promax rotation.

Table 6.5: Final Retained Factors, Competencies, and Variance Explained

Factor	**Factor Name**	**Returned Competencies**	**% Variance Explained**
1	Digital Execution and Optimisation	S3, S22, S20, S23, & S15	25.789%
2	Human-Centred Digital Leadership	CP5, CP1, CP3, & CP2	8.460%
3	Lifecycle Risk and Compliance Knowledge	K7, K8, & K6	6.347%
4	Digital Sustainability Intelligence	K19, K17, & K18	4.404%
5	Digital Tools Proficiency and Automation	S11, S12, & S14	3.542%
6	Digital Content and Data Management	S7, S8, & S10	2.927%
7	Digital Transformation Enablement Skills	S21, S4, S26, & S16	2.088%
			Total = 53.556%

Together, these seven latent factors capture the multi-dimensional nature of digital PM competencies in the context of digital transformation within the construction sector. They reflect a balanced integration of technical, cognitive, and behavioural competencies, offering a data-driven foundation for the development of next-gen digital PMs framework.

6.6 Final EFA-Derived Competency Framework for Next-Gen Digital PMs

This section presents the final structural and visual representation of the empirically validated Digital PM competency framework. Based on the EFA outcomes detailed in Section 5.4, seven distinct latent factors were identified, each comprising statistically and conceptually coherent clusters of competencies. These groupings reflect the evolving demands of digital project environments and consolidate the core capabilities required for PMs operating in technology-integrated construction settings.

As detailed in Section 6.5.3.4, each factor was thematically interpreted and named based on the shared intent, functional application, and behavioural or knowledge-based nature of its underlying competencies. Collectively, the seven latent constructs form a holistic framework that aligns with the integrated competency taxonomy developed through the identification of traditional competencies in Chapter 3, the development of digital competencies in Chapter 4, and their synthesis into a unified taxonomy in Chapter 5.

The final empirically derived factors are Digital Execution and Optimisation, Human-Centred Digital Leadership, Lifecycle Risk and Compliance Knowledge, Digital Sustainability Intelligence, Digital Tool Proficiency and Automation, Digital Content and Data Management, and Digital Transformation Enablement Skills.

To support clarity and practical usability, a visual model has been developed to illustrate the framework's internal structure. As shown in Figure 6.17, each latent factor is presented as a central node, with its associated competencies branching outward. This tree-style diagram provides a high-level overview of the competency architecture and enables intuitive comprehension of how specific digital capabilities are grouped within broader thematic domains.

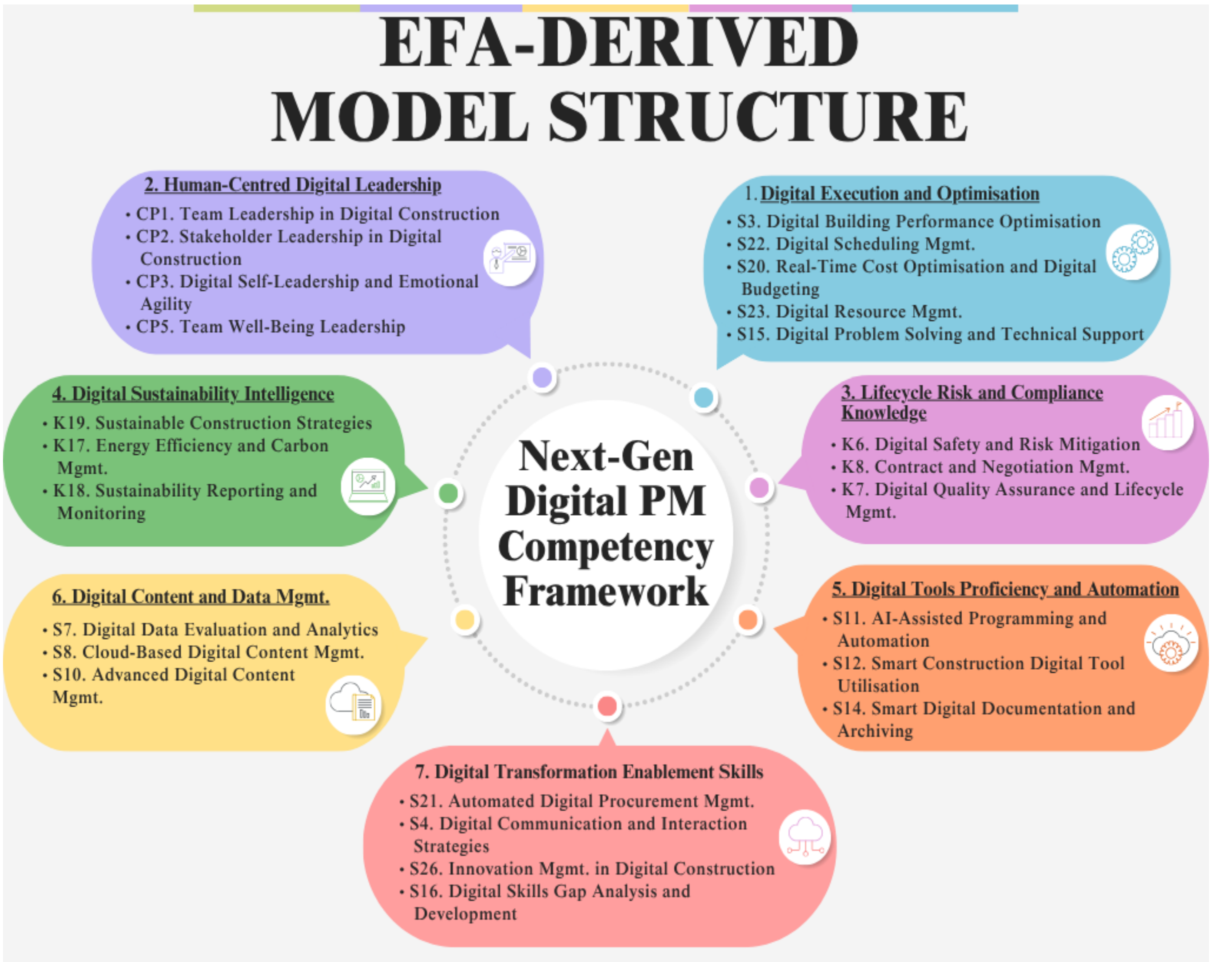


Figure 6.17: Next-Gen Digital PM Competency Framework: EFA-Derived Model Structure

This visual framework serves as both a summary of the EFA findings and a foundational model for confirmatory validation. It captures the multidimensional nature of digital PM competencies, integrating behavioural leadership, technical proficiency, innovation capability, and sustainability insight into a unified structure. This empirically grounded framework will now be subject to further validation through SEM in Chapter 7.

6.7 Limitations and Future Research

While this study offers a validated and empirically grounded competency framework for next-gen digital PMs competencies, several limitations must be acknowledged to ensure transparency and encourage scholarly advancement. The scope of the research was shaped by a purposive sampling strategy targeting professionals within a specific regional and industry context. As such, the generalisability of the findings may be limited across different geographic, cultural, or sectoral settings. Although the competencies reflect contemporary digital practices in construction, they may not fully account for variation in digital maturity or project delivery modes across global contexts.

Methodologically, the research employed a single-phase EFA to derive the underlying structure of digital PM competencies. While EFA served as a robust tool for uncovering latent patterns, it does not confirm model fit or allow for predictive validation. In this sense, the study is exploratory in nature and must be complemented by future confirmatory efforts, such as SEM, to test the framework's reliability and theoretical coherence across broader datasets. Although a sufficient sample size was achieved for EFA, future studies using larger and more diverse samples could strengthen the statistical power and enable more granular analysis of domain-level differences.

Another limitation relates to the exclusion of 30 competencies during the EFA refinement process. While their removal was necessary to enhance structural clarity, parsimony, and discriminant validity, these competencies remain conceptually valuable. Their absence narrows the immediate scope of the validated framework, but they may still inform specialised or extended competency sets in future studies. Re-examining these competencies in larger or more diverse samples, or in role-specific contexts such as cybersecurity, AI integration, or training development, represents an important pathway for model expansion.

In light of these limitations, several opportunities for future research are proposed. The framework would benefit from cross-country and cross-sector validation to explore how digital PM competencies manifest under varying socio-economic, cultural, and regulatory conditions. Longitudinal research could also be undertaken to assess how these competencies evolve over time and contribute to project performance and leadership outcomes in dynamic digital environments. Moreover, as digital transformation accelerates, new competencies are likely to emerge, and future studies may expand the framework to account for these developments, ensuring that it remains adaptive and responsive to the continuous evolution of digital construction practices.

By acknowledging these limitations and outlining clear directions for future inquiry, this research positions the current framework as a foundational model, one that offers a robust starting point for academic refinement, professional application, and sector-wide innovation. Rather than presenting a finalised structure, the framework serves as a platform upon which future researchers can build, advancing competency-based models for digital leadership in the built environment.

6.8 **Conclusion**

This chapter presented the results of the Exploratory Factor Analysis (EFA), leading to the development of an empirically grounded competency framework for Next-Gen Digital PM. Through a structured, multi-stage analysis, 55 digital competency items were assessed for statistical adequacy and theoretical coherence.

The final EFA output revealed a seven-factor structure comprising 25 retained competencies, as illustrated in Figure 6.17, which were statistically grouped into coherent thematic clusters aligned with the competency list and taxonomy introduced in Chapters 3, 4 and 5. The final empirically derived factors are Digital Execution and Optimisation, Human-Centred Digital Leadership, Lifecycle Risk and Compliance Knowledge, Digital Sustainability Intelligence, Digital Tool Proficiency and Automation, Digital Content and Data Management, and Digital Transformation Enablement Skills. Together, these factors represent the core domains required for digital PMs to operate effectively in the evolving construction sector.

By empirically identifying the underlying structure of digital PM competencies, this chapter confirmed the theoretical foundations laid out in earlier chapters while also strengthening the framework's practical applicability by eliminating weak or overlapping items and preserving conceptual integrity. Principal Axis Factoring (PAF) with Promax rotation was applied, resulting in a seven-factor solution supported by scree plot analysis, eigenvalue thresholds, and thematic interpretability criteria.

The chapter concludes with a visual representation of the empirically synthesised framework, setting the stage for confirmatory analysis. Chapter 7 will build on these findings by applying Confirmatory Factor Analysis (CFA) as part of the Structural Equation Modelling (SEM) process to test the structural validity of the framework. This transition marks a shift from exploratory development to confirmatory validation, completing the methodological arc of this research and advancing toward a rigorously tested competency framework for digital project leadership.

In addressing RQ4, *"How can the integrated taxonomy of traditional and digital competencies be empirically synthesised and modelled into an initial validated framework?"*, this chapter has empirically synthesised the integrated taxonomy through EFA and modelled it into an initial validated seven-factor framework for Next-Gen Digital PM.

Chapter 7 Confirmatory Validation of the Next-Gen Digital Project Manager Competency Framework via Structural Equation Modelling

This chapter is extended from:

- Owais, O. A., Poshdar, M., Ghaffarian Hoseini, A., & Jaafar, K. (2026). *Confirmatory factor analysis of a next-gen digital project manager competency model for construction digital transformation* (unpublished manuscript).

7.1 Abstract

This chapter validates the EFA-derived Next-Gen Digital Project Manager (PM) Competency Model through Confirmatory Factor Analysis (CFA), establishing its measurement quality and structural robustness. The baseline model comprised 25 observed indicators across seven first-order latent constructs. Iterative refinement removed three items flagged by high standardised residuals (±2.0), improving fit without compromising theoretical scope. The final model retained 22 indicators grouped into seven constructs: Digital Execution and Optimisation, Multi-Level Leadership, Governance and Risk Oversight, Sustainability Intelligence, Tools and Automation Proficiency, Content and Data Management, and Innovation and Change Enablement.

Model fit indices ($\chi^2/df = 1.276$, RMSEA = 0.052, SRMR = 0.0725, CFI = 0.928, TLI = 0.909, GFI = 0.841) met accepted benchmarks, with all loadings statistically significant ($p < 0.001$). Measurement quality was supported by strong reliability, convergent validity, and discriminant validity. As an early-stage validation, the CFA demonstrates that the model provides a credible and scalable baseline for digital PM competency assessment. It offers both a theoretical contribution and a foundation for practical applications, including workforce capability evaluation, training design, and future Structural Equation Modelling (SEM) to test predictive links between competencies and project outcomes.

7.2 Introduction and Background

The increasing integration of digital technologies into the architecture, engineering, and construction (AEC) industry has significantly reshaped the role of the Project Manager (PM). Digital platforms such as Building Information Modelling (BIM), Artificial Intelligence (AI), Digital Twins (DTs), cloud collaboration, and automated procurement tools are now central to how projects are planned, coordinated, and delivered. Within this context, the digital competency of PMs has emerged as a critical enabler of performance, innovation, and transformation. However, despite this shift, existing digital competency frameworks either lack sector-specific relevance or fail to capture the multidimensional requirements of digital PM, namely, technical proficiency (Skills), cognitive/strategic understanding (Knowledge), and behavioural adaptability (Core Personality Traits). This chapter presents the final validation phase of the proposed Next-Gen Digital PM Competency Framework, using Confirmatory Factor Analysis (CFA) to evaluate the structural integrity and measurement quality of the model developed through the preceding research phases.

Several existing digital competency models have provided valuable foundations for understanding digital skills in broader domains. The European Digital Competence Framework for Citizens (DigComp 2.2), developed by the European Commission, outlines 21 core competences across five areas: Information and Data Literacy, Communication and Collaboration, Digital Content Creation, Safety, and Problem Solving (Vuorikari et al., 2022). While this model is widely adopted in education and digital inclusion strategies, it is not tailored to the construction sector and does not reflect the complex leadership, technical integration, and domain-specific demands faced by PMs in digitally driven construction environments.

The European e-Competence Framework (e-CF) further contributes to digital skills development by offering 41 digital competencies structured across ICT roles and proficiency levels (CEN, 2019). While more oriented toward professional and workforce applications, the e-CF remains predominantly IT-centric. It lacks contextual relevance to construction PMs, especially in areas such as lifecycle information management, sustainability integration, and cross-organisational leadership in smart construction ecosystems.

Other studies have attempted to bridge the gap. Liu et al. (2022) proposed a "Digital Era Diamond Model" based on the analysis of 2,387 project management job advertisements in China. The model includes nine domains of PM capability, identifying digital competency as an emerging cluster. However, this digital domain is treated as a standalone component rather than a cross-cutting enabler that underpins all PM functions. Moreover, the model lacks statistical validation and does not account for the behavioural and strategic dimensions of digital leadership in construction.

Similarly, Mandičák et al. (2020) examined digital skillsets in construction, highlighting the growing use of BIM, simulation tools, cloud systems, and data analytics. While insightful, their work focuses on identifying tool-specific competencies and does not synthesise these into an integrated framework. The absence of empirical testing and conceptual grounding limits its application to competency modelling for construction PMs.

Collectively, these models demonstrate the growing attention to digital skills across various sectors but also expose a clear research gap. To date, no existing framework offers a validated, construction-specific, and multidimensional model of digital PM competency that integrates technical, strategic, and behavioural domains. Existing frameworks are either too generic (e.g., DigComp, e-CF), too IT-centric and lacking contextual relevance to construction PMs in areas such as lifecycle information management, sustainability integration, and cross-organisational leadership, too narrow (e.g., Diamond Model), or not statistically substantiated. Given the sector's rapid digitalisation, there is a critical need for a model that defines and validates the digital competencies required for PMs to lead digital transformation across the built environment (Mandičák et al., 2020; Rodrigues et al., 2023; Aibinu & Venkatesh, 2014).

This study addresses this gap through a multi-phase methodology that systematically builds and validates the Next-Gen Digital PM Competency Framework. As detailed in earlier chapters, the framework was developed through an intensive round of Literature Review (LR) and thematic grouping of traditional PM competencies (Chapter 3), a Systematic Literature Review (SLR), NVivo-based thematic analysis, and Large Language Modelling (LLM)-assisted synthesis to identify digital competencies (Chapter 4), followed by taxonomy-based classification and comparative analysis to integrate traditional and digital domains (Chapter 5) and Exploratory Factor Analysis (EFA) to uncover latent structures (Chapter 6). These stages yielded a theoretically coherent and empirically grounded preliminary model comprising seven latent constructs and 25 observed indicators (Brown, 2015; Hair et al., 2010).

The current chapter marks the shift from exploratory to confirmatory modelling. Using CFA in IBM SPSS Analysis of Moment Structures (AMOS) Version 29.0.0 (Build 4029781), this phase evaluates the robustness and statistical validity of the proposed factor structure. CFA tests whether the hypothesised model fits the observed data and meets established psychometric standards of internal consistency, convergent validity, and discriminant validity (Brown, 2015; Hair et al., 2010; Kline, 2023). This phase is guided by Research Question 5 (RQ5): *To what extent does the proposed framework demonstrate empirical validity and alignment with the competency demands of the digitally transformed construction industry?*

To answer this question, a CFA model comprising seven first-order latent constructs was tested. These constructs were initially represented by 25 observed indicators retained from the EFA process. The analysis was based on data collected from a sample of 103 AEC professionals across New Zealand and Australia. All data collection procedures were conducted in accordance with the ethical approval obtained from Auckland University of Technology (AUT), reference number (23/257), as detailed in Appendix A1: Ethics Approval and Documentation. Following model refinement guided by theoretical justifications and empirical diagnostics, such as modification indices and overall model fit, the final CFA model retains 22 indicators.

The validated constructs include Digital Execution and Optimisation, Multi-Level Leadership in Digital Construction, Governance and Risk Oversight in Digital Construction, Digital Sustainability Intelligence, Smart Construction Tools and Automation Proficiency, Digital Content and Data Management, and Digital Innovation and Change Enablement. Collectively, these constructs reflect the strategic, behavioural, and technical domains of digital PM capability required to lead innovation and transformation in smart construction environments.

Model evaluation is based on standard Structural Equation Modelling (SEM) practices, using key indices such as Chi-square/df, Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardised Root Mean Square Residual (SRMR). Measurement quality is further assessed using Composite Reliability (CR), Average Variance Extracted (AVE), and the Fornell–Larcker criterion (Hair et al., 2010; Kline, 2023). Only the 22 retained items are included in this analysis to maintain parsimony and ensure alignment with the refined factor structure.

In summary, this chapter completes the validation arc of the proposed framework. Through CFA, it provides empirical support for a conceptually grounded and statistically validated model of digital PM competencies in construction. This validated model strengthens the overall contribution of the thesis, bridging theory and practice, and offers a foundation for workforce development, curriculum design, and digital leadership planning.

7.3 Method

This section outlines the implementation of CFA using SEM in IBM SPSS AMOS (Version 29.0.0.0). CFA is a multivariate statistical technique used to test whether a set of observed variables reliably and validly represents a smaller number of underlying latent constructs, based on a predefined theoretical structure (Brown, 2015; Hair et al., 2010; Byrne, 2016). It allows researchers to assess how well the hypothesised model fits the observed data by evaluating the strength and consistency of the relationships between indicators and latent variables (Kline, 2023).

In this study, CFA is applied to validate the measurement model developed from the seven-factor competency framework empirically derived through EFA in Chapter 6. This model underpins the Next-Gen Digital PM Competency Framework, comprising 25 observed competency items grouped into seven first-order latent constructs. Following refinement, only 22 retained items were included in the CFA to ensure parsimony and alignment with the refined factor structure. The CFA procedure was therefore designed to assess the measurement model, with outcomes discussed in Section 7.4, including factor loadings, internal consistency, convergent validity, and discriminant validity (Brown, 2015; Hair et al., 2010; Kline, 2023).

The sample size (N = 103) is consistent with the dataset used in the previous EFA phase. All data collection procedures were conducted in accordance with the ethical approval obtained from AUT, reference number (23/257), as illustrated in Appendix A1. This dataset was previously cleaned and validated to ensure normality, reliability, and suitability for factor analysis. No further modifications were made prior to CFA, ensuring continuity between exploratory and confirmatory stages.

It is acknowledged that both EFA and CFA were conducted using the same dataset (N = 103). While independent samples are typically recommended for confirmatory validation to enhance generalisability and reduce the risk of overfitting, the available sample size did not permit data splitting without compromising statistical power and model stability. In line with established methodological guidance (e.g., Hair et al., 2010; Brown, 2015; Kline, 2023), this approach is considered acceptable in early-stage model development and validation research. To mitigate potential overfitting, model refinement was guided by theoretical justification, parsimony was maintained, and unnecessary modifications were avoided.

CFA was conducted using the Maximum Likelihood Estimation (MLE) method, widely recognised for its robustness and suitability in SEM applications when sample sizes exceed 100 and multivariate normality is assumed (Hair et al., 2010; Kline, 2023). The analysis was based on the covariance matrix of the 25 observed variables retained from the EFA process identified in Chapter 6. Each of the 22 refined items represents a digital PM competency aligned with one of the seven latent constructs.

