Modelling the enablers of effective digital technology implementation for competitiveness enhancement among subcontracting organisations in New Zealand's residential construction industry

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Abstract

Purpose – To evaluate the key factors that enable the effective implementation of digital technologies to improve competitiveness among subcontracting organisations in New Zealand's residential construction industry.

Design/methodology/approach – A quantitative survey of 142 subcontracting organisations was analysed using principal component analysis to derive core competitiveness dimensions and