The CFA model tested in this chapter includes seven first-order latent variables, with no higher-order model specified. Each latent construct is measured by 3 to 5 observed indicators, consistent with the factor structure empirically derived in the EFA. In line with CFA assumptions, no cross-loadings were permitted; each item was specified to load only on its corresponding factor (Brown, 2015). Importantly, each factor represents a thematically distinct domain grounded in the competency taxonomy developed in earlier chapters, aligning with one of the three overarching dimensions: Skills, Knowledge, or Core Personality Traits.

CFA was selected for this phase because it allows researchers to rigorously test the fit between observed data and a predefined factor structure, providing empirical validation for theoretical models developed through exploratory procedures (Hair et al., 2010). By evaluating multiple indicators simultaneously, CFA enables a robust assessment of both the structural integrity and statistical reliability of the proposed framework, with outcomes discussed in Section 7.5.

To assess the adequacy of model fit, the following standardised fit indices were employed:

- Chi-square/df (normed chi-square)
- Comparative Fit Index (CFI)
- Tucker–Lewis Index (TLI)
- Root Mean Square Error of Approximation (RMSEA)

- Standardised Root Mean Square Residual (SRMR)

The following thresholds guided the interpretation of model fit, based on widely accepted SEM criteria (Hair et al., 2010; Kline, 2023; Hu & Bentler, 1999):

- χ^2 / df ≤ 3.00 indicates acceptable absolute model fit
- CFI and TLI ≥ 0.90 are required for acceptable incremental fit, with ≥ 0.95 considered excellent
- RMSEA ≤ 0.08 is acceptable, with ≤ 0.06 representing a close fit
- SRMR ≤ 0.08 indicates a good residual fit between the model and the data

In addition to overall fit, construct validity was evaluated through:

- CR ≥ 0.70 for internal consistency
- AVE ≥ 0.50 for convergent validity
- Fornell–Larcker criterion for discriminant validity, where the square root of AVE must exceed inter-construct correlations (Hair et al., 2010)

Only the 22 refined items retained from the EFA were included in the CFA model to ensure parsimony and maintain theoretical coherence with the previously validated structure. The outcomes of this confirmatory analysis, including standardised loadings, fit indices, and validity coefficients, are presented in Sections 7.4 and 7.5, followed by a detailed interpretation in Section 7.5.4.

7.4 Measurement Model Assessment

This section presents a detailed assessment of the CFA model's psychometric quality, focusing on the strength, consistency, and validity of relationships between observed indicators and their corresponding latent variables. The evaluation aims to confirm that the seven-factor measurement model developed in Chapter 6 demonstrates both empirical adequacy and theoretical coherence. Specifically, four key aspects are examined in turn: Section 7.4.1 assesses the factor loadings of observed items onto their designated latent constructs; Section 7.4.2 evaluates the internal consistency of each construct using CR and Cronbach's Alpha (α); Section 7.4.3 examines convergent validity based on AVE; and Section 7.4.4 investigates discriminant validity through the Fornell–Larcker criterion. In addition, inter-factor correlations, error variances, and correlated residuals are reviewed to ensure that relationships between constructs are well understood and theoretically justified. Together, these subsections ensure that the proposed Next-Gen Digital PM Competency Framework, as operationalised through the seven-factor measurement model, represents a valid and reliable structure of latent dimensions aligned with the demands of the digitally transformed construction industry.

7.4.1 Factor Loadings

This subsection evaluates the strength of association between each observed competency item and its corresponding latent construct, using the standardised factor loadings derived from the CFA output in AMOS. According to best-practice SEM literature, factor loadings quantify the extent to which a measured item reflects the underlying latent variable it is intended to measure. Values of 0.40 or higher are typically considered acceptable for construct validity, particularly in exploratory contexts or when working with moderate sample sizes (Byrne, 2016; Tabachnick & Fidell, 2013). Higher loading values (e.g., ≥ 0.60) are preferred for stronger measurement precision, although theoretical justification and model parsimony may support retaining items with slightly lower loadings (Hair et al., 2010).

The final CFA model tested in this chapter includes 22 observed items grouped across seven first-order latent constructs, based on the factor structure empirically derived in Chapter 6. The model was refined by removing three indicators, S3. Digital Building Performance Optimisation, S16. Digital Skills Gap Analysis and Development, and S23. Digital Resource Management, which were flagged by high standardised residuals (±2.0) during diagnostic assessment, indicating localised model misfit rather than conceptual weakness. Each observed item was constrained to load on a single latent construct only, with no cross-loadings permitted, in accordance with CFA assumptions of unidimensionality.

In line with best-practice guidance from SEM literature, all subsequent measurement quality assessments in this chapter, including internal consistency, convergent validity, and discriminant validity, are conducted using the final, refined CFA model. This approach ensures that validity statistics are calculated based on the most parsimonious and theoretically sound solution. As Hair et al. (2010) emphasise, “Only when the measurement model is validated and achieves acceptable model fit can we turn our attention to a test of the structural relationships” (p. 650). Similarly, (Brown, 2015) underscores the importance of model validation through independent replication, noting that “in this strategy, the first sample is used to develop a good-fitting solution where some parameters are freely estimated… The final model is then fit in the second sample to determine its replicability with independent data” (p. 301).

As shown in Table 7.1, the majority of observed items achieved standardised factor loadings above the 0.40 threshold. However, one item, S11. AI-Assisted Programming and Automation yielded a slightly lower loading of 0.386. Despite this, it was retained due to its conceptual relevance to the Smart Construction Tools and Automation Proficiency construct and its satisfactory contribution to the internal consistency of the factor. The decision to retain S11 aligns with accepted CFA practices, where loadings just below conventional cutoffs may be preserved when theoretically justified and when the item does not negatively impact model fit (Weston & Gore, 2006; Brown, 2015).

In contrast, one item, S10. Advanced Digital Content Management had previously demonstrated a sub-threshold loading in the EFA phase (Chapter 6) but showed an improved loading of 0.499 in the CFA, exceeding the minimum threshold and affirming its empirical and conceptual value. By comparison, S16. Digital Skills Gap Analysis and Development continued to produce localised misfit and was therefore removed from the final model despite its theoretical relevance. The retention of S10 strengthens the integrity of its respective construct and supports the robustness of the overall factor structure (Hair et al., 2010).

In addition to factor loadings, the CFA output reports error variances (e1, e2, e3, etc.) for each observed item, see Figure 7.2. These represent the proportion of variance in each competency not explained by its corresponding latent construct. For example, S22 reported a low error variance of 0.14, indicating strong explanatory power from its factor, while S20 reported a higher value of 0.37, reflecting that a larger portion of its variance is item-specific and not explained by the latent construct. Across the 22 retained items, error variances ranged from 0.14 to 0.48, showing that while most items were strongly explained by their latent constructs, each retained a degree of unique variance. This balance demonstrates that items are reliable indicators while also capturing competency-specific variation that is not entirely reducible to the latent domain. In practice, lower error variances are preferable as they indicate stronger indicators, though moderate values may still be retained when theoretically justified.

Table 7.1: Standardised Factor Loadings from CFA

Construct (Factor)	Item	Loading
F1: Digital Execution and Optimisation	S15	0.722
	S20	0.587
	S22	0.836
F2: Multi-Level Leadership in Digital Construction	CP1	0.637
	CP2	0.648
	CP3	0.772
	CP5	0.556
F3: Governance and Risk Oversight in Digital Construction	K6	0.725
	K7	0.856
	K8	0.685
F4: Digital Sustainability Intelligence	K17	0.762
	K18	0.822
	K19	0.776
F5: Smart Construction Tools and Automation Proficiency	S11	0.386
	S12	0.473
	S14	0.705
F6: Digital Content and Data Management	S7	0.563
	S8	0.725
	S10	0.499
F7: Digital Innovation and Change Enablement	S4	0.567
	S21	0.549
	S26	0.737

Overall, the standardised loading structure presented in Table 7.1 reinforces the empirical adequacy of the model. The observed indicators display strong and consistent relationships with their associated latent variables, validating the structure of the proposed measurement model and providing a solid basis for evaluating internal consistency, convergent validity, and discriminant validity in Sections 7.4.2 to 7.4.4.

7.4.2 Internal Consistency

This subsection assesses the internal consistency of each latent construct using two complementary reliability measures: CR and Cronbach's Alpha (α). These indicators evaluate the extent to which observed competency items within each construct consistently reflect a shared underlying dimension.

CR refers to the degree to which a set of observed variables reliably measures a latent construct, considering both standardised factor loadings and measurement errors. It is widely regarded as a more accurate indicator of internal consistency in CFA models compared to α, as it accounts for item-specific contributions and model-based error terms (Raykov, 1997; Fornell & Larcker, 1981). The CR for each construct was calculated using the formula:

$$Composite\ Reliability\ (CR) = \frac{(\sum \lambda i)^2}{(\sum \lambda i)^2 + \sum \theta i}$$

Where:

- λi: Standardised factor loading of item *i*
- θi: Error variance of item *i* (calculated as $1 - \lambda_i^2$ if not directly reported)

Although many scholars use a benchmark of CR ≥ 0.70, values of 0.60 or higher are generally considered acceptable, particularly in exploratory models or constructs with fewer indicators (Bagozzi & Yi, 1988; Diamantopoulos & Siguaw, 2000).

α is a classical reliability coefficient that evaluates the internal consistency of a scale based on the average inter-item correlations. It assumes equal contribution from all items (tau-equivalence) and remains one of the most widely used reliability estimates in social sciences (Taber, 2018; Tavakol & Dennick, 2011). It is calculated as:

$$Cronbach's\ Alpha\ (\alpha) = \frac{\mathcal{N}.\bar{c}}{\bar{\mathcal{V}} + (\mathcal{N} - 1).\bar{c}}$$

Where:

- $\mathcal{N}$: Number of items in the construct
- $\bar{c}$: Average covariance between item pairs
- $\bar{\mathcal{V}}$: Average variance of individual items

α values ≥ 0.70 are traditionally regarded as good, though values between 0.60–0.70 remain acceptable, especially in the early stages of construct development or for scales with a small number of indicators (Hair et al., 2010; Taber, 2018; Peterson, 1994).

Table 7.2 summarises the CR and α values for all seven latent constructs in the final CFA model. Most CR values meet or exceed the 0.60 threshold, with four constructs surpassing the more conservative 0.70 benchmark, confirming satisfactory internal consistency in these cases. One construct records a CR value of 0.535; while below 0.60, such values can be acceptable in early-stage validation when supported by strong theoretical justification and adequate factor loadings. Similarly, several α values fall within the 0.60–0.70 range, which is justifiable given the conceptual relevance of items and the brevity of their respective constructs.

Table 7.2: Composite Reliability and Cronbach's Alpha for Each Construct

Laten Construct	Composite Reliability (CR)	Cronbach's Alpha (α)
1. Digital Execution and Optimisation	0.762	0.654
2. Multi-Level Leadership in Digital Construction	0.750	0.770
3. Governance and Risk Oversight in Digital Construction	0.801	0.790
4. Digital Sustainability Intelligence	0.830	0.826
5. Smart Construction Tools and Automation Proficiency	0.535	0.674
6. Digital Content and Data Management	0.626	0.613
7. Digital Innovation and Change Enablement	0.652	0.642

These findings indicate that the finalised measurement model demonstrates acceptable to strong reliability across most constructs. While three constructs (F5, F6, and F7) exhibit CR values below the widely recommended 0.70 threshold, two remain above 0.60, and one (F5) falls slightly below at 0.535. Values in the 0.50–0.60 range are generally seen as weak but can be tolerated in early-stage or developmental models when supported by strong theoretical rationale and acceptable factor loadings (Bagozzi & Yi, 1988; Diamantopoulos & Siguaw, 2000). In this case, the retention of F5 is justified because of its conceptual importance in representing automation and digital tool competencies, a domain central to the research problem. In all cases, the theoretical integrity of the constructs and the empirical adequacy of their retained indicators justify their inclusion. This supports the internal consistency of the model and affirms the reliability of retained items in capturing digital PM competencies across

Skills, Knowledge, and Core Personality domains. The following subsections examine convergent validity (7.4.3) and discriminant validity (7.4.4) to complete the validity assessment.

7.4.3 Convergent Validity

Convergent validity refers to the extent to which multiple indicators of a given construct are in agreement, thus confirming that they are measuring the same underlying concept. In CFA, this is commonly assessed using the AVE, which calculates the average proportion of variance that a construct explains in its associated observed variables (Fornell & Larcker, 1981; Hair et al., 2010). An AVE value of 0.50 or higher indicates that a construct explains more than half of the variance in its indicators and is generally considered evidence of good convergent validity.

The AVE values for each of the seven latent constructs in the CFA model were calculated using the following formula:

$$Average\ Variance\ Extracted\ (AVE) = \frac{(\sum \lambda i^2)}{\eta}$$

Where:

- λi = Standardised factor loading of item *i*
- η = Number of items in the construct

Table 7.3 presents the calculated AVE values for each construct.

Table 7.3: Average Variance Extracted (AVE) per Construct

Construct	**Items**	**AVE**	**Interpretation**
1. Digital Execution and Optimisation	3	0.525	Acceptable
2. Multi-Level Leadership in Digital Construction	4	0.433	Below - Conceptually justified, CR acceptable
3. Governance and Risk Oversight in Digital Construction	3	0.576	Strong
4. Digital Sustainability Intelligence	3	0.620	Strong
5. Smart Construction Tools and Automation Proficiency	3	0.290	Below - Weak AVE, retained with justification
6. Digital Content and Data Management	3	0.364	Below - Retained based on CR and relevance
7. Digital Innovation and Change Enablement	3	0.388	Below - CR acceptable, high conceptual fit

As shown in Table 7.3, three constructs (F1, F3, and F4) satisfy the AVE ≥ 0.50 threshold, confirming strong convergent validity. However, four constructs (F2, F5, F6, and F7) yield AVE values below this benchmark.

While these lower values suggest weaker convergence at the item level, each of the four constructs meets or exceeds the CR threshold of 0.60, which supports internal consistency. Moreover, the retained items in these constructs demonstrated acceptable factor loadings (all ≥ 0.40) and strong conceptual alignment with the theoretical framework established in Chapters 3 and 4. The lower AVE values can be attributed to the presence of several borderline yet theoretically important indicators with moderate factor loadings, as well as the limited number of items per construct (primarily three indicators), which increases sensitivity in AVE calculations. This is consistent with methodological recommendations that AVE values slightly below 0.50 may be tolerated when CR is satisfactory, the constructs are theoretically sound, and model fit indices are acceptable (Fornell & Larcker, 1981; Diamantopoulos & Siguaw, 2000; Bagozzi & Yi, 1988).

This approach is further defensible within developmental or exploratory CFA applications where model structures are emerging and empirical validation is still being refined (Hair et al., 2010). Additionally, the emerging nature of digital competency constructs in construction, combined with a moderate sample size (N = 103), may contribute to reduced shared variance among indicators, particularly in early-stage validation studies. Accordingly, slightly lower AVE values are considered acceptable when supported by satisfactory CR, strong theoretical grounding, and overall model adequacy.

In conclusion, despite four constructs falling short of the ideal AVE threshold, the overall model demonstrates acceptable convergent validity, supported by satisfactory CR values and strong theoretical justification. The next section (7.4.4) assesses discriminant validity using the Fornell–Larcker criterion to complete the construct validity evaluation.

7.4.4 Discriminant Validity

Discriminant validity refers to the extent to which a latent construct is truly distinct from other constructs in a structural model, both conceptually and empirically. It ensures that the indicators assigned to one latent variable are not unduly influenced by or redundant with indicators from another, thereby confirming that each factor captures a unique dimension of the theoretical framework (Fornell & Larcker, 1981; Kline, 2023). Within the context of this study, where digital PM competencies span diverse domains such as governance, sustainability, automation, and innovation, establishing discriminant validity is essential to demonstrate that the proposed seven-factor structure represents a multifaceted yet non-overlapping constellation of digital capabilities, as illustrated in Figure 7.1 (structural model without estimates).

Without adequate discriminant validity, the practical interpretability and theoretical coherence of the model would be compromised. Constructs that are highly correlated or conceptually indistinguishable may signal poor instrument design, item redundancy, or underlying model misspecification (Brown, 2015; Hair et al., 2010). This is particularly important when constructs are intended to support targeted interventions. For example, distinguishing between "Smart Construction Tools and Automation Proficiency" and "Digital Innovation and Change Enablement" is vital when designing domain-specific upskilling programs for PMs. If these constructs cannot be empirically separated, any intervention relying on such categories would risk conflating skills or misdirecting development resources.

Establishing discriminant validity is especially challenging in emerging or interdisciplinary domains such as digital construction, where construct boundaries are still being defined and technological overlap is often inherent. Nevertheless, rigorous testing helps determine whether empirical support exists for the theoretical distinctions proposed in the model. In this section, discriminant validity is evaluated using the Fornell-Larcker criterion, one of the most widely applied methods in SEM. This approach compares the square root of the Average Variance Extracted ($\sqrt{AVE}$) for each construct with its correlations with all other constructs in the model. The model output with standardised estimates is shown in Figure 7.2 (structural model with estimates), while the detailed results are presented in Table 7.4 and Table 7.5.

The inter-factor correlations (right-hand arrows in Figure 7.2) illustrate the empirical relationships among constructs. These values, ranging from 0.01 to 0.22, indicate generally weak-to-moderate associations, confirming that most constructs are empirically distinct. In this study, weak correlations were defined as $r < 0.10$, moderate as $0.10 \leq r < 0.15$, and strong as r

≥ 0.15, consistent with the thresholds applied in Figure 7.3. For example, stronger associations are observed between F1 and F4 (r = 0.16) and F3 and F4 (r = 0.22), while others such as F1 and F3 (r = 0.12) remain more moderate. This pattern reinforces the Fornell–Larcker results, which identified partial overlap among related domains. Such correlations are theoretically expected, as automation tools often depend on digital content systems and innovation-led strategies, underscoring both the interconnectedness and the partial distinctiveness of these competency areas.

A construct is considered to demonstrate discriminant validity when its $\sqrt{AVE}$ exceeds its correlations with all other constructs. Conversely, when a construct's correlation with another construct is greater than its $\sqrt{AVE}$, it indicates a lack of discriminant validity. This suggests that the two constructs may not be empirically distinct, possibly due to conceptual overlap, shared variance, or cross-domain interdependence. While this does not automatically invalidate the construct, it signals the need for careful theoretical justification and potential refinement. The discriminant validity outcomes for this study are presented in Table 7.4 and discussed in detail below.

The discriminant validity values for each of the seven latent constructs in the CFA model were calculated using the following formula:

$$\sqrt{AVE_i} > r_{ij}$$

Where:

- $\sqrt{AVE_i}$: Square root of the AVE for construct i, representing the amount of variance the construct explains in its own indicators. These values appear on the diagonal of Table 7.4.
- r_{ij}: Pearson correlation between constructs i and j, representing shared variance between different constructs. These values are reported in the off-diagonal cells of Table 7.4.

According to the Fornell-Larcker criterion, discriminant validity is established for construct i when the value of $\sqrt{AVE}$ (diagonal) is greater than all corresponding r_{ij} values (off-diagonal) in its row and column.

Table 7.4: Fornell–Larcker Discriminant Validity Matrix

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**
F1. Digital Execution and Optimisation	0.724	0.523	0.589	0.534	0.434	0.129	0.608
F2. Multi-Level Leadership	0.523	0.658	0.372	0.497	0.428	0.075	0.410
F3. Governance and Risk Oversight	0.589	0.372	0.759	0.634	0.214	0.227	0.539
F4. Sustainability Intelligence	0.534	0.497	0.634	0.787	0.283	0.291	0.551
F5. Tools & Automation Proficiency	0.434	0.428	0.214	0.283	0.538	0.793	0.727
F6. Content & Data Management	0.129	0.075	0.227	0.291	0.793	0.603	0.602
F7. Innovation & Change Enablement	0.608	0.410	0.539	0.551	0.727	0.602	0.623

To provide a consolidated view of reliability and validity, Table 7.5 summarises the CR, AVE, and $\sqrt{AVE}$ values alongside the inter-construct correlations. This integrated format facilitates quick verification of both convergent and discriminant validity, consistent with reporting practices in CFA/SEM literature.

Table 7.5: Summary of Construct Reliability and Validity (CR, AVE, √AVE, and Inter-Construct Correlations)

	CR	AVE	$\sqrt{AVE}$	F1	F2	F3	F4	F5	F6	F7
F1. Digital Execution and Optimisation	0.762	0.525	0.724	0.724	0.523	0.589	0.534	0.434	0.129	0.608
F2. Multi-Level Leadership	0.750	0.433	0.658	0.523	0.658	0.372	0.497	0.428	0.075	0.410
F3. Governance and Risk Oversight	0.801	0.576	0.759	0.589	0.372	0.759	0.634	0.214	0.227	0.539
F4. Sustainability Intelligence	0.830	0.620	0.787	0.534	0.497	0.634	0.787	0.283	0.291	0.551
F5. Tools & Automation Proficiency	0.535	0.290	0.538	0.434	0.428	0.214	0.283	0.538	0.793	0.727
F6. Content & Data Management	0.626	0.364	0.603	0.129	0.075	0.227	0.291	0.793	0.603	0.602
F7. Innovation & Change Enablement	0.652	0.388	0.623	0.608	0.410	0.539	0.551	0.727	0.602	0.623

As shown in Table 7.4, constructs F1 to F4 satisfy the Fornell-Larcker criterion, with each construct's $\sqrt{AVE}$ exceeding its correlations with other constructs. This confirms that these four domains, covering digital execution, leadership, governance, and sustainability, are empirically distinct.

However, constructs F5, F6, and F7 fail to meet the criterion, as their $\sqrt{AVE}$ values are lower than their correlations with at least one other construct. Specifically:

- **F5 (Tools & Automation)** correlates at 0.793 with F6 and 0.727 with F7, both of which exceed its $\sqrt{AVE}$ of 0.538, indicating a lack of discriminant validity.
- **F6 (Content & Data Management)** correlates at 0.793 with F5, which exceeds its $\sqrt{AVE}$ of 0.603, indicating a lack of discriminant validity. Its correlation with F7 is 0.602, which is marginally below the threshold and therefore acceptable.
- **F7 (Innovation & Change Enablement)** correlates at 0.727 with F5, exceeding its $\sqrt{AVE}$ of 0.623, which indicates insufficient discriminant validity between those two constructs. Its correlation with F6 is 0.602, which remains just under the threshold and therefore acceptable.

These results suggest statistical overlap between constructs related to operational tools, digital content, and innovation, which may reflect the interconnected nature of digital competencies in contemporary project environments. For example, automation tools (F5) often rely on digital content platforms (F6) and are implemented through innovation-led strategies (F7), making these constructs functionally interdependent.

Despite this, the theoretical distinction between these domains is well established in the literature and is reinforced by the competency taxonomy developed in Chapter 5. Furthermore, each of these constructs demonstrated:

- Acceptable CR ≥ 0.60 (with F5 just below at 0.535, retained on theoretical grounds)
- Factor loadings ≥ 0.40
- Alignment with distinct thematic pillars in the digital PM model

Therefore, although discriminant validity is not fully established for F5, F6, and F7, their inclusion in the final model is justified on conceptual and empirical grounds. This approach is consistent with recommendations from Fornell and Larcker (1981), who acknowledge that the AVE-based criterion is conservative and may not always reflect theoretical realities. Additionally, discriminant validity concerns are common in emerging models with conceptually adjacent constructs, particularly in complex domains such as digital transformation (Hair et al., 2010; Henseler et al., 2015).

In summary, the CFA model exhibits satisfactory discriminant validity for four constructs, with partial overlap identified among three others. This outcome highlights important areas for refinement in future research while maintaining the structural integrity and practical relevance of the current framework.

7.4.5 Residual Variances of Latent Constructs

The CFA output also reports residual variances for each latent construct, representing the proportion of variance not explained by its observed indicators. These values provide additional insight into the explanatory power of the model. As illustrated in Figure 7.2 (structural model with estimates) and summarised in Table 7.6, residual variances for the seven constructs range from 0.13 to 0.40. Lower residual variances indicate that a larger proportion of variance in the factor is explained by its items, whereas higher residuals suggest that more variance remains unexplained. his is a common outcome in social science models, where latent constructs capture complex, multidimensional competencies that cannot be fully represented by a limited set of indicators (Brown, 2015; Kline, 2023).

Table 7.6: Residual Variances of Latent Constructs (with strongest indicators and implications)

Latent Construct	Residual Variance	Interpretation	Strongest Indicator	Implication
F1. Digital Execution and Optimisation	0.27	Moderate unexplained variance; strong item contribution	S22 (0.836)	Solid representation of execution/optimisation, some variance reflects operational breadth
F2. Multi-Level Leadership	0.18	Low residual; factor well explained by items	CP3 (0.772)	Leadership indicators provide robust coverage; minimal unexplained variance
F3. Governance and Risk Oversight	0.29	Moderate residual; acceptable explanatory power	K7 (0.856)	Governance strongly indicated; residual reflects multidimensional oversight/risk facets
F4. Sustainability Intelligence	0.40	Highest residual; broader construct breadth	K18 (0.822)	Sustainability spans environmental/social/economic logics; harder to capture fully with few items
F5. Tools & Automation Proficiency	0.23	Low–moderate residual	S14 (0.705)	Adequately explained; expected overlap with content systems and innovation activities
F6. Content & Data Management	0.14	Very low residual; strong explanatory power	S8 (0.725)	Tightly defined construct; items capture most variance
F7. Innovation & Change Enablement	0.13	Very low residual; strong explanatory power	S26 (0.737)	Cohesive construct; indicators map closely to innovation/change enablement

*Strongest indicators are taken from the standardised factor loadings reported in Table 7.1.

Overall, these results show that while all seven constructs are well represented by their observed indicators, some (e.g., F4 Sustainability Intelligence) naturally retain more unexplained variance due to their conceptual scope. Conversely, F6 and F7 exhibit very low residuals, indicating that their items provide a strong empirical representation of the underlying domains. Taken together, the residual variance evidence complements the factor loadings, CR, AVE, and discriminant validity results presented in Sections 7.4.1–7.4.4 and supports the robustness of the seven-factor measurement model.

7.5 Confirmatory Factor Analysis (CFA) Model Specification

This section presents the CFA model used to validate the factor structure identified in the preceding EFA. The CFA was conducted to assess the goodness-of-fit of the proposed measurement model comprising seven latent constructs and 22 observed indicators. Each item was specified to load on one latent construct only, with no cross-loadings permitted, thereby maintaining theoretical alignment and ensuring consistency with CFA assumptions (Brown, 2015; Kline, 2023). The CFA analysis was carried out using IBM SPSS AMOS Version 29.0.0 (Build 4029781).

The final model retained 22 indicators across the seven first-order constructs: Digital Execution and Optimisation (F1), Multi-Level Leadership in Digital Construction (F2), Governance and Risk Oversight in Digital Construction (F3), Digital Sustainability Intelligence (F4), Smart Construction Tools and Automation Proficiency (F5), Digital Content and Data Management (F6), and Digital Innovation and Change Enablement (F7). Three items (S3, S16, and S23) were deleted during model refinement due to high standardised residuals and weak contribution to model fit, thereby ensuring parsimony and theoretical coherence. As discussed in the previous chapters, these constructs were derived through rigorous content validation and thematic analysis and subsequently tested empirically via EFA. The observed items corresponding to each latent construct are detailed in Table 7.8: Standardised Factor Loadings per Construct.

Figure 7.1 illustrates the clean baseline CFA model, displaying all latent constructs and their 22 retained observed indicators, following the deletion of three items to strengthen model fit and parsimony. No residual covariances are included in this baseline solution, which therefore represents the unrefined measurement model prior to the adjustments described in Section 7.5.1. The measurement quality of this baseline model, including factor loadings, internal consistency, and convergent and discriminant validity, has been evaluated in Sections 7.4.1 through 7.4.4. The remainder of this chapter now turns to a detailed evaluation of the model's structural fit and statistical adequacy.

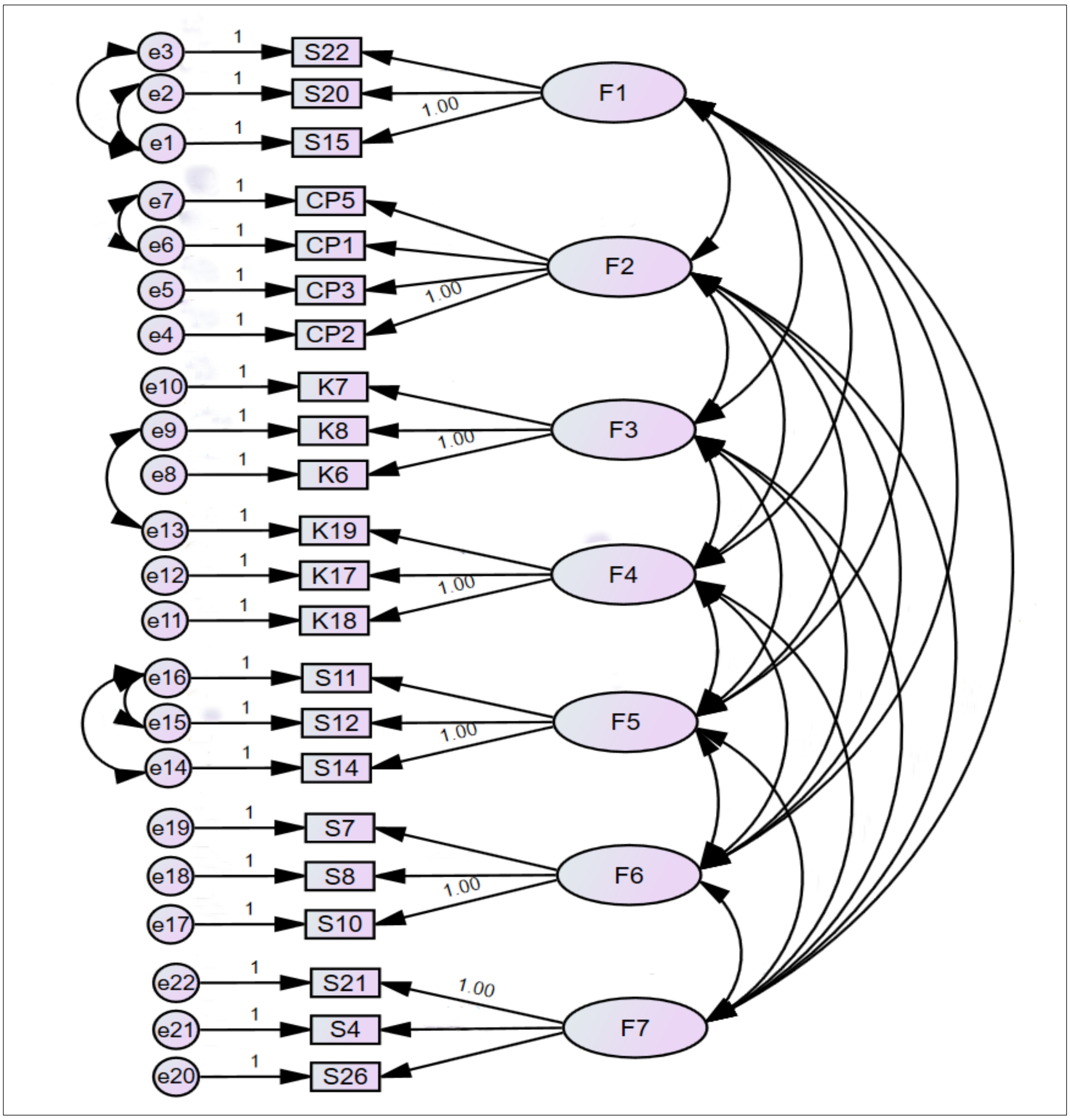


Figure 7.1: Final clean CFA model showing seven latent constructs and 22 retained observed indicators (baseline solution, no residual covariances).

This confirmatory phase builds upon the exploratory insights derived from earlier works (Chapters 3-6), aiming to statistically validate the underlying competency structure through a robust model fit evaluation. The CFA process not only affirms the theoretical integrity of the proposed constructs but also assesses the empirical strength of item/factor relationships. By triangulating conceptual foundations with quantitative evidence, the model offers a validated framework for understanding the digital PM's role within smart construction environments, while also providing a foundation for replication and refinement in different regional or industry contexts.

7.5.1 Model Fit Indices and Interpretation

To evaluate the adequacy of the CFA model, several model fit indices were examined, including the Chi-square to degrees of freedom ratio (χ^2/df), CFI, TLI, Goodness-of-Fit Index (GFI), RMSEA, and SRMR. These indices were selected based on their widespread use in SEM literature and their complementary strengths in assessing absolute, incremental, and residual-based model fit (Hair et al., 2010; Kline, 2023).

The final model yielded the following fit indices, as presented in Table 7.7.

Table 7.7: Summary of Core Model Fit Indices

Fit Index	Model Value	Recommended Threshold	Interpretation
Chi-Square/df (CMIN/DF)	1.276	≤ 3.0 (ideal: ≤ 2.0)	Good fit
RMSEA	0.052	≤ 0.08 (ideal: ≤ 0.06)	Acceptable
SRMR	0.0725	< 0.08	Good fit
CFI	0.928	≥ 0.90 (ideal: ≥ 0.95)	Good fit
TLI	0.909	≥ 0.90	Acceptable to good
GFI	0.841	≥ 0.90 acceptable (≥ 0.95 ideal)	Slightly below, but near acceptable

Evaluating the fit of the CFA model is a crucial step in validating the hypothesised latent structure derived from the earlier EFA. Model fit indices offer quantitative criteria to assess how well the theoretical model aligns with the empirical data (Hair et al., 2010; Kline, 2023).

The CFA model included seven first-order latent constructs and 22 observed indicators, with no cross-loadings permitted. Most of the model fit values met or closely approached the recommended thresholds, indicating that the model fits the data well. The RMSEA and SRMR values fall within the acceptable range, suggesting a minimal degree of residual error. Similarly, the CFI and TLI exceeded the widely accepted threshold of 0.90, confirming satisfactory incremental fit.

The slightly lower GFI (0.841), although below the ideal benchmark, is commonly observed in models with moderate complexity and is not uncommon in social science research involving multiple latent variables (Byrne, 2016). Given that all other fit indices converged around acceptable thresholds, the overall model is considered empirically robust, theoretically coherent, and defensible for confirmatory purposes.

To improve model fit and reflect theoretically meaningful relationships, a limited number of residual covariances were introduced between selected error terms (e.g., e1–e3, e6–e7), as illustrated in Figure 7.2 (final validated CFA model). These were informed by high modification indices and supported by strong conceptual proximity among specific indicators. Importantly, the refinement process remained strictly theory-driven, ensuring that adjustments enhanced the model's explanatory power without compromising parsimony or introducing statistical bias.

Specifically:

- **F1. Digital Execution and Optimisation:** Residual covariances were introduced between S15–S20 and S15–S22, based on their shared emphasis on enhancing digital workflow continuity and technical efficiency. All three items belong to the Skills domain, as outlined in the competency taxonomy. S15. Digital Problem Solving and Technical Support addresses the identification and resolution of technical issues, including software troubleshooting, model auditing, and innovation enablement. These problem-solving capacities underpin the operational success of S20. Real-Time Cost Optimisation and Digital Budgeting, which involves dynamic adjustments to cost models and design-linked budget planning. Similarly, S22. Digital Scheduling Management relies on responsive coordination and time-linked modelling to achieve delivery efficiency. All three competencies interact within feedback-driven digital ecosystems where system adaptability and cross-functional alignment are essential. Their conceptual overlap, centred on continuous model responsiveness, data-informed decision-making, and digitally supported coordination, justifies the observed covariances and supports their inclusion under the digital execution construct.

- **F2. Multi-Level Leadership:** A residual covariance was introduced between CP1. Team Leadership in Digital Construction and CP5. Team Well-Being Leadership to reflect their interdependent roles in guiding high-performing digital teams. Both items are classified under the Core Personality domain, contributing to the behavioural competencies required for leadership in digital contexts. CP1 focuses on strategic and interpersonal leadership skills, such as goal alignment, conflict resolution, mentoring, and inclusive task management. In contrast, CP5 highlights psychosocial leadership, including stress management, emotional safety, and team morale. Despite their different emphases, both competencies converge on the same leadership function, ensuring cohesive, motivated teams capable of delivering under digital complexity. Their shared focus on team engagement, psychological resilience, and participatory environments explains the empirical association and strengthens the internal consistency of the leadership construct in the CFA model.
- **F5. Tools and Automation Proficiency:** Residual covariances were introduced between S11 and S12, and S11 and S14, due to their conceptual overlap in supporting automated and documentation-driven workflows. S11. AI-Assisted Programming and Automation captures the use of coding and automation to streamline repetitive tasks. S12. Smart Construction Digital Tool Utilisation focuses on applying advanced digital tools in design and modelling environments. Both competencies emphasise efficiency through digital technology. Similarly, S14. Smart Digital Documentation and Archiving reflects the structured management of digital project files, often facilitated by automated systems. The use of AI-assisted solutions (S11) directly supports the implementation and maintenance of structured documentation (S14), justifying their empirical association. Together, these indicators represent an integrated digital toolkit aimed at improving productivity, standardisation, and data-driven delivery in construction.
- **F3-F4. Governance and Risk Oversight - Digital Sustainability Intelligence:** A cross-construct residual covariance was introduced between K8 and K19, both of which belong to the Knowledge domain, as defined in the taxonomy presented in earlier chapters. This shared domain affiliation underscores their conceptual proximity, even though they load onto separate latent constructs. K8. Contract and Negotiation Management focuses on managing contractual obligations and risk mitigation strategies across the project lifecycle, supporting legal, regulatory, and financial governance. Meanwhile, K19. Sustainable Construction Strategies relates to embedding environmental responsibility into construction practices through long-term planning and resource optimisation. Both competencies require lifecycle-oriented thinking and strategic foresight to guide successful project delivery, whether through legal compliance or environmental stewardship. Their empirical association is therefore theoretically justified, reflecting a unified approach to informed decision-making across governance and sustainability themes within the Knowledge domain.

These modifications align with recommendations from SEM literature (Brown, 2015; Henseler et al., 2015) and enhance the model's ability to represent complex but realistic digital PM competency relationships. Additional fit indices, including AGFI, PGFI, Hoelter Index, PCLOSE, and PCFI, are reported in Appendix G: Supplementary Goodness-of-Fit Indices to further support the model's acceptability.

In summary, the final CFA model demonstrates satisfactory overall fit, supported by both core and supplementary indices. The inclusion of a limited number of theoretically justified error covariances enhanced model performance without compromising its structural or conceptual clarity. These results confirm that the model provides a stable, theoretically grounded, and empirically validated representation of the latent competency structure underpinning digital PM roles in the built environment.

Building on this foundation, the following section (7.5.2: Factor Loadings and Item Retention) provides a detailed overview of the individual indicator loadings, highlighting the strength of each item's contribution to its corresponding latent construct. This evaluation further substantiates the validity and reliability of the measurement model.

7.5.2 Factor Loadings and Item Retention

This section presents the standardised factor loadings for all retained items in the final CFA model and offers a clear rationale for their inclusion based on both empirical strength and conceptual relevance. Factor loadings reflect the degree to which each observed variable (indicator) represents its underlying latent construct. Higher values indicate stronger contributions, with interpretation thresholds adapted from best-practice literature: loadings ≥ 0.70 are considered strong, 0.60–0.69 moderate to strong, 0.50–0.59 acceptable, and 0.40–0.49 as borderline but still acceptable with theoretical justification. Loadings below 0.40 are deemed marginal and typically require strong conceptual support to be retained (Brown, 2015; Hair et al., 2010; Kline, 2023).

The final model retained 22 observed indicators across 7 latent constructs, representing core domains of digital PM competencies. These items were refined through successive iterations of EFA and CFA. All standardised loadings were statistically significant ($p < 0.001$), supporting reliable associations between the observed items and their corresponding constructs.

Table 7.8 presents the item-level factor loadings, abbreviated descriptions, and categorised loading strength for each construct. To enhance traceability between the validated CFA model and the original competency framework, Table 7.8 includes a column linking each retained indicator to its corresponding competency from the initial list of 55 digital PM competencies presented in Chapter 4 (Figure 4.15). These constructs reflect a balance of technical, managerial, and behavioural domains, aligned with both the conceptual taxonomy introduced in Chapter 5 and the empirical structure derived in Chapter 6.

Table 7.8: Standardised Factor Loadings per Construct

Construct	**Item Code**	**Original Competency (Chapter 4, Fig. 4.15)**	**Item Description (Shortened)**	**Standardised Loading**	**Loading Strength**
F1. Digital Execution and Optimisation	S15	S15. Digital Skills Gap Analysis and Development	Troubleshoot and support digital workflows	0.722	Strong
	S20	S20. Real-Time Cost Optimisation and Digital Budgeting	Optimise project costs with 5D BIM tools	0.587	Acceptable
	S22	S22. Digital Scheduling Management	Manage scheduling via 4D BIM integration	0.836	Very Strong

F2. Multi-Level Leadership	CP1	CP1. Team Leadership in Digital Construction	Lead and motivate digital construction teams	0.637	Moderate–Strong
	CP2	CP2. Stakeholder Leadership in Digital Construction	Engage stakeholders through digital tools	0.648	Moderate–Strong
	CP3	CP3. Digital Self-Leadership and Emotional Agility	Self-lead, adapt emotionally in digital settings	0.772	Strong
	CP5	CP5. Team Well-Being Leadership	Ensure team well-being in digital projects	0.556	Acceptable
F3. Governance and Risk Oversight	K6	K6. Digital Safety and Risk Mitigation	Digital Safety and Risk Mitigation	0.725	Strong
	K7	K7. Digital Quality Assurance and Lifecycle Management	Digital Quality Assurance & Lifecycle Mgmt.	0.856	Very Strong
	K8	K8. Contract and Negotiation Management	Contract and Negotiation Management	0.685	Moderate–Strong
F4. Sustainability Intelligence	K17	K17. Energy Efficiency and Carbon Management	Energy Efficiency and Carbon Mgmt.	0.762	Strong
	K18	K18. Sustainability Reporting and Monitoring	Sustainability Reporting and Monitoring	0.822	Very Strong
	K19	K19. Sustainable Construction Strategies	Sustainable Construction Strategies	0.776	Strong
F5. Tools & Automation Proficiency	S11	S11. AI-Assisted Programming and Automation	AI-Assisted Automation	0.386	Marginal
	S12	S12. Smart Construction Digital Tool Utilisation	Smart Construction Tool Use	0.473	Borderline / Low
	S14	S14. Smart Digital Documentation and Archiving	Digital Documentation & Archiving	0.705	Strong
F6. Content & Data Management	S7	S7. Digital Data Evaluation and Analytics	Data Evaluation & Analytics	0.563	Acceptable
	S8	S8. Cloud-Based Digital Content Management	Cloud-Based Content Mgmt.	0.725	Strong
	S10	S10. Advanced Digital Content Management	Advanced Content Management	0.499	Borderline / Low
F7. Innovation & Change Enablement	S4	S4. Digital Communication and Interaction Strategies	Digital Communication and Interaction Strategies	0.567	Acceptable
	S21	S21. Automated Digital Procurement Management	Automated Digital Procurement Management	0.549	Acceptable

S26	S26. Innovation Management in Digital Construction	Innovation Management in Digital Construction	0.737	Strong

While most items meet or exceed the acceptable 0.40 threshold, several indicators were retained despite marginal or borderline values due to their theoretical importance and alignment with the underlying constructs. As supported by Hair et al. (2010), Brown (2015), and Kline (2023), factor loadings of 0.40 or above are considered suitable for early-stage CFA models, especially when indicators provide unique conceptual coverage that would otherwise be lost. Retaining such items ensures that the model captures the full breadth of competencies needed in digital project environments.

- **S11 (0.386)** was retained despite its marginal loading because it captures AI-assisted programming and automation, a foundational capability in digital transformation. Its conceptual proximity to S12, and supported residual covariance, justify its inclusion.
- **S12 (0.473) and S10 (0.499)** are both within the borderline range but offer essential coverage of automation tools and advanced content management practices. Removing them would omit important technical elements relevant to contemporary digital PMs.

This approach reflects academic best practice, whereby theoretical and contextual integrity are prioritised alongside statistical thresholds, particularly in formative stages of model validation (Hair et al., 2010; Brown, 2015; Kline, 2023).

Three items, S3, S16, and S23, were removed during earlier CFA refinement due to large, standardised residuals (±2.0) and signs of potential cross-loading behaviour, indicating localised model misfit. Their removal enhanced the model's parsimony and interpretability. Importantly, the retained items still cover the core conceptual domains of the digital PM competency taxonomy, ensuring no loss of theoretical depth.

In sum, the distribution of factor loadings supports both the multidimensionality and internal coherence of the model. Constructs such as Governance and Risk Oversight and Sustainability Intelligence demonstrate high internal consistency, with all loadings ≥ 0.70. Other constructs, such as Tools and Automation Proficiency, exhibit wider variation in factor loadings, including a marginal value below 0.40, highlighting the fragmented and rapidly evolving nature of digital skills in modern construction environments. These variations enhance the realism of the framework and affirm its capacity to model diverse digital competencies across technical, managerial, and behavioural domains.

Having established the strength and theoretical relevance of each retained item, the next section interprets the validated latent constructs in detail, illustrating how each contributes to the development of a structured, early-stage model of the Next-Gen Digital PM Competency. This interpretive analysis is followed by a summary of CFA outcomes and the presentation of the final validated model.

7.5.3 Interpretation of Latent Constructs and Contribution to Digital PM Competency

This section interprets the seven latent constructs validated through CFA, offering a conceptual explanation of how the grouped indicators contribute to a multidimensional model of digital PM competency. These constructs reflect the key capability domains required for leading digital transformation within smart construction environments. Building on the taxonomy established in Chapter 5, and the validated item definitions from earlier stages, this section elaborates on the theoretical coherence, practical utility, and leadership implications of each factor. Particular attention is given to how these latent constructs collectively support the development of a structured, early-stage competency model that empowers PMs to lead effectively in digitally enabled construction contexts and to serve as enablers of transformation within smart built environments.

Inter-factor relationships. As shown by the right-hand arrow's correlations between factors, Figure 7.2, most constructs are only weakly to moderately associated (≈ 0.01–0.22), supporting their empirical distinctiveness. Notable higher associations include F3–F5 (≈ 0.22), F1–F3 (≈ 0.18), and F1–F4 (≈ 0.16), which are theoretically expected: governance (F3) interacts with tool/automation practices (F5), and execution (F1) aligns with governance (F3) and sustainability (F4). Using conventional guidelines (small ≈ 0.10, medium ≈ 0.30), these values indicate limited overlap while acknowledging functional linkages needed in practice .

- **F1. Digital Execution and Optimisation:** Factor 1 captures the foundational technical capabilities that enable PMs to convert digital designs into real-time, cost-effective, and time-sensitive outcomes. It represents the operational core of digital project execution.
  - **S15. Digital Problem Solving and Technical Support** reflects the PM's ability to diagnose and resolve technical problems in digital environments, audit modelling outputs, and support team troubleshooting through strategic and repeatable interventions.
  - **S20. Real-Time Cost Optimisation and Digital Budgeting** highlights the use of advanced tools (e.g. 5D BIM) for live cost estimation, financial tracking, and resource alignment, empowering PMs to make financially informed design and procurement decisions.
  - **S22. Digital Scheduling Management** centres on integrating scheduling data into 4D models, enabling dynamic timeline visualisation, real-time updates, and coordination of construction activities based on digital model progression.

Collectively, these competencies equip PMs to synchronise cost, time, and performance through digital interfaces. This triadic optimisation is critical in reducing delays, preventing budget overruns, and increasing model accuracy. In smart construction, where precision and agility are paramount, the ability to execute efficiently through digital tools is essential. This construct forms a technical cornerstone of the digital PM's role in delivering complex projects with confidence, enabling proactive control over executional variables in dynamic environments.

- **F2. Multi-Level Leadership:** This construct encapsulates the behavioural and Emotional Intelligence (EI) capabilities needed for effective leadership across internal teams and external stakeholder networks in digitally intensive contexts.
  - **CP1. Team Leadership in Digital Construction and CP5. Team Well-Being Leadership** reflect the capacity to foster inclusion, build trust, promote psychological safety, and manage diverse teams within high-pressure, tech-enabled environments.
  - **CP2. Stakeholder Leadership in Digital Construction** extends leadership outward, focusing on aligning stakeholder goals, managing expectations, and resolving conflicts using digital coordination tools.
  - **CP3. Digital Self-Leadership and Emotional Agility** introduce the internal dimension of leadership, empowering PMs to stay emotionally grounded, resilient, and adaptable while role-modelling positive behaviour.

Together, these indicators build a robust leadership profile that spans personal mastery, interpersonal influence, and collective well-being. In digital construction, where rapid change and virtual collaboration are common, the PM must lead with emotional dexterity and relational intelligence. This factor reinforces the PM's critical role as a human-centred leader in an increasingly digitised and interconnected environment, bridging technological progress with sustainable team engagement.

- **F3. Governance and Risk Oversight:** Factor 3 anchors the strategic and compliance-focused dimension of digital PM. It highlights the importance of managing project safety, lifecycle quality, and contractual complexity through digital tools.
  - **K6. Digital Safety and Risk Mitigation** emphasise proactive risk identification and hazard resolution, supported by digital modelling, simulations, and automated safety checks.
  - **K7. Digital Quality Assurance and Lifecycle Management** enables real-time performance monitoring and compliance tracking through data-driven feedback loops and integrated lifecycle analysis.
  - **K8. Contract and Negotiation Management** brings in the legal-operational perspective, including the ability to manage contracts, resolve disputes, and negotiate terms within digital workflows.

These governance-oriented competencies ensure that digital PMs act not only as coordinators but also as custodians of compliance, accountability, and lifecycle integrity. Their ability to enforce safety, monitor quality, and manage contracts through digital systems positions them as strategic guardians of both project performance and legal sustainability, especially vital in regulated and risk-sensitive smart construction environments.

- **F4. Sustainability Intelligence:** This construct underscores the PM's emerging role as a sustainability champion within smart construction projects. It focuses on embedding environmental intelligence into design, delivery, and operational strategies.
  - **K17. Energy Efficiency and Carbon Management** reflects the use of smart technologies to measure, simulate, and optimise energy and carbon performance.
  - **K18. Sustainability Reporting and Monitoring** involves tracking environmental data and generating transparent sustainability reports to meet stakeholder and regulatory expectations.
  - **K19. Sustainable Construction Strategies** promotes ecological decision-making in design and construction processes, emphasising material efficiency, lifecycle sustainability, and green innovation.

By embedding these competencies, digital PMs are not just responders to sustainability mandates, they become leaders of change, capable of aligning project goals with long-term environmental values. This construct reinforces that sustainability is not a peripheral concern but a core strategic driver of innovation, resilience, and value in the smart built environment.

- **F5. Tools and Automation Proficiency:** This construct highlights the hands-on technical skills necessary for leveraging automation and digital tools in everyday project execution. This includes both high-level programming and routine tool application.
  - **S11. AI-Assisted Programming and Automation** signals advanced ability to automate tasks, write scripts, and apply AI-powered logic for improved productivity and reduced manual effort.

- **S12. Smart Construction Digital Tool Utilisation** supports proficiency in mainstream tools (e.g., CAD, BIM) used for modelling, rendering, documentation, and collaboration.
- **S14. Smart Digital Documentation and Archiving** adds rigour to digital record-keeping, ensuring structured archiving, version control, and information retrieval throughout the project lifecycle.

These competencies collectively drive digital fluency, allowing PMs to streamline processes, reduce duplication, and apply technical solutions independently. In environments where digital disruption is constant, this factor empowers PMs to adapt to new tools, configure automated workflows, and ensure documentation integrity, key enablers of consistent digital project delivery and long-term innovation.

➢ **F6. Content and Data Management:** This factor represents the PM's ability to curate, manage, and interpret digital information in collaborative and cloud-based environments, an essential capability in data-intensive construction projects.
  - **S7. Digital Data Evaluation and Analytics** supports critical data appraisal for informed decision-making, integrating model updates and performance feedback.
  - **S8. Cloud-Based Digital Content Management** enables shared access to project documents, promoting data fluidity and collaborative efficiency through secure cloud platforms.
  - **S10. Advanced Digital Content Management** covers adaptive reuse of digital resources and creative content development tailored to project needs.

Together, these competencies equip PMs to manage the full lifecycle of digital content and ensure that data is accurate, accessible, and actionable. In digital ecosystems where information overload is common, PMs must act as intelligent data stewards, transforming fragmented digital inputs into coherent, value-adding project insights and ensuring operational continuity across dispersed teams.

➢ **F7. Innovation and Change Enablement:** The final construct focuses on strategic transformation competencies, those that enable PMs to lead innovation, scale digital initiatives, and manage the human side of technological change.
  - **S4. Digital Communication and Interaction Strategies** equip PMs with the communication fluency to bridge gaps between technical and non-technical actors across platforms.
  - **S21. Automated Digital Procurement Management** supports advanced planning and procurement through cost simulations, vendor coordination, and 5D scheduling tools.
  - **S26. Innovation Management in Digital Construction** reflects forward-looking capacity to champion new technologies, navigate adoption barriers, and promote digital maturity across teams.

This construct captures the PM's role as a digital strategist and change agent, facilitating innovation not only through tools but through mindset and culture. As construction moves toward platform-based delivery and continuous digital evolution, the PM becomes the linchpin in scaling innovation, fostering digital readiness, and shaping future-ready project environments.

In summary, these seven latent constructs constitute a theoretically grounded and empirically validated framework of digital PM competency. They encompass a broad yet interrelated spectrum of skills, knowledge, and behavioural traits, each critical for enabling

PMs to lead, adapt, and thrive in digital construction settings. This framework offers not only a classification of capability domains but also a developmental roadmap for digital PMs, forming the structural basis for the CFA model outcomes summarised in Section 7.5.4 and laying the foundation for practical and research implications presented in Section 7.6.

7.5.4 Summary of Confirmatory Factor Analysis (CFA) Outcomes

This section synthesises the outcomes of the CFA conducted to validate the structural foundation of the digital PM competency model developed through the earlier phases of this study. Building on the integrated methodology presented in Chapters 3–6, CFA served as the final step to test the measurement validity of the model derived from EFA.

Inter-factor relationships. As shown by the right-hand arrow correlations in Figure 7.2, most constructs are only weakly to moderately associated (0.01–0.22), supporting their empirical distinctiveness. Stronger associations include F2–F4 (0.22) and F1–F4 (0.18), which are theoretically expected: leadership and sustainability (F2–F4) are closely linked, while execution (F1) aligns with sustainability (F4). Moderate associations such as F1–F2 (0.12) and F1–F4 (0.13) point to functional linkages between execution and leadership, and between execution and sustainability. Weak correlations, including F6–F7 (0.08) and F3–F5 (0.05), suggest that while these constructs are conceptually related in theory, they operate with greater empirical independence in the current model. Collectively, these values indicate limited overlap while acknowledging functional linkages needed in practice.

Considering all six core CFA fit indices, the present digital PM competency model (χ^2/df = 1.276, RMSEA = 0.052, SRMR = 0.0725, CFI = 0.928, TLI = 0.909, and GFI = 0.841) demonstrates robust structural validity. To contextualise these results, Salahshouri et al. (2023) reported χ^2/df ≈ 2.05, RMSEA = 0.068, and CFI = 0.98 for a first-order CFA of the Iranian version of the Interpersonal Communication Skills Scale (ICSS), with a lower GFI of 0.82. Similarly, Misba (2019) found marginal model fit for a skills questionnaire, reporting χ^2/df = 3.17, RMSEA = 0.08, SRMR = 0.092, CFI ≥ 0.90, and GFI = 0.82. Compared with these studies, the present model achieves a lower χ^2/df ratio and stronger error-based indices (RMSEA, SRMR), while producing comparable incremental fit (CFI, TLI) and a GFI that, although slightly below the ideal 0.90, is consistent with values commonly observed in complex social science models. Collectively, these comparisons reinforce the structural integrity and relative strength of the current CFA model, positioning it favourably alongside other validated measurement frameworks.

All standardised factor loadings in the model were statistically significant ($p < 0.001$), confirming strong relationships between observed items and their associated latent constructs. A majority of the indicators met or exceeded the conventional loading threshold of 0.40, with several items, particularly within Governance and Risk Oversight and Sustainability Intelligence, surpassing 0.70, signalling high construct reliability and internal consistency. Residual variances for the latent constructs (shown as the values above each factor in Figure 7.2) ranged from 0.13 to 0.40, showing that while some constructs (e.g., Innovation & Change Enablement) were tightly explained by their items, others (e.g., Sustainability Intelligence) retained more unexplained variance due to their broader conceptual scope. This pattern is typical in social science CFA models and reflects the multidimensional nature of competencies.

Notably, three items with marginal to borderline loadings, S11 (0.386), S12 (0.473), and S10 (0.499), were retained based on strong theoretical justification and their centrality to digital construction practices. This is consistent with recommendations by Hair et al. (2010) and Brown (2015), who argue that lower loading thresholds can be accepted in early-stage validation if conceptually warranted. Inter-factor correlations between the latent constructs (correlations between the seven CFA factors, r = 0.01–0.22) further confirmed that most constructs are empirically distinct, with modest but theoretically meaningful associations between governance, automation, and sustainability. These overlaps highlight the interconnected nature of digital PM roles, where technical, managerial, and strategic capabilities converge in practice (Cohen, 1988).

The strength of the final model lies not only in its statistical adequacy but also in its conceptual robustness and practical alignment with the evolving needs of digital PMs. The constructs were derived from the intensive review and thematic grouping of traditional PM competencies (Chapter 3), extended through validated digital competency definitions (Chapter 4), and integrated via taxonomy-based classification and comparative analysis of traditional and digital domains (Chapter 5), ensuring thematic coherence throughout the research process. These integrated competencies were then subjected to EFA (Chapter 6), which empirically revealed the seven latent constructs subsequently validated through CFA in this chapter. The model also reflects real-world complexity. For example, Tools and Automation Proficiency displayed variability in item loadings, from marginal (0.386) and borderline (0.473) to strong (0.705), which mirrors the fragmented and evolving nature of digital tool adoption in construction. Rather than undermining validity, such variability strengthens the model's capacity to represent the uneven maturity of technical competencies in actual practice.

The CFA results affirm that this early-stage model provides a credible and structured basis for understanding and evaluating digital PM competencies. It captures not only the technical, managerial, and behavioural facets of digital transformation, but also the strategic foresight needed to lead change across the smart built environment. The final validated CFA model is presented in Figure 7.2, showing the seven latent constructs, retained indicators, and their standardised factor loadings for quick visual reference.

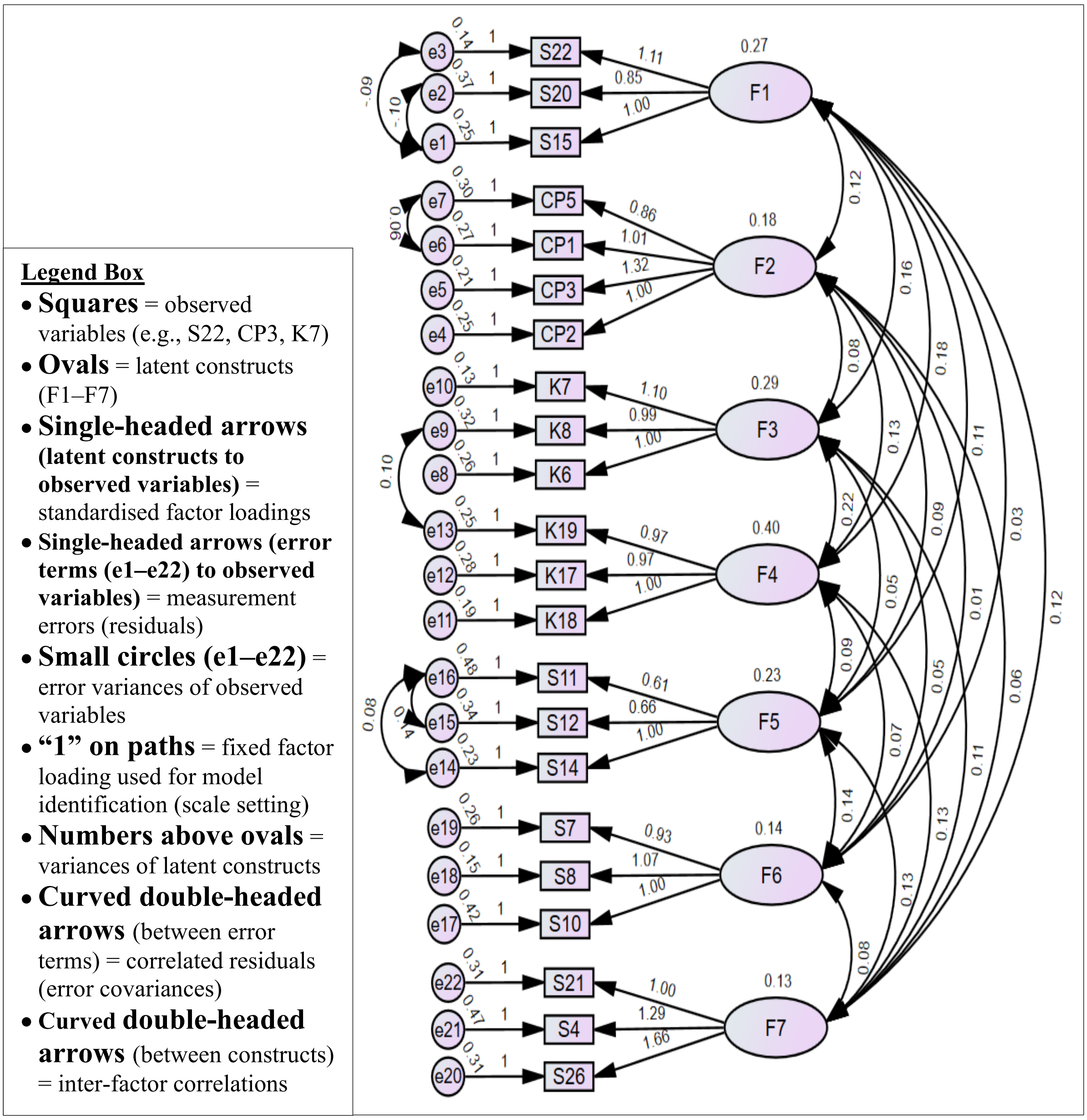


Figure 7.2: Final Validated CFA Model of the Next-Gen Digital PM Competency Framework

To enhance interpretability, a simplified version of the validated CFA model is presented in Figure 7.3. Whereas Figure 7.2 displays the technical AMOS output with factor loadings, error variances, and inter-factor correlations, the simplified diagram consolidates competencies into their respective latent constructs and illustrates the relative strength of inter-factor relationships using differentiated arrow thickness. A legend is included within Figure 7.3 to clarify the weighting scheme, where thicker lines denote stronger correlations, thinner lines denote moderate correlations, and dotted line denote weak correlation. This dual representation ensures both methodological transparency and conceptual clarity, allowing the model to be appreciated by technical and non-technical audiences alike.

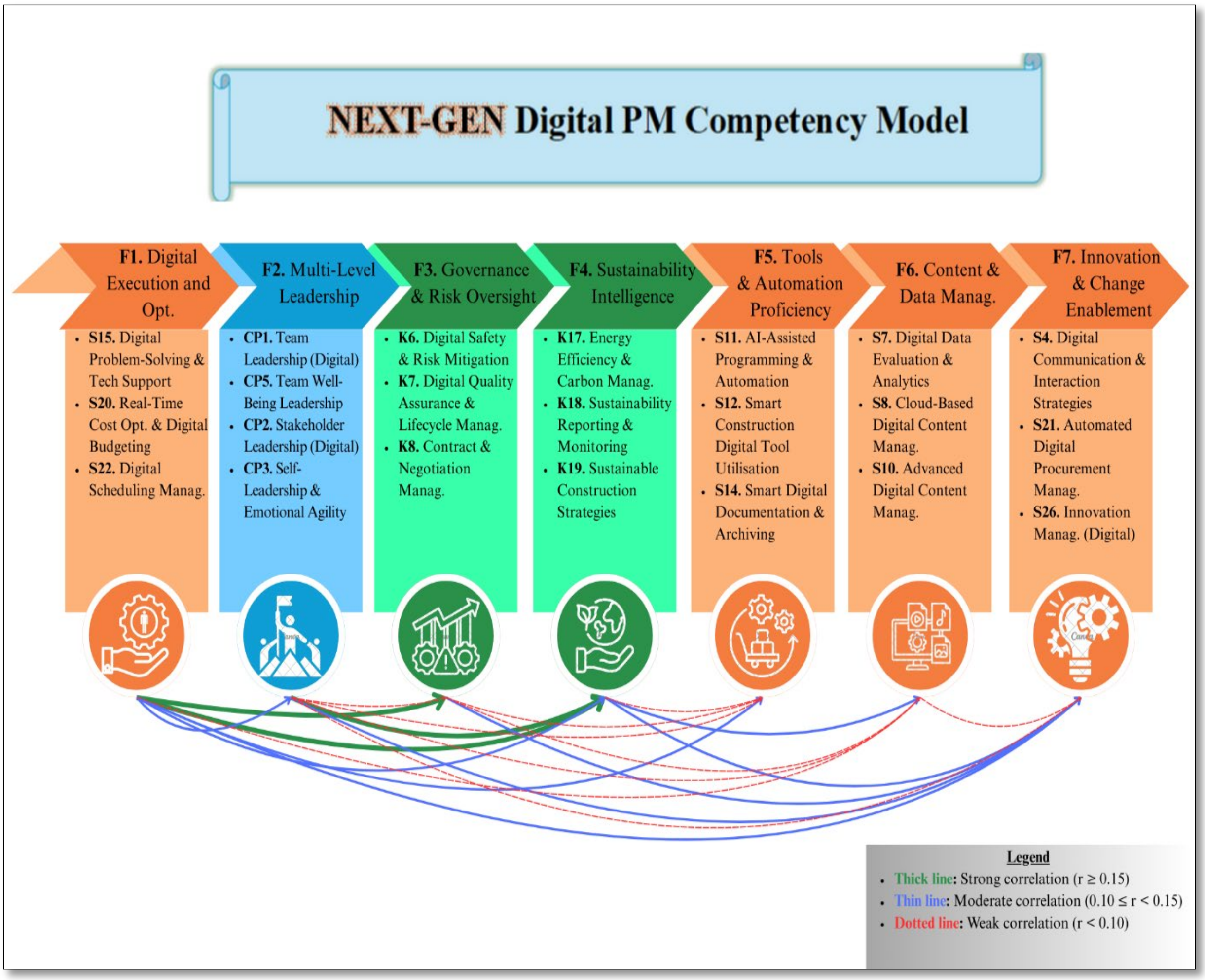


Figure 7.3: Simplified CFA Model of the Next-Gen Digital PM Competency Model

To further aid interpretation, Figure 7.3 highlights the relative strength of correlations between the seven latent constructs. Strong correlations ($r \geq 0.15$, shown as thick lines) emerged between F1-F3, F1-F4, and F2-F4, reflecting the practical interdependence of executional efficiency, compliance, and sustainability, as well as the role of leadership in embedding sustainability priorities in digital construction. Moderate correlations ($0.10 \leq r < 0.15$, thin lines) were identified between F1-F2, F1-F5, F1-F7, F2-F7, F3-F7, F4-F6, and F4-F7, pointing to functional overlaps in areas such as operational workflows, digital tool integration, leadership, and innovation. Weak correlations ($r < 0.10$, dotted lines) were observed between F1-F6, F2-F3, F2-F5, F2-F6, F3-F5, F3-F6, F4-F5, and F6-F7, indicating that while these constructs are conceptually related in theory, their weak correlations suggest they operate with greater empirical independence in the current model. This layered correlation structure confirms that the model balances empirical distinctiveness with theoretically meaningful linkages across competency domains.

In conclusion, the CFA confirms the structural validity and practical relevance of the proposed digital PM competency model. It provides the first empirically grounded measurement model to capture the integrated technical, behavioural, and strategic competencies necessary for effective PM in digitally enabled construction contexts. As an early-stage validation, the model is both credible and scalable, providing a structured baseline that future studies can refine by testing additional items, higher-order constructs, and longitudinal validation. These findings not only consolidate the outcomes of this study but also establish a foundation for future validation efforts, capability-building programs, and targeted professional development in the construction industry.

7.5.5 Practical Operationalisation Example

To demonstrate the practical applicability of the validated CFA model, selected competencies can be operationalised into measurable assessment criteria for evaluating PM performance in digitally enabled construction environments. In practice, each competency may be translated into observable behavioural indicators that reflect how effectively a PM applies digital skills, knowledge, and leadership capabilities within real project contexts. These indicators can then be assessed using a structured rating scale, enabling organisations to systematically evaluate and compare competency levels across individuals or teams.

Table 7.9 provides an illustrative example of how selected competencies from the validated model may be operationalised. The examples are drawn from different competency domains to demonstrate the model's multidimensional applicability, covering technical execution (Skills), leadership (Core Personality Traits), and domain knowledge (Knowledge). Each competency is expressed through a simplified assessment indicator that captures its practical manifestation in digital construction settings, alongside a standard five-point rating scale (1 = low proficiency, 5 = high proficiency).

Table 7.9: Illustrative Example of Operationalising Selected Digital PM Competencies into Assessment Indicators

Construct	**Competency**	**Sample Assessment Indicator**	**Scale**
Digital Execution & Optimisation	S22: Digital Scheduling Management	Applies 4D BIM tools to manage and optimise project scheduling	1-5
Multi-Level Leadership	CP1: Team Leadership in Digital Construction	Leads and coordinates digital teams across platforms effectively	1-5
Sustainability Intelligence	K18: Sustainability Reporting and Monitoring	Monitors and reports sustainability performance using digital systems	1-5

It is important to note that this table is intended as a conceptual illustration rather than a complete assessment framework. The selected items do not represent the full set of validated competencies but instead demonstrate how the model can be translated into an applied evaluation tool. The development of a comprehensive competency assessment instrument, incorporating all validated indicators, detailed scoring rubrics, and empirical benchmarking, represents an important direction for future research. Such extensions would enable more robust application of the model in workforce development, performance evaluation, and professional training within the construction industry.

7.6 Limitations and Implications for Future Research

This chapter outlines the key limitations of the study and proposes directions for future research that can build upon the validated digital PM competency model developed herein. While the model represents a theoretically grounded and empirically supported foundation for understanding digital PM competencies in smart construction, it also reflects the early-stage nature of research in this emerging field.

First, the study's sample of 103 AEC professionals across New Zealand and Australia, though adequate for EFA and CFA, limits the generalisability of the findings. Participants were primarily drawn from developed economies and digitally engaged project environments. To ensure broader applicability, future studies should test the model in other regions and project types, particularly those in emerging markets or with varying levels of digital maturity.

Second, a methodological limitation of this study relates to the use of a single dataset for both EFA and CFA. While this approach ensured consistency between exploratory and confirmatory stages, it does not provide independent confirmatory validation of the factor structure. Ideally, CFA should be conducted on a separate dataset to strengthen confirmatory robustness and reduce the risk of overfitting. However, given the sample size (N = 103), splitting the dataset would have reduced statistical power and potentially compromised model stability. Consistent with established methodological guidance (e.g., Hair et al., 2010; Brown, 2015; Kline, 2023), the use of a single dataset is considered acceptable in early-stage model development and validation research. Nevertheless, this limitation may constrain the generalisability and confirmatory strength of the framework. Future research should therefore aim to cross-validate the proposed model using independent samples and diverse international datasets to enhance external validity and support broader applicability across different construction contexts. This is particularly important given the model's intended applicability across construction environments with varying levels of digital maturity.

Third, while this research presents a validated and structured measurement model, it is based on a cross-sectional design. Competency requirements in digital construction are dynamic and influenced by ongoing technological change. As such, longitudinal studies are essential to assess how digital PM competencies evolve over time in response to emerging tools such as AI, blockchain, or advanced DT ecosystems. Ongoing validation and adaptation will ensure the model remains relevant to future practice.

Future research could also extend validation through multi-group CFA to assess measurement invariance across subgroups, such as geographic regions, organisational sizes, or levels of digital maturity. Establishing invariance would strengthen the generalisability of the model and confirm that its latent constructs operate consistently across diverse contexts.

Fourth, the study applied a robust methodological approach, combining an intensive round of LR, thematic analysis, SLR, taxonomy-based classification and comparative analysis, EFA, and CFA, to construct and validate the digital PM competency model. One of the key objectives was to provide a foundation for workforce development, including digital PM training programs and capability-building strategies. The model already supports this purpose by offering a structured competency baseline that can underpin the design of future tools such as workforce assessment instruments, training curricula, and performance evaluation systems. These practical applications lie beyond the scope of this thesis but represent the logical next step in translating the validated model into operational systems for industry use. Future research should therefore shift from exploration to deployment, testing how the model performs when embedded into training systems, organisational assessments, and digital upskilling initiatives. In this way, the present study should be understood as a first step, with future work extending the model into practical applications.

Fifth, while the CFA successfully validated the seven latent constructs, it did not test a second-order factor model. A higher-order CFA could examine whether the seven first-order constructs load onto broader meta-domains (e.g., technical, managerial, behavioural), providing additional structural clarity and theoretical parsimony. This step was beyond the scope of the current study but represents an important direction for future research to explore the hierarchical nature of digital PM competencies.

Sixth, while the CFA confirmed the distinctiveness of the latent constructs, it does not provide a ranking of which domains are most critical. Future research could extend this work by examining factor importance, weighting, or predictive influence on project outcomes, enabling prioritisation of competencies for training and industry adoption. Here again, the current model serves as an essential starting point, while future research must refine its precision and practical applicability.

Seventh, while inter-factor correlations were generally weak to moderate, indicating strong empirical independence, this pattern may also reflect the early emergence of digital technologies in construction. As integration between domains such as governance, automation, and sustainability matures, stronger overlaps may emerge. Future research should revisit these relationships, potentially through higher-order or bifactor CFA, to assess whether they represent broader meta-domains or context-specific interdependencies.

The validated factor structure presented here lays a robust foundation for future SEM applications. Specifically, the model can be extended to examine how digital PM competencies influence project outcomes such as delivery performance, innovation uptake, team satisfaction, or digital maturity levels. By integrating this competency model with dependent outcome constructs, future research can test causal relationships and develop predictive models of performance in digitally enabled construction environments. This alignment supports both theoretical advancement and practical relevance for leadership development and workforce planning initiatives.

Despite these limitations, this thesis offers a critical contribution to the emerging discourse on digital PM competency. It establishes a replicable and adaptable model that other researchers can extend or refine in diverse contexts. The validated constructs serve as a blueprint for further research into digital leadership, workforce transformation, and competency-based performance outcomes in construction.

Ultimately, this study aims to serve as a conceptual and empirical stepping stone for the academic community. It is anticipated that future research will build on this work, using the model as a referential base to explore new domains of digital transformation, advance competency theory, and contribute to the development of next-gen PM competencies across the global built environment.

7.7 Conclusion

This chapter presents the validation of the EFA-derived Next-Gen Digital Project Manager (PM) Competency Model through Confirmatory Factor Analysis (CFA), establishing both its measurement quality and structural robustness. Using CFA, the chapter confirmed that the proposed seven-factor model provides an empirically supported representation of digital PM competency in the construction sector. Measurement quality was evaluated using factor loadings, internal consistency (Composite Reliability and Cronbach's Alpha), convergent validity (Average Variance Extracted), and discriminant validity, ensuring statistical adequacy and conceptual alignment.

The final validated model retained 22 indicators, all statistically significant at $p < 0.001$. While some retained items (S10, S11, S12) exhibited marginal loadings, their inclusion was supported by strong theoretical relevance and alignment with real-world digital PM practice. The seven resulting constructs, Digital Execution and Optimisation, Multi-Level Leadership, Governance and Risk Oversight, Sustainability Intelligence, Tools and Automation Proficiency, Content and Data Management, and Innovation and Change Enablement, capture the multi-dimensional nature of digital PM competency in the smart built environment. This balance between statistical performance and conceptual coherence reflects the pragmatic nature of competency development in practice.

Overall, the CFA results confirm that the proposed model demonstrates acceptable fit, satisfactory reliability, and sufficient construct validity for an early-stage competency framework. The final validated CFA model, Figure 7.2, provides a clear visual representation of the latent constructs, retained indicators, and standardised factor loadings, serving as a practical reference for both academic and industry application.

The outcomes of this chapter deliver significant theoretical and practical contributions. Theoretically, this is the first empirically tested model to integrate technical, managerial, and behavioural competencies into a coherent structure tailored for digital PM in construction. Practically, the model offers a reliable baseline for competency assessment, targeted training program design, and workforce capability development in digitally enabled project environments. It also provides a structured foundation for subsequent model testing in relation to broader project and organisational outcomes.

In summary, this chapter confirms that the proposed Next-Gen Digital PM Competency Model is empirically valid and meaningfully aligned with the competency demands of the digitally transformed construction industry. In addressing RQ5, *"To what extent does the proposed framework demonstrate empirical validity and alignment with the competency demands of the digitally transformed construction industry?"*, this chapter has validated the proposed framework through CFA, confirming both its empirical validity and its alignment with the competency requirements of the digitally transformed construction sector.

Chapter 8 Conclusion, Contributions, and Future Research

8.1 Introduction

This thesis set out to address a critical gap in the construction industry's capacity to navigate digital transformation. As established in Chapter 1, the problem statement guiding this study is: *"There is currently an absence of a sector-specific, empirically validated competency framework and model for construction project managers. Existing frameworks do not adequately unite traditional competencies with emerging digital demands or respond to the transformative pressures of digital transformation in the construction sector."*

Empirical evidence reinforces this need, with studies showing that up to 47% of project success can be attributed to the competency of the PM, underscoring their pivotal role in enhancing performance and productivity in the construction sector (Hwang & Ng, 2013; Owais et al., 2025b).

In response, the thesis pursued the research aim: *"To develop and validate a sector-specific digital PM competency model tailored to the needs of the AEC sector in the context of rapid digital transformation."*

To achieve this, the study employed a five-phase mixed-methods design that systematically progressed from the identification and thematic categorisation of traditional project manager (PM) competencies, through the classification and refinement of emerging digital competencies, to their integration within a taxonomy-based framework, and ultimately to empirical validation via Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA). This sequential structure ensured both conceptual depth and statistical robustness.

The overarching direction of the research was further guided by the primary research question: *"How can traditional and emerging digital project manager competencies be identified, systematically integrated into a taxonomy, and empirically validated to create a robust competency model that supports construction project managers in leading digital transformation within the AEC sector."*

This final chapter revisits the research problem, consolidates findings across all stages, and demonstrates how the research aim and objectives were achieved. It also highlights the study's theoretical, methodological, and practical contributions, acknowledges its limitations, and provides recommendations for future research. The chapter concludes with a reflective statement that positions this work as a foundation for advancing scholarship and practice in digital project management for the built environment.

8.2 Summary of Key Findings

The findings of this thesis are presented in direct alignment with the research aim and objectives, ensuring a coherent response to the primary research question:

"How can traditional and emerging digital project manager competencies be identified, systematically integrated into a taxonomy, and empirically validated to create a robust competency model that supports construction project managers in leading digital transformation within the AEC sector?"

This section highlights the main outcomes of the study, structured around the five research questions (RQ1–RQ5) and their corresponding research objectives (RO1–RO5), as shown in Table 8.1. Together, these findings demonstrate how the study progressed from the identification of competencies to the development and validation of a comprehensive competency model.

Table 8.1: Overview of Research Questions and Objectives

Research Questions	Research Objectives
• **RQ1.** *Which traditional project manager competencies are identified in literature and professional frameworks, and how can these be categorised into skills, knowledge, and core personality traits?*	• **RO1.** *To identify traditional project manager competencies from literature and professional frameworks, and to categorise them into skills, knowledge, and core personality traits.*
• **RQ2.** *What are the emerging digital competencies required for project managers to excel in the evolving construction sector?*	• **RO2.** *To identify the emerging digital competencies required for project managers to excel in the evolving construction sector.*
• **RQ3.** *How can traditional and emerging digital competencies be systematically integrated into a taxonomy-based classification that reflects construction's digital transformation needs?*	• **RO3.** *To systematically integrate traditional and emerging digital competencies into a taxonomy-based classification that reflects construction's digital transformation needs.*
• **RQ4**. *How can the integrated taxonomy of traditional and digital competencies be empirically synthesised and modelled into an initial validated framework*?	• **RO4.** *To empirically synthesise and model the integrated taxonomy of traditional and digital competencies into an initial validated framework.*
• **RQ5.** *To what extent does the proposed framework demonstrate empirical validity and alignment with the competency demands of the digitally transformed construction industry?*	• **RO5.** *To confirm the empirical validity of the proposed framework and assess its alignment with the competency demands of the digitally transformed construction industry.*

To provide a clear and structured account, the following subsections present the outcomes associated with each research question and objective. For each pair, the objective is restated to emphasise the intended focus of inquiry, followed by a summary of the key findings that demonstrate how the objective was achieved and the question addressed. This format highlights the sequential logic of the study, showing how the research progressed from the identification of traditional and digital competencies through integration, empirical synthesis, and final validation.

RO1 / RQ1: Identification of Traditional Competencies

- **Objective:** To identify and categorise traditional PM competencies reported in the literature and industry practice for the AEC sector.
- **Finding:** Chapter 3 systematically reviewed and synthesised established competency frameworks (e.g., PMI, IPMA, PMCD Framework) and industry reports. The identified competencies were then organised through thematic categorisation into the three domains of Skills, Knowledge, and Core Personality Traits. This process reaffirmed the enduring relevance of traditional competencies such as scope, cost, risk, stakeholder, and quality management, while also exposing their limitations in digitally enabled contexts. The findings confirmed that while foundational competencies remain essential, they are insufficient on their own for leading digital transformation in construction.

RO2 / RQ2: Identification of Emerging Digital Competencies

- **Objective:** To identify, categorise, and refine emerging digital competencies essential for PMs to excel in the evolving construction sector.

- **Finding:** Chapter 4 employed a three-stage methodology, Systematic Literature Review (SLR), NVivo-based Thematic Analysis, and Large Language Modelling (LLM) synthesis, to identify and define 55 emerging digital competencies across three domains: Skills (26), Knowledge (21), and Core Personality Traits (8). Expert validation ensured the relevance and clarity of these definitions, producing the Next-Gen Digital PM Competency List. This list provides a comprehensive and standardised foundation of digital competencies that extends beyond generic frameworks to meet the specific needs of the construction sector.

RO3 / RQ3: Integration into a Taxonomy

- **Objective:** To systematically integrate traditional and emerging digital PM competencies into a taxonomy-based classification.
- **Finding:** Chapter 5 integrated the traditional and digital competencies through a structured taxonomy of Skills, Knowledge, and Core Personality Traits. This process also involved a comparative analysis to systematically map traditional PM competencies into the digital taxonomy, identifying similarities, differences, and transformations. The comparative process, guided by criteria and outcomes presented in Table 5.2, enabled the assessment of whether competencies were digitally enhanced, newly emerged, or conceptually distinct. The result was a unified taxonomy that preserved the value of traditional PM skills while situating them within the broader digital transformation landscape.

RO4 / RQ4: Empirical Synthesis via EFA

- **Objective:** To empirically synthesise and model the integrated taxonomy into a validated framework through EFA.
- **Finding:** Chapter 6 presented the results of EFA using survey data from AEC professionals. Analysis revealed seven latent constructs encompassing 25 retained competency items, which empirically confirmed the underlying structure of the taxonomy. This outcome resulted in the Next-Gen Digital PM Competency Framework, a statistically grounded representation of how digital PM competencies are structured across Skills, Knowledge, and Core Personality domains. While 30 competencies were excluded during refinement due to statistical or thematic issues, their conceptual importance was acknowledged, and they remain valuable candidates for future model expansion. Such expansion could involve tailoring the model to specific PM roles (e.g., program managers, BIM managers, digital delivery leads), aligning with particular technologies (e.g., AI, blockchain, digital twins), or adapting to sectoral or regional contexts where regulatory and cultural differences reshape competency demands.

RO5 / RQ5: Confirmatory Validation via CFA

- **Objective:** To confirm the empirical validity of the proposed digital PM competency framework and assess its alignment with industry needs.
- **Finding:** Chapter 7 employed CFA to test and validate the EFA-derived framework. The final model demonstrated satisfactory fit indices (χ^2/df, CFI, TLI, RMSEA, SRMR), strong internal consistency, convergent validity, and discriminant validity. This phase resulted in the Next-Gen Digital PM Competency Model, a fully validated measurement model consisting of seven interrelated constructs encompassing 22 retained competency items that together define the hybrid set of

Skills, Knowledge, and Core Personality traits required for digital project management in the AEC sector.

Taken together, the findings demonstrate that the research problem has been successfully addressed, and the research aim achieved. The thesis systematically progressed from identifying traditional competencies, to developing the Next-Gen Digital PM Competency List, integrating it into a taxonomy, empirically validating it as the Next-Gen Digital PM Competency Framework, and ultimately confirming it as the Next-Gen Digital PM Competency Model. In doing so, the study provides a comprehensive answer to the primary research question and establishes a validated competency model that equips PMs to lead digital transformation within the AEC sector.

8.3 Contributions to Knowledge, Method, and Practice

This study makes several significant contributions that advance both academic scholarship and professional practice in construction project management. These contributions span three interrelated dimensions: theoretical knowledge, methodological advancement, and practical application.

Theoretical Contributions

The thesis contributes to the body of knowledge on PM competencies in the context of digital transformation by:

- Developing the Next-Gen Digital PM Competency List in Chapter 4, consisting of 55 competencies systematically identified and defined across Skills, Knowledge, and Core Personality Traits.
- Establishing a taxonomy-based classification of competencies in Chapter 5 by integrating the digital list with traditional PM competencies, thereby providing a structured approach to understanding hybrid professional capabilities.
- Distinguishing between digitally enhanced traditional competencies and newly emerged digital competencies, clarifying how PM roles evolve under technological disruption.
- Progressively validating the outputs: first as a taxonomy, then as an empirically synthesised Framework (Chapter 6), and ultimately as the fully validated Next-Gen Digital PM Competency Model (Chapter 7).
- Empirically demonstrating the latent structure of digital PM competencies through EFA and CFA, ensuring the model is both conceptually grounded and statistically validated.

Together, these contributions extend existing competency frameworks (e.g., PMI, IPMA, PMCD) by explicitly incorporating digital transformation demands, which prior models did not address in a systematic and validated manner. Even digital-focused frameworks (e.g., BIM Project Information Management models) have tended to emphasise specific tools or processes in isolation rather than offering an empirically validated, holistic competency model for PMs.

Methodological Contributions

The research also advances methodological practice in competency studies by:

- Designing and implementing a five-phase mixed-methods strategy, integrating intensive round of literature review, thematic categorisation, SLR, NVivo-based

Thematic Analysis, LLM-driven synthesis, and multivariate statistical validation (expert review, EFA, and CFA).
- Demonstrating the novel use of LLMs in competency definition, showing how AI-assisted synthesis can complement expert validation to produce precise, standardised definitions.
- Applying a comparative analysis technique to integrate traditional and digital competencies within a taxonomy framework, offering a replicable model for future integration studies in related fields.
- Documenting the removal of 30 competencies during EFA to ensure statistical rigour, while acknowledging their conceptual importance for future role or domain-specific applications.
- Combining qualitative taxonomic analysis with quantitative structural modelling, thereby setting a methodological precedent for mixed-methods research in construction management scholarship.

These methodological innovations strengthen the reliability, transparency, and replicability of competency research and provide a blueprint for other scholars conducting hybrid competency studies.

Practical Contributions and Implications

The validated Next-Gen Digital PM Competency Model also makes direct contributions to professional practice by:

- **Supporting workforce planning and capability development:** Organisations can use the model to identify digital competency gaps, benchmark current capability levels, and design targeted training initiatives to prepare PMs for digital transformation.
- **Guiding professional development, certification, and education:** Industry bodies, universities, and training providers can adopt the model to update competency frameworks, curricula, and certification systems, ensuring alignment with the evolving demands of the digital construction environment.
- **Shaping policy and organisational strategy:** Policymakers and industry leaders can apply the findings to workforce upskilling initiatives, fostering a culture of innovation, resilience, and digital readiness across the construction sector.
- **Facilitating organisational transformation:** By highlighting the competencies that bridge traditional expertise with digital demands, the model provides PMs with actionable guidance to lead digital adoption, enhance collaboration, and deliver value in complex project environments.

- **Supporting competency self-assessment and professional reflection:** The model provides a validated reference point that PMs can use to evaluate their competencies against an empirically grounded benchmark and identify priority areas for development.
- **Establishing a foundation for practical tools and future development:** The model offers a structured basis for the development of competency assessment instruments, implementation guidelines, and role-specific frameworks, while also serving as an adaptable baseline that can evolve alongside emerging technologies such as AI, cybersecurity, automation, and environmental intelligence.
- Recommendations for practice: Industry stakeholders should integrate the model into competency frameworks, training programmes, and digital adoption strategies.

Organisations are encouraged to use the model as a diagnostic tool to benchmark PM capabilities, while professional bodies can embed it into accreditation and certification pathways. Policymakers should align workforce development initiatives with the competencies identified in the model to ensure sector-wide readiness for digital transformation.

Through these practical implications and recommendations, the study equips the AEC sector with a research-informed tool that directly supports digital leadership, capability development, and strategic competitiveness in the Smart Built Environment.

8.4 Research Backbone and Model Practical Deployment

This section demonstrates how the validated Next-Gen Digital PM Competency Model functions as both a research backbone, a stable, empirically grounded structure, and a practical deployment tool for guiding PMs, organisations, and academia in navigating digital transformation. The model's dual role ensures that it is not only a rigorous academic output but also a directly applicable framework for industry.

The discussion unfolds in four parts. First, the model is presented as a research and universal backbone, consolidating the evidence generated across Chapters 3-7. Second, it distinguishes between the elements of the model that remain fixed and those that may vary in emphasis in response to contextual differences. Third, it demonstrates how the universal backbone remains adaptable to regional contexts while preserving empirical integrity. Fourth, it identifies the implications of the model for PMs, organisations, and academia, showing how it can be used immediately as a diagnostic and developmental resource. The section then links to subsequent sections that outline pathways toward guidelines, tools, and sector-specific frameworks.

8.4.1 Research Backbone and Universal Backbone

The validated Next-Gen Digital PM Competency Model serves as the research backbone of this study. It consolidates multiple stages of inquiry into a coherent, empirically validated structure that provides both stability and transferability. This backbone is anchored in four interdependent elements:

- **Competencies**: The 55 digital PM competencies classified into Skills, Knowledge, and Core Personality Traits, which form the foundation of the model.
- **Methodology**: A systematic, staged process encompassing an intensive literature review, thematic categorisation, SLR, thematic analysis, LLM synthesis, taxonomy construction, comparative analysis, expert validation, EFA, and CFA.
- **Taxonomy Integration**: The fusion of traditional and digital competencies into a unified classification framework, demonstrating the value of traditional competencies while showing that they are not sufficient on their own to respond to digital transformation.
- **Validated Model**: The seven-factor model empirically confirmed through both EFA and CFA, representing the culmination of the research process.

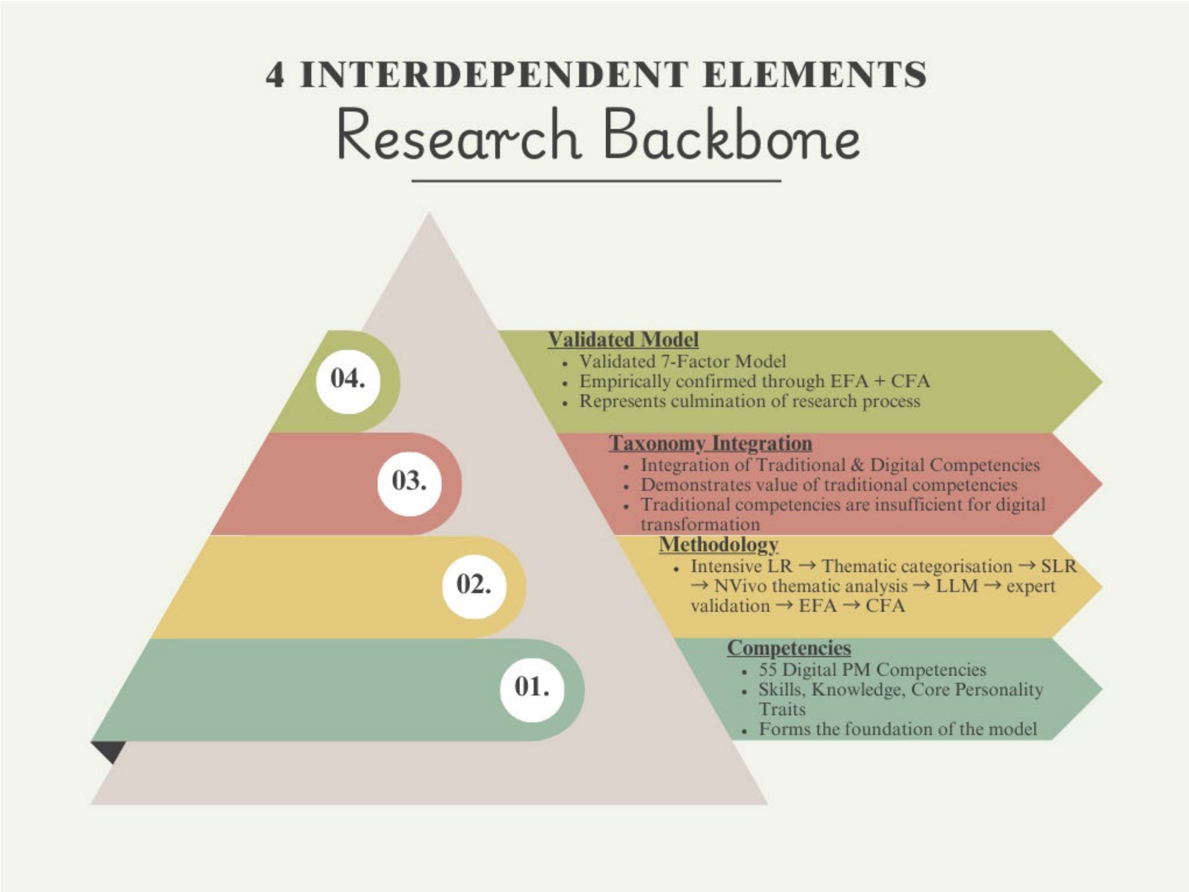


Figure 8.1: The Research Backbone of the Thesis

As illustrated in Figure 8.1, these four interdependent elements collectively constitute the research backbone of this thesis, progressing from foundational competencies and systematic methodology through taxonomy integration to the validated seven-factor model.

In addition to serving as a research construct, the model also operates as a universal backbone for project management practice. By articulating competencies at a level that transcends specific tools, processes, or jurisdictions, it establishes a common platform of digital capability that is adaptable to diverse project environments. This universal backbone ensures that PMs, organisations, and academic institutions can align around a shared, empirically validated framework while allowing for regional adaptation.

8.4.2 What Stays Fixed and What Might Change

While the validated Next-Gen Digital PM Competency Model provides a stable backbone, its application acknowledges the distinction between what remains fixed and what may vary in emphasis when applied across different contexts. This balance between stability and flexibility reflects how the model operates as both an empirically grounded and practically usable structure.

What Stays Fixed

- **Core Competencies**: The set of 55 digital PM competencies classified into Skills, Knowledge, and Core Personality Traits remain the foundation of the model.
- **Methodological Process**: The staged development approach forms a replicable process that does not change across applications.

- **Validated Structure**: The seven-factor model empirically confirmed through EFA and CFA represents the stable outcome of the research and should be regarded as the universal reference point for digital PM competencies.

What Might Change

- **Competency Emphasis Within Factors**: While the seven latent constructs remain constant, the relative importance or prioritisation of competencies within each factor may vary in emphasis depending on context.
- **Legislation**: Local regulations may elevate certain competencies, such as cybersecurity under strict data protection regimes or sustainability competencies under environmental legislation.
- **Cultural Priorities**: National and organisational cultures may shape the interpretation of competencies, for example, emphasising collaborative leadership in collectivist cultures versus individual initiative in more individualist contexts.
- **Technological Maturity**: Digital maturity levels influence which competencies are prioritised; digitally advanced regions may weight AI or automation skills more heavily, while less mature contexts may emphasise basic digital literacy or integration capabilities.

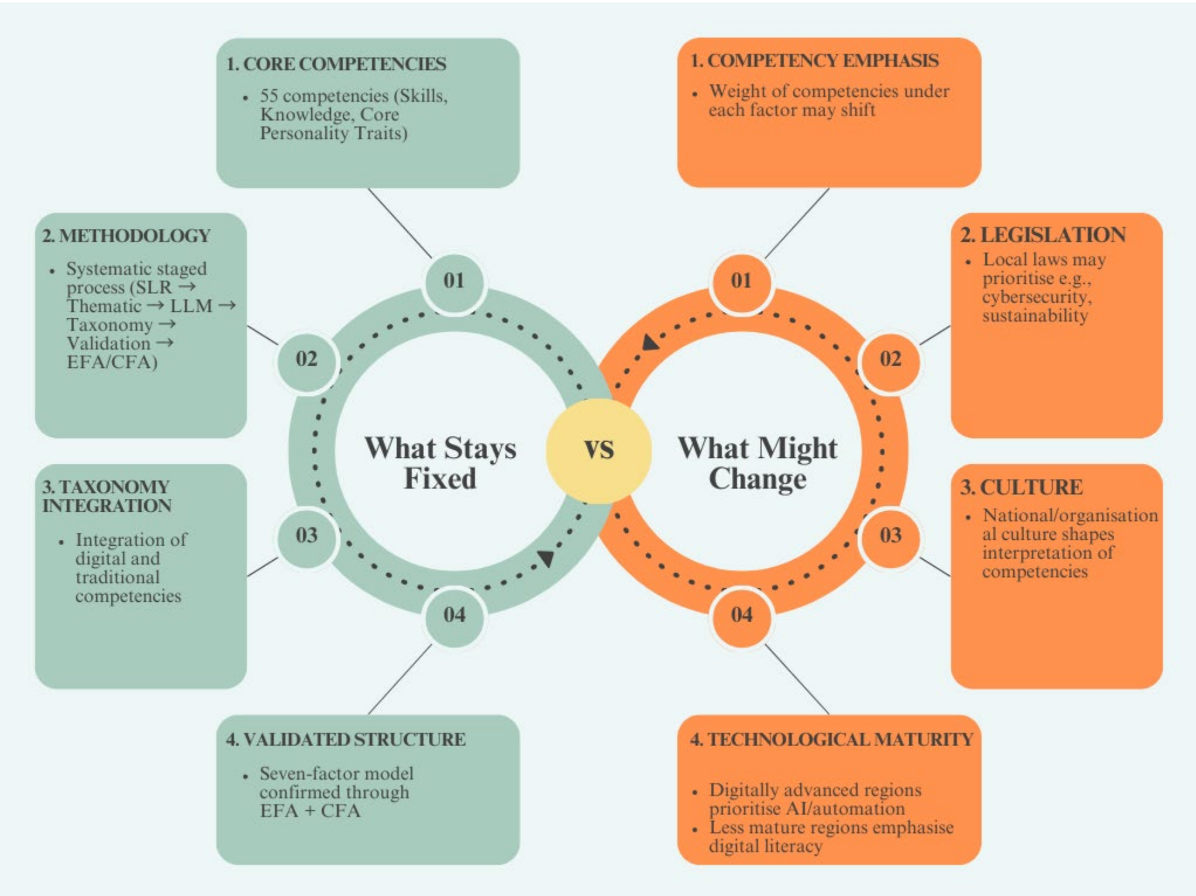


Figure 8.2: Fixed versus adaptable elements of the research backbone

As illustrated in Figure 8.2, the research backbone remains anchored in core competencies, methodology, taxonomy integration, and validated structure, while contextual factors such as legislation, culture, and technological maturity may influence how specific competencies are prioritised within the model.

8.4.3 Universal Backbone and Regional Fit

The Next-Gen Digital PM Competency Model is presented as a universal backbone, providing a stable and empirically validated structure for project management competencies across the global AEC sector. The foundation, comprising the 55 competencies, the systematic methodology, and the seven-factor model, remains constant regardless of context. This stability ensures that the model can serve as a common language of digital competencies, enabling comparability, consistency, and shared understanding across professional, organisational, and academic domains.

At the same time, the model supports regional fit, where specific competencies or their relative importance is interpreted in response to contextual drivers. Four domains illustrate this balance between universality and adaptability:

- **Legislation**: Regional laws and regulations can elevate the importance of certain competencies. For instance, strict data protection regimes may emphasise cybersecurity, while sustainability regulations may strengthen the weight of environmental management competencies.
- **Culture**: National and organisational cultures influence how competencies are enacted in practice. Collectivist contexts may prioritise collaborative leadership, while more individualist settings may value innovation and entrepreneurial initiative.
- **Technological Maturity**: Levels of digitalisation affect which competencies are prioritised. Digitally advanced regions may emphasise AI, automation, and data-driven optimisation, whereas less mature regions may focus on foundational digital literacy and integration skills.
- **Backbone**: Despite these contextual variations, the model remains grounded in the same validated backbone. The competencies, methodology, and factor structure provide a stable foundation that does not change across regions.

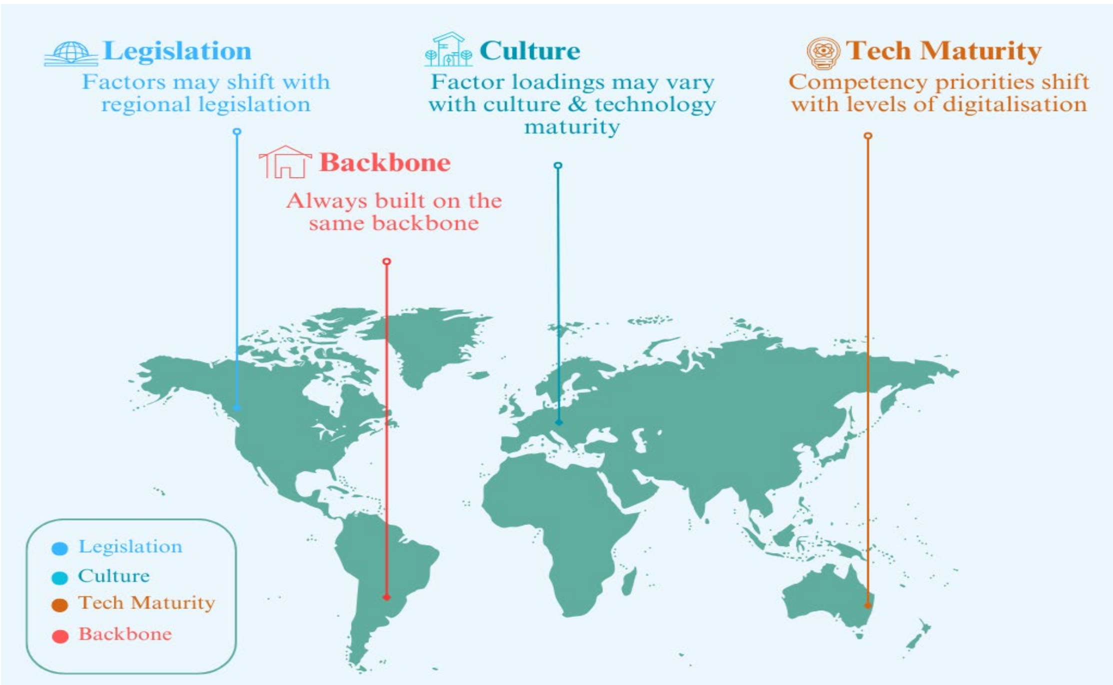


Figure 8.3: Universal backbone of the model with regional adaptations

As illustrated in Figure 8.3, the universal backbone remains constant, while legislation, culture, and technological maturity shape regional adaptations. Yet across all contexts, the model remains anchored in the same validated backbone.

8.4.4 Implications for PMs, Organisations, and Academia: A Foundation for Current Application

The validated Next-Gen Digital PM Competency Model extends beyond a research contribution and has immediate implications for professional practice, organisational strategy, and academic development. By positioning the model as a universal backbone with the capacity for regional adaptation, this study provides a framework that stakeholders can directly apply to assess, align, and strengthen digital project management capabilities.

For Project Managers (PMs):

- The model provides a validated reference point for self-assessment, enabling PMs to evaluate their competencies against an empirically grounded benchmark.
- It clarifies the distinction between digitally enhanced traditional competencies and newly emerged digital competencies, supporting more targeted professional development.
- The seven validated factors offer a structured lens through which PMs can prioritise competency development in digitally enabled project environments.

For Organisations:

- The model serves as a diagnostic baseline for identifying competency gaps and supporting workforce capability development.
- It enables high-level benchmarking of digital readiness and supports alignment between project management practices and emerging digital requirements.

For Academia and Professional Bodies:

- The model provides a research-informed foundation for reviewing and adapting curricula, training programmes, and competency standards.
- It supports the alignment of education and certification systems with empirically validated digital competency requirements.

Together, these implications demonstrate that the model is not only a theoretical construct but also a practically applicable foundation for advancing digital capability across the AEC sector. It provides a validated basis for self-assessment, benchmarking, and preliminary alignment of competencies by PMs, organisations, and academic institutions. In this sense, the model serves as a foundation for current application within digitally enabled construction environments.

8.5 Limitations

While this study has made significant contributions to knowledge, methodology, and practice, it is important to acknowledge several limitations that define the boundaries of its findings and highlight areas for further exploration. These limitations are not weaknesses of the research design, but rather reflections of scope and methodological choices that create opportunities for future refinement.

- **Sample Size and Generalisability:** The survey sample consisted of 103 AEC professionals with project management experience of five years or more. While sufficient for EFA and CFA, the relatively modest sample size limits the generalisability of findings to the broader global construction industry. Larger and more diverse datasets would enhance statistical robustness and enable subgroup analyses across regions, roles, and organisational contexts.
- **Use of a Single Dataset for EFA and CFA:** Both the exploratory and confirmatory analyses were conducted using the same dataset (N = 103). While this approach ensured consistency between model development and validation, it does not provide independent confirmatory validation of the proposed factor structure. Ideally, CFA should be conducted on a separate dataset to enhance confirmatory robustness and reduce the risk of overfitting. Although this approach is considered acceptable in early-stage model development, it may limit the generalisability and external validity of the findings. Future studies should therefore seek to cross-validate the model using independent and more diverse datasets.
- **Geographic and Sectoral Scope:** The study primarily reflects the context of professionals working in the AEC sector, with a focus on New Zealand, Australia, and comparable environments. While the competencies identified are broadly relevant, cultural, regulatory, and market-specific factors in other regions may influence how competencies are prioritised or enacted. Cross-country validation is therefore required before universal generalisations can be made.
- **Reliance on Self-Reported Data:** The survey instrument relied on participants' self-assessment of competencies. While widely used in competency research, this method introduces the possibility of bias, such as overestimation or underestimation of abilities. Observational or performance-based assessments, combined with triangulated data sources, could provide a more objective validation in future studies.
- **Design and Methodological Boundaries:** The study employed a cross-sectional research design, capturing a single point in time. This limits the ability to assess how competencies evolve throughout the project lifecycle or under varying organisational maturity levels. Furthermore, while the integration of traditional and digital competencies through taxonomy and comparative analysis was rigorous, some degree of subjective judgement was unavoidable in mapping overlaps and distinctions. Longitudinal or case study approaches could address these limitations by testing the framework in dynamic project environments.
- **Exclusion of Competencies During Refinement:** Of the 55 competencies identified in Chapter 4, 30 were excluded during the EFA process due to statistical issues such as cross-loadings, low communalities, thematic ambiguity, or redundancy with more stable items. Their removal was necessary to improve parsimony and discriminant validity; however, this narrowing may constrain the comprehensiveness of the validated framework. Importantly, these competencies remain conceptually relevant and may be reintroduced in future studies, particularly in role-specific sub-frameworks (e.g., cybersecurity, AI adoption, training design) or in studies with larger and more diverse datasets.

By acknowledging these limitations, the thesis demonstrates transparency and establishes a foundation for subsequent studies to refine, extend, and validate the Next-Gen Digital PM Competency Model, ensuring its continued relevance and applicability across diverse contexts and project environments.

8.6 Future Research Directions

Building on the limitations identified, several avenues for future research can extend and deepen the contributions of this thesis. These directions focus on enhancing the generalisability and long-term applicability of the Next-Gen Digital PM Competency Model.

- **Larger and More Diverse Samples:** Future studies should draw on larger datasets from multiple countries and regions to strengthen statistical robustness and broaden representativeness. Comparative analyses across different cultural, regulatory, and market environments could reveal how competency priorities vary and provide insights into context-specific adaptations of the model.
- **Longitudinal and Dynamic Studies:** This thesis employed a cross-sectional design that captured competencies at a single point in time. Future research could adopt longitudinal designs to track how competencies evolve as projects progress, as organisations mature digitally, or as new technologies reshape workflows. Such studies would provide deeper insights into competency development trajectories and their relationship with project outcomes.
- **Alternative Validation Approaches:** This study applied a rigorous validation process using EFA and CFA within SEM, providing strong evidence of the model's reliability and theoretical coherence. Future research could build on these findings by employing complementary methods such as second-order factor models, multi-group analyses, or predictive SEM approaches. These techniques would not replace the current validation but extend it, allowing for testing across subgroups (e.g., by role, organisation size, or geographic region) and exploring additional dimensions such as predictive power or higher-order competency constructs.
- **Reintegration of Excluded Competencies:** Of the 55 digital competencies identified, 30 were excluded during the EFA refinement process for statistical reasons. These competencies remain conceptually significant and present opportunities for further study. Future research could reintroduce them into larger or more diverse samples, examine their role in role-specific competency sets (e.g., cybersecurity, AI integration, or training-focused PM roles), or explore their value through qualitative approaches such as expert Delphi studies. By doing so, researchers can test whether these competencies form distinct sub-frameworks or contribute to higher-order constructs not evident in this dataset.
- **Adaptability to Emerging Technologies:** As digital innovation continues to accelerate, competencies related to artificial intelligence, cybersecurity, environmental intelligence, and other emerging domains will become increasingly important. The current model represents an empirically validated foundation, but it should be revisited and expanded periodically to ensure its continued relevance. Future research can explore how the model adapts to disruptive technologies, ensuring it remains a living framework for digital project management in the Smart Built Environment.

In summary, the Next-Gen Digital PM Competency Model developed in this thesis provides a robust initial foundation, but it is not static. Future research has the opportunity to refine, expand, and contextualise the model, ensuring that it evolves alongside the AEC sector's digital transformation. By reintroducing excluded competencies, exploring emerging technologies, and testing the model across diverse contexts and timescales, subsequent studies can ensure its ongoing relevance as both an academic framework and a practical tool for digital leadership in construction.

8.6.1 Pathway to Guidelines and Tools

Future research should focus on operationalising the validated Next-Gen Digital PM Competency Model into applied tools and guidelines that support consistent adoption across the AEC sector. While the model provides a robust, empirically validated foundation, its full practical impact depends on its translation into structured instruments and implementation frameworks.

The pathway to operationalisation can be advanced through three complementary streams of future research:

- **Competency Assessment Instruments**: Future studies should develop diagnostic tools that enable PMs and organisations to systematically evaluate digital readiness. These instruments would translate the seven validated factors into measurable indicators, supporting consistent assessment across individuals, teams, and organisations.
- **Practical Guidelines and Frameworks**: Future research should produce structured guidance for organisations, policymakers, and professional bodies on how to embed the model into workforce planning, capability development, and certification schemes. This would support the formal recognition and structured development of digital competencies across the sector.
- **Role-Specific Adaptations**: Future work should explore tailored applications of the model for distinct digital project management roles (e.g., BIM specialists, Digital Twin managers, AI integration leads). These adaptations would retain the universal competency backbone while highlighting role-specific competency configurations relevant to different digital functions.

Figure 8.4 illustrates this progression from a validated research backbone toward the development of guidelines, assessment tools, and role-specific adaptations. This staged pathway highlights how the model can evolve from an empirically validated framework into a scalable and practically deployable system for the AEC sector.

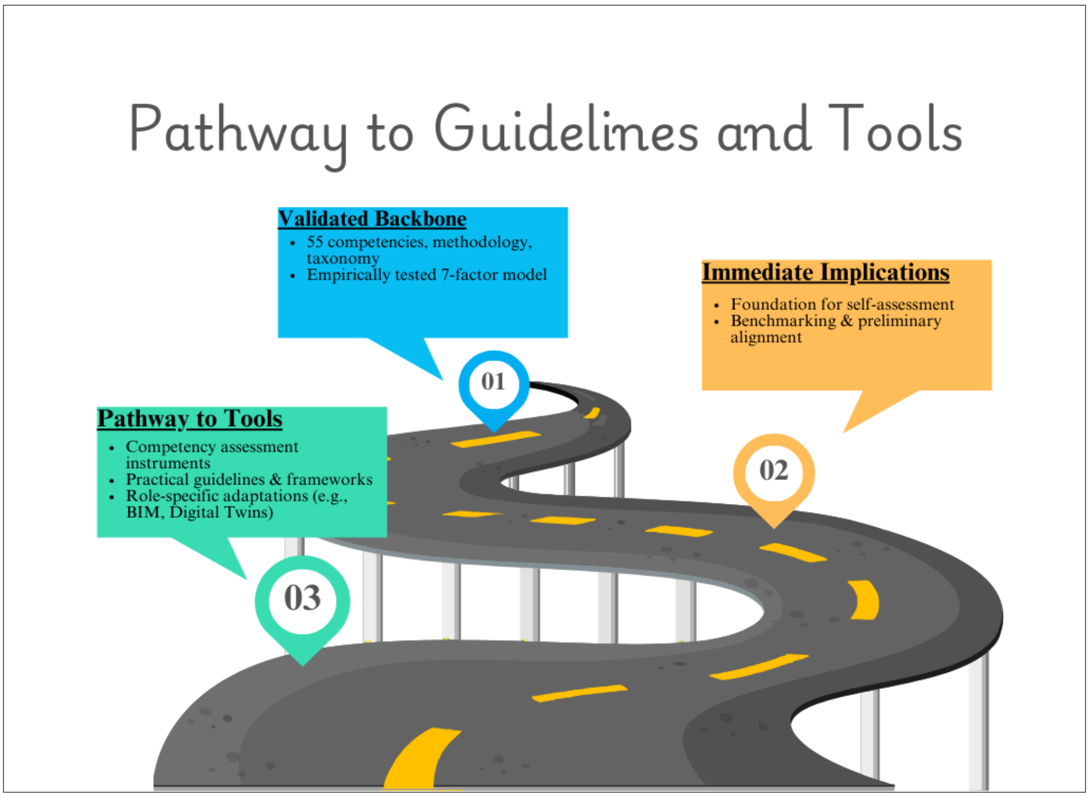


Figure 8.4: Roadmap from validated research backbone through immediate implications toward the development of guidelines, tools, and role-specific adaptations

By advancing these directions, future research can support the transition of the model from a validated research construct into a structured and adaptable framework for practice, enabling more systematic competency assessment, workforce development, and digital transformation across construction environments.

8.6.2 Pathways for International and Contextual Uptake

Future research should examine the international applicability and contextual adaptation of the validated Next-Gen Digital PM Competency Model across diverse regions and project environments. While the model establishes a universal competency backbone, its meaningful adoption requires empirical testing and alignment with different policy, organisational, and project contexts.

Three key pathways can guide this future research:

- **Policy and Professional Recognition**: Future studies should investigate how the model can be embedded within professional certification systems and policy frameworks. Alignment with standards such as PMI's Talent Triangle, IPMA's ICB, and national accreditation schemes would support the formal integration of digital competencies into training, licensing, and capability development processes, reducing the risk of fragmented adoption.
- **Scalability Across Project Types**: Future research should explore how the relative emphasis of competencies varies across different project scales and delivery contexts. Large-scale infrastructure projects may prioritise data-driven optimisation, digital twin integration, and lifecycle resilience, whereas smaller or less digitally mature projects may require greater emphasis on foundational digital literacy and collaborative

capabilities. This line of inquiry would clarify how the universal backbone can be flexibly applied without compromising its validity.

- **Mechanisms for Adaptation and Revalidation**: Future studies should replicate the EFA–CFA validation process across different geographic, cultural, and sectoral contexts to test the stability of the model's factor structure. Such empirical revalidation would strengthen confidence in the model's generalisability while enabling evidence-based contextual refinement where necessary.

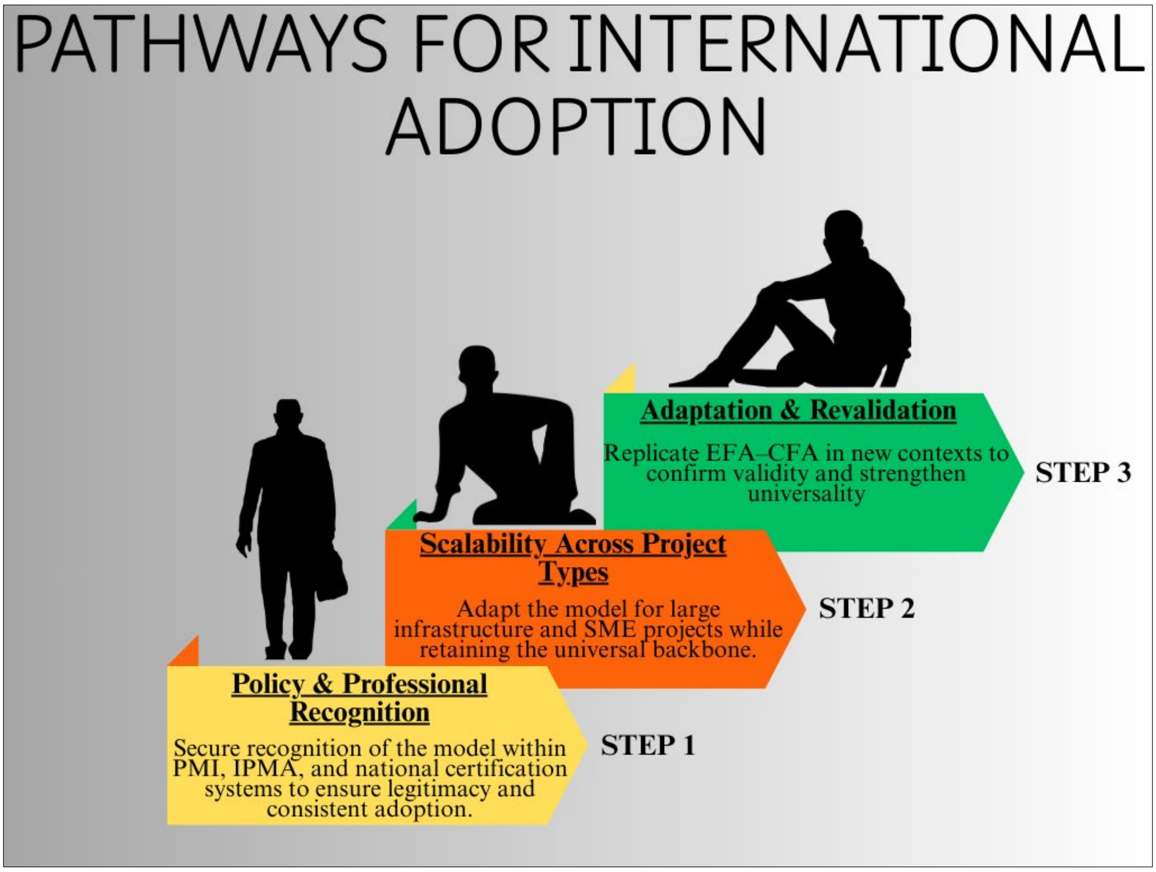


Figure 8.5: Pathways for international and contextual uptake of the validated backbone

Figure 8.5 illustrates a staged pathway for international and contextual uptake of the validated model. Step 1 highlights policy and professional alignment, Step 2 demonstrates scalability across project types, and Step 3 emphasises adaptation and revalidation through empirical testing in new contexts.

By advancing these directions, future research can ensure that the model evolves as a globally relevant and context-sensitive framework, supporting consistent and scalable adoption of digital project management competencies across the AEC sector.

8.7 Closing Reflection

This thesis set out to address a critical gap in the field of construction project management:

"There is currently an absence of a sector-specific, empirically validated competency framework and model for construction project managers. Existing frameworks do not adequately unite traditional competencies with emerging digital demands or respond to the transformative pressures of digital transformation in the construction sector."

In response, the research aimed *"To develop and validate a sector-specific digital PM competency model tailored to the needs of the AEC sector in the context of rapid digital transformation."* Guided by the primary research question *"How can traditional and emerging digital project manager competencies be identified, systematically integrated into a taxonomy, and empirically validated to create a robust competency model that supports construction project managers in leading digital transformation within the AEC sector?"* this study systematically progressed from the identification of competencies, through taxonomy-based integration, to empirical validation.

The resulting Next-Gen Digital Project Manager (PM) Competency Model provides a validated, practice-relevant foundation that empowers PMs to act as leaders of digital transformation in the Architecture, Engineering, and Construction (AEC) sector. The model is designed to function as a universal backbone, offering stability through its empirically validated competencies and factor structure, while also accommodating contextual adaptations shaped by legislation, culture, technological maturity, and project scale. This balance between a stable backbone and adaptable applications ensures that the model can serve both as a shared global reference point and as a flexible framework responsive to diverse environments.

While the model is robust and grounded in empirical evidence, it is not a final endpoint. Instead, it should be understood as an initial, living framework that evolves alongside the industry it serves. Its strength lies in providing a stable, validated backbone, but its long-term value depends on continuous refinement, expansion, and contextualisation as new technologies emerge, organisational practices mature, and sector-wide priorities shift. In this sense, the model is not static but iterative, encouraging researchers, practitioners, and policymakers to revisit, test, and adapt it over time to ensure its enduring relevance in guiding digital project management within the Smart Built Environment.

In closing, this thesis makes a twofold contribution. **Academically**, it offers a theoretically and statistically validated model that advances knowledge in competency modelling, digital project management, and construction management research. **Practically**, it provides industry with a research-informed basis that can inform workforce planning, professional development, and strategic digital leadership. By linking traditional strengths with emerging digital demands, and by establishing a foundation for future development into guidelines, assessment instruments, and stakeholder-specific adaptations, the model positions PMs not only to adapt to technological change but also to actively lead it, shaping the future of construction in an era of digital transformation.

Future research should focus on operationalising the model through the development of diagnostic tools, practical guidelines, and role-specific frameworks, thereby ensuring its sustained impact across research, industry, and policy domains.

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TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Appendix A1: Ethics Approval and Documentation

30 January 2025

Mani Poshdar
Faculty of Design and Creative Technologies

Dear Mani

Re Ethics Application: **23/257 Project manager competency in the digital construction era**

Thank you for your responses to AUTEC's conditions.

Your ethics application (survey) has been approved for three years until 28 January 2028.

Non-Standard Conditions of Approval

1. Please ensure that the online survey introduction Information Sheet) includes the AUT logo, and an indication of where an interested participant may find a summary or report of the research findings.

Non-standard conditions do not need to be submitted to or reviewed by AUTEC unless requested but must be completed before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

Auckland University of Technology Ethics Committee (AUTEC)

All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact the Secretariat at ethics@aut.ac.nz

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat

Auckland University of Technology Ethics Committee

Cc: Omar Owais

Appendix A2: Qualtrics Survey Instrument

Welcome and Thank You!

Dear Participant,

Thank you for considering participation in this research study titled "Project Manager Competency in the Digital Construction Era". This research is part of my PhD study at Auckland University of Technology (AUT).

The purpose of this study is to explore and define the digital competencies required for project managers in the evolving construction industry. By participating in this survey, you will contribute to identifying key competencies that support the shift from traditional to digital practices, ultimately enhancing construction project performance.

The survey will take approximately 15 minutes to complete, and your responses will remain completely anonymous and confidential. Participation is entirely voluntary, and you may exit the survey at any time by closing your browser. Completing the survey will be considered your consent to participate.

In appreciation of your valuable participation, you will have access to the "Check Research Results" link at the end of the survey. This will allow you to stay informed and gain early access to a summary of the key findings once the study is completed

If you have any questions regarding the survey, please do not hesitate to contact me at omar.owais@autuni.ac.nz.

AUT Ethics Approval: #23/257

We truly value your insights and expertise, and your participation will contribute significantly to this important research.
Thank you for your time and support!

Kind regards,

Omar Owais
PhD Candidate
School of Future Environments
Auckland University of Technology (AUT)

Let's get started!

Section 1: Demographic Information

1. **In what age group are you?**

(a) Under than 19 (b) 20-29 (c) 30-39
(d) 40-49 (e) 50+

2. **Gender:**

(a) Male (b) Female (c) Non-binary / third gender
(d) Prefer not to say

3. **How many years of experience do you have working in the Architecture, Engineering, and Construction (AEC) industry?**

(a) Less than 5 years (b) 5 - 10 years (c) 10 - 15 years
(d) 15 - 20 years (e) More than 20 years

4. **Please indicate your professional field within your organisation:**

(a) Construction Engineering (Civil, Structural, Construction)	(b) Design and Architecture (Architect, Architectural Technologist, Interior Designer)	(c) Project Management (Construction Project Manager, Site Manager / Construction Manager, Project Coordinator)
(d) Digital and Technology (BIM Manager / Virtual Design, Digital Construction Engineer, Data Analyst (Construction-Specific))	(e) Another (please specify): ___	

5. **Please indicate your current position within your organisation:**

(a) Director (b) Senior Manager (c) Manager
(d) Quantity Surveyor (e) Another (please specify): ____

6. **Please indicate your highest level of educational qualification:**

(a) Diploma (b) Bachelor’s Degree (c) Master’s Degree
(d) PhD (e) Another (please specify): ____

7. **How would you rate your level of awareness of emerging digital technologies in the construction industry?**

(a) Very Familiar (b) Familiar (c) Moderately Familiar
(d) Not Familiar

Section 2: Foundations of Digital Project Management

❖ **Based on your experience, please indicate the level of importance of the following <u>strategic and operational management factors</u> for a digital project manager competency in the construction sector.**

Guide for Rating:
When rating the importance, please consider how frequently this factor impacts project success based on your professional experience.

Project Manager Competencies/Skills	Level of Importance				
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. *Holding professional qualifications and certifications (e.g., BIM management, LEED AP) to ensure compliance with industry standards and evolving practices.*					
2. *Collaborating with academic institutions to develop industry-specific curricula that integrate technical knowledge and best practices.*					
3. *Identifying, evaluating, and addressing information needs within digital environments (e.g., BIM, project dashboards) to support informed decision-making.*					
4. *Assessing the quality, relevance, and reliability of digital content and data to ensure accuracy and project success.*					
5. *Organising, storing, and retrieving digital data and content efficiently (e.g., cloud-based platforms) to enable effective project communication and collaboration.*					
6. *Creating, editing, and managing digital content across various formats (e.g., 3D models, reports) to communicate ideas and enhance project success.*					
7. *Refining and integrating existing digital content to produce innovative and tailored outputs for project requirements.*					
8. *Utilising programming and automation to optimise workflows, analyse data, and solve project challenges.*					
9. *Applying advanced digital tools (e.g. BIM, simulation tools) to design, model, and document project deliverables effectively.*					
10. *Providing training and development for construction professionals to use digital tools (e.g., BIM) effectively in projects.*					
11. *Organising and maintaining electronic project files, ensuring accurate documentation and version control throughout the project lifecycle.*					
12. *Communicating effectively with team members, stakeholders, and clients to ensure coordination and collaboration across multidisciplinary teams.*					
13. *Establishing and maintaining strong relationships with stakeholders to align objectives and ensure seamless project communication.*					
14. *Using language proficiency (spoken and written) to facilitate clear and efficient communication across diverse teams and cultures.*					
15. *Engaging with stakeholders and teams using digital platforms to adapt communication methods for technical and non-technical audiences.*					
16. *Sharing data, information, and digital content through technologies like BIM and Digital Twins for real-time collaboration.*					
17. *Documenting and sharing lessons learned through digital tools to promote team learning and continuous improvement.*					

Section 3: Strategic and Operational Management

❖ **Based on your experience, please indicate the level of importance of the following <u>strategic and operational management factors</u> for a digital project manager in the construction sector.**

Guide for Rating:
When rating the importance, please consider how frequently this factor impacts project success based on your professional experience.

Project Manager Competencies/Skills	Level of Importance				
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. *Using digital tools (e.g., BIM for risk analysis) to identify, assess, and mitigate risks across the project lifecycle.*					
2. *Managing risks in adopting and integrating new technologies (e.g., BIM, IoT) by ensuring feasibility, standardisation, and minimising disruptions during implementation in construction projects.*					
3. *Addressing financial risks related to cost overruns, unexpected expenses, and budgeting uncertainties in technology-driven projects (e.g., 5D BIM cost estimation).*					
4. *Managing costs associated with new technologies, materials, and training in smart building projects.*					
5. *Using digital tools (e.g., BIM 5D models) for precise cost estimation, real-time feedback, and efficient budget management.*					
6. *Optimising procurement activities through digital tools (e.g., e-procurement platforms) for accurate material quantity predictions and resource planning.*					
7. *Ensuring project objectives align with broader organisational strategies by collaborating with management and setting actionable goals.*					
8. *Integrating multidisciplinary aspects of projects using collaborative technologies (e.g., cloud-based project management tools) for efficient planning, execution, and delivery.*					
9. *Managing safety across the project lifecycle using digital tools (e.g., AI-driven hazard detection) for hazard identification, mitigation, and compliance.*					
10. *Overseeing quality control and lifecycle data management to ensure continuous monitoring, informed decision-making, and long-term project sustainability.*					
11. *Managing contract negotiations and administration to mitigate risks, ensure compliance, and foster strong relationships with stakeholders.*					
12. *Ensuring adherence to regulatory frameworks and industry standards (e.g., building codes) throughout the project lifecycle using digital tools.*					

Section 4: Execution, Innovation, and Continuous Improvement

❖ **Based on your experience, please indicate the level of importance of the following <u>execution, innovation, and leadership factors</u> for a digital project manager competency in the construction sector.**

Guide for Rating:
When rating the importance, please consider how frequently this factor influences project outcomes in your experience.

Project Manager Competencies/Skills	Level of Importance				
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. *Managing project schedules using digital technologies (e.g., BIM 4D scheduling) to optimise timelines and ensure timely delivery.*					
2. *Allocating and coordinating resources (e.g., materials, labour, and technology) using digital tools (e.g., BIM-based resource allocation) for efficient project execution.*					
3. *Ensuring quality control using digital tools (e.g., drone-based site monitoring) to monitor, audit, and document project elements in real time.*					
4. *Managing project scope and changes using digital technologies (e.g., BIM to visualise design modifications) to adapt to evolving project requirements effectively.*					
5. *Adopting and integrating emerging technologies (e.g., AI, automation, big data) to enhance efficiency and project performance.*					
6. *Fostering innovation and creativity within teams to leverage digital tools (e.g., VR for virtual prototyping) for problem-solving and improved*					

Project Manager Competencies/Skills	Level of Importance				
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
outcomes.					
7. Leveraging data-driven approaches and analytical tools to make precise, evidence-based project decisions.					
8. Standardising technology processes and workflows in construction to enhance collaboration and minimise errors.					
9. Leading and inspiring multidisciplinary teams to achieve project goals through collaboration and effective communication.					
10. Managing relationships with diverse stakeholders (e.g., clients, government entities) to foster collaboration and ensure project success.					
11. Demonstrating self-management, emotional resilience, and adaptability to maintain productivity under pressure.					
12. Making timely, effective decisions that align with project goals while taking accountability for outcomes.					
13. Creating a supportive work environment that prioritises team well-being, safety, and morale.					
14. Identifying, evaluating, and resolving technical issues with digital tools (e.g., automated clash detection) to ensure smooth project execution and performance optimisation.					
15. Assessing and addressing gaps in digital skills within teams to enhance performance and adapt to evolving digital technologies.					
16. Safeguarding devices and data through effective digital security practices, including risk mitigation and cyber threat management.					
17. Protecting personal and organisational data by ensuring compliance with privacy regulations and preventing unauthorised access or breaches.					
18. Using digital tools and software (e.g., BIM, project management platforms, cloud-based data systems) to enhance project planning, execution, and data management in construction.					
19. Integrating and utilising digital tools (e.g., BIM, IoT, model analysis software) to enhance project workflows, collaboration, and innovation in construction projects.					
20. Using digital tools (e.g., Digital Twins) to simulate, monitor, and optimise building performance, maintenance planning, and resource management throughout the project lifecycle.					
21. Managing complex construction processes, integrating technical data, and leveraging digital tools (e.g., BIM for coordination) to enhance engineering workflows and project execution.					
22. Applying emerging technologies (e.g., IoT, AI, VR, drones) to improve efficiency, innovation, and project outcomes in construction projects.					
23. Managing and utilising advanced digital systems (e.g., AI-driven analytics) to ensure data integrity, structured project planning, and efficient construction execution.					
24. Using digital tools (e.g., BIM, Digital Twins) to optimise energy efficiency, reduce carbon footprint, and support sustainable construction practices.					
25. Tracking and analysing the environmental performance of construction projects to ensure transparency, sustainability reporting, and continuous improvement.					
26. Integrating sustainability concepts and environmentally responsible practices into construction projects to reduce environmental impact and promote smart buildings.					

Feedback is Optional.

We value your feedback! Please share any comments or suggestions you have about this survey or our research.

Thank You for Your Participation!

Dear Participant,

Thank you for taking the time to complete this survey. Your valuable insights and contributions are greatly appreciated and will play a key role in advancing our research on **Project Manager Competency in the Digital Construction Era.**

The research findings are not yet available, but you can check for updates and access the results once the study is complete by visiting the following link:

Check Research Results

Please save this link for future reference.

Once again, thank you for your valuable input!

Warm regards,
The Research Team

Appendix A3: LLM Prompt Template and Input Structure

This appendix outlines the standardised prompt template and input structure used in Phase Three of the study to support transparency and replicability of the LLM-based competency definition process.

1. **Input Structure**

For each competency, the LLM was provided with a structured input dataset derived from the outputs of the Systematic Literature Review (Phase One) and Thematic Analysis (Phase Two). The structured input comprised:

- Competency Name: The title of the competency
- NVivo-Derived Keywords: Key descriptors and thematic codes extracted during qualitative analysis
- Source Definitions: Multiple definitions obtained from peer-reviewed literature

All inputs were formatted consistently across competencies to maintain alignment and traceability to the original literature sources.

2. **Prompt Template**

The following standardised prompt template was used for all competency definitions:

Task:

Generate one clear and comprehensive definition for the given competency based solely on the provided inputs.

Inputs:

- Competency Name: [Insert competency name]
- Keywords: [Insert NVivo-derived keywords]
- Source Definitions: [Insert extracted definitions from literature]

Instructions:

- Use only the provided inputs
- Do not introduce new concepts, ideas, or external knowledge
- Integrate and consolidate the information into a single coherent definition
- Remove redundancy and repetition
- Ensure alignment with the original meaning of the source material
- Maintain academic clarity and professional tone
- Ensure relevance to digital project management in the construction sector

Output Requirement:

- Provide one concise, unified definition that reflects the collective meaning of the inputs

3. **Procedural Controls for Bias and Hallucination Mitigation**

The following procedural controls were applied to minimise the risk of hallucination and bias:

- **Input Restriction:** The LLM was limited to structured inputs derived from validated literature sources
- **Prompt Constraints:** Explicit instructions prevented the introduction of new or unsupported concepts
- **Manual Verification:** Outputs were systematically cross-checked against original sources to ensure accuracy and consistency
- **Expert Review:** Definitions were assessed for clarity, accuracy, and industry relevance

Appendix B: Impermissible Value Screening

Descriptive Statistics

	N	Minimum	Maximum
S1	103	1	4
S2	103	1	3
S3	103	1	4
S4	103	1	4
S5	103	1	4
S6	103	1	3
S7	103	1	3
S8	103	1	3
S9	103	1	4
S10	103	1	4
S11	103	1	4
S12	103	1	3
S13	103	1	3
S14	103	1	4
S15	103	1	4
S16	103	1	5
S17	103	1	4
S18	103	1	4
S19	103	1	3
S20	103	1	3
S21	103	1	3
S22	103	1	4
S23	103	1	4
S24	103	1	4
S25	103	1	4
S26	103	1	4
K1	103	1	3
K2	103	1	5
K3	103	1	4
K4	103	1	3
K5	103	1	3
K6	103	1	4
K7	103	1	3
K8	103	1	3
K9	103	1	3
K10	103	1	3
K11	103	1	4
K12	103	1	3
K13	103	1	3
K14	103	1	3
K15	103	1	4
K16	103	1	4

Descriptive Statistics

	N	Minimum	Maximum
K17	103	1	4
K18	103	1	4
K19	103	1	4
K20	103	1	5
K21	103	1	5
CP1	103	1	4
CP2	103	1	3
CP3	103	1	4
CP4	103	1	3
CP5	103	1	3
CP6	103	1	4
CP7	103	1	4
CP8	103	1	5
Valid N (listwise)	103		

Appendix C: Skewness and Kurtosis Screening

Descriptive Statistics

	N	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Std. Error
S1	103	.597	.238	-.207	.472
S2	103	.294	.238	-.779	.472
S3	103	.346	.238	-.369	.472
S4	103	.770	.238	-.093	.472
S5	103	1.006	.238	.861	.472
S6	103	.589	.238	-.639	.472
S7	103	.844	.238	-.281	.472
S8	103	.422	.238	-.869	.472
S9	103	.936	.238	.378	.472
S10	103	.808	.238	1.005	.472
S11	103	.320	.238	-.733	.472
S12	103	.435	.238	-.754	.472
S13	103	.640	.238	-.571	.472
S14	103	.735	.238	.241	.472
S15	103	.742	.238	.378	.472
S16	103	1.029	.238	2.263	.472
S17	103	.609	.238	-.335	.472
S18	103	.482	.238	-.233	.472
S19	103	.140	.238	-.970	.472
S20	103	.147	.238	-1.222	.472
S21	103	.022	.238	-.737	.472
S22	103	.445	.238	-.181	.472
S23	103	.636	.238	.358	.472
S24	103	.469	.238	-.311	.472
S25	103	.655	.238	-.112	.472
S26	103	.280	.238	-.778	.472
K1	103	.627	.238	-.749	.472
K2	103	.538	.238	.308	.472
K3	103	.273	.238	-.049	.472
K4	103	.167	.238	-.537	.472
K5	103	.341	.238	-.860	.472
K6	103	.388	.238	-.640	.472
K7	103	.267	.238	-.907	.472
K8	103	.052	.238	-1.369	.472
K9	103	.167	.238	-.537	.472
K10	103	.620	.238	-.621	.472
K11	103	.682	.238	.776	.472
K12	103	.449	.238	-.993	.472
K13	103	.364	.238	-.872	.472
K14	103	.234	.238	-.983	.472
K15	103	.398	.238	-.216	.472

Descriptive Statistics

	N	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Std. Error
K16	103	.591	.238	.529	.472
K17	103	.353	.238	-.358	.472
K18	103	.522	.238	-.123	.472
K19	103	.649	.238	.060	.472
K20	103	.946	.238	1.255	.472
K21	103	.537	.238	.223	.472
CP1	103	.823	.238	.409	.472
CP2	103	.560	.238	-.654	.472
CP3	103	.548	.238	-.391	.472
CP4	103	.560	.238	-.654	.472
CP5	103	.650	.238	-.600	.472
CP6	103	1.324	.238	2.334	.472
CP7	103	.909	.238	.484	.472
CP8	103	.773	.238	.970	.472
Valid N (listwise)	103				

Appendix D: KMO and Bartlett's Test results

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.736
Bartlett's Test of Sphericity	Approx. Chi-Square	3579.238
	df	1485
	Sig.	<.001

Communalities

	Initial	Extraction
S1	.761	.665
S2	.846	.822
S3	.765	.648
S4	.742	.576
S5	.839	.640
S6	.829	.824
S7	.727	.673
S8	.758	.580
S9	.731	.748
S10	.568	.517
S11	.652	.468
S12	.711	.679
S13	.678	.419
S14	.791	.663
S15	.769	.502
S16	.718	.506
S17	.824	.737
S18	.813	.705
S19	.766	.629
S20	.773	.654
S21	.661	.630
S22	.790	.657
S23	.764	.691
S24	.784	.626
S25	.820	.630
S26	.818	.700
K1	.703	.621
K2	.786	.663
K3	.775	.581
K4	.732	.732
K5	.775	.710
K6	.782	.726
K7	.822	.698
K8	.823	.817
K9	.678	.437

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Communalities

	Initial	Extraction
K10	.655	.472
K11	.720	.558
K12	.728	.639
K13	.764	.667
K14	.777	.726
K15	.804	.621
K16	.686	.499
K17	.791	.633
K18	.874	.796
K19	.859	.681
K20	.665	.466
K21	.587	.358
CP1	.746	.681
CP2	.675	.572
CP3	.785	.629
CP4	.809	.766
CP5	.715	.613
CP6	.805	.815
CP7	.760	.600
CP8	.734	.615

Extraction Method: Principal Axis Factoring.

Appendix E: Total Variance Explained – SPSS Outcome

Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	14.506	26.375	26.375	14.157	25.739	25.739
2	3.996	7.265	33.640	3.648	6.633	32.372
3	3.170	5.763	39.404	2.808	5.105	37.478
4	2.438	4.433	43.837	2.078	3.779	41.257
5	2.335	4.245	48.081	1.989	3.616	44.873
6	2.104	3.825	51.906	1.759	3.198	48.071
7	1.696	3.083	54.989	1.330	2.418	50.489
8	1.521	2.766	57.755	1.155	2.100	52.588
9	1.421	2.583	60.338	1.074	1.953	54.541
10	1.405	2.554	62.892	1.045	1.901	56.442
11	1.246	2.265	65.157	.910	1.655	58.097
12	1.193	2.169	67.326	.838	1.523	59.620
13	1.153	2.097	69.422	.801	1.456	61.077
14	1.081	1.965	71.388	.723	1.314	62.391
15	1.017	1.849	73.237	.663	1.206	63.597
16	.964	1.753	74.990			
17	.919	1.672	76.662			
18	.882	1.604	78.266			
19	.804	1.463	79.728			
20	.782	1.422	81.151			
21	.705	1.283	82.433			
22	.692	1.259	83.692			
23	.642	1.168	84.860			
24	.600	1.091	85.951			
25	.584	1.062	87.013			
26	.544	.989	88.002			
27	.540	.981	88.983			
28	.475	.864	89.847			
29	.438	.796	90.644			
30	.420	.764	91.408			
31	.405	.737	92.145			
32	.396	.719	92.864			
33	.332	.603	93.467			
34	.320	.583	94.050			
35	.299	.544	94.594			
36	.285	.518	95.112			
37	.268	.488	95.600			
38	.251	.456	96.057			
39	.236	.430	96.486			
40	.224	.408	96.894			
41	.209	.380	97.274			

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Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
42	.190	.346	97.620			
43	.175	.318	97.938			
44	.166	.302	98.240			
45	.149	.271	98.511			
46	.127	.231	98.743			
47	.111	.201	98.944			
48	.104	.190	99.134			
49	.101	.183	99.317			
50	.085	.154	99.471			
51	.084	.153	99.624			
52	.073	.132	99.756			
53	.056	.102	99.858			
54	.044	.079	99.937			
55	.034	.063	100.000			

Extraction Method: Principal Axis Factoring.

Appendix F: Communalities of Extracted Factors

Communalities

	Initial	Extraction
S1	.761	.619
S2	.846	.578
S3	.765	.564
S4	.742	.478
S5	.839	.540
S6	.829	.372
S7	.727	.322
S8	.758	.583
S9	.731	.473
S10	.568	.419
S11	.652	.334
S12	.711	.491
S13	.678	.292
S14	.791	.455
S15	.769	.434
S16	.718	.455
S17	.824	.549
S18	.813	.416
S19	.766	.613
S20	.773	.602
S21	.661	.296
S22	.790	.573
S23	.764	.344
S24	.784	.599
S25	.820	.599
S26	.818	.596
K1	.703	.438
K2	.786	.503
K3	.775	.498
K4	.732	.435
K5	.775	.538
K6	.782	.450
K7	.822	.591
K8	.823	.612
K9	.678	.343
K10	.655	.290
K11	.720	.386
K12	.728	.422
K13	.764	.448
K14	.777	.624
K15	.804	.542
K16	.686	.357

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Communalities

	Initial	Extraction
K17	.791	.502
K18	.874	.628
K19	.859	.630
K20	.665	.337
K21	.587	.264
CP1	.746	.521
CP2	.675	.482
CP3	.785	.511
CP4	.809	.681
CP5	.715	.542
CP6	.805	.505
CP7	.760	.520
CP8	.734	.570

Extraction Method: Principal Axis Factoring.

Appendix G: Supplementary Goodness-of-Fit Indices

Model Fit Summary

CMIN

Model	NPAR	CMIN	DF	P	CMIN/DF
Default model	71	232.163	182	.007	1.276
Saturated model	253	.000	0		
Independence model	22	927.035	231	.000	4.013

RMR, GFI

Model	RMR	GFI	AGFI	PGFI
Default model	.037	.841	.779	.605
Saturated model	.000	1.000		
Independence model	.137	.400	.343	.365

Baseline Comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.750	.682	.933	.909	.928
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

Parsimony-Adjusted Measures

Model	PRATIO	PNFI	PCFI
Default model	.788	.591	.731
Saturated model	.000	.000	.000
Independence model	1.000	.000	.000

NCP

Model	NCP	LO 90	HI 90
Default model	50.163	15.103	93.361
Saturated model	.000	.000	.000
Independence model	696.035	606.057	793.561

FMIN

Model	FMIN	F0	LO 90	HI 90
Default model	2.276	.492	.148	.915
Saturated model	.000	.000	.000	.000
Independence model	9.089	6.824	5.942	7.780

RMSEA

Model	RMSEA	LO 90	HI 90	PCLOSE
Default model	.052	.029	.071	.424
Independence model	.172	.160	.184	.000

AIC

Model	AIC	BCC	BIC	CAIC
Default model	374.163	415.505	561.229	632.229
Saturated model	506.000	653.316	1172.586	1425.586
Independence model	971.035	983.845	1028.999	1050.999

ECVI

Model	ECVI	LO 90	HI 90	MECVI
Default model	3.668	3.325	4.092	4.074
Saturated model	4.961	4.961	4.961	6.405
Independence model	9.520	8.638	10.476	9.646

HOELTER

Model	HOELTER .05	HOELTER .01
Default model	95	101
Independence model	30	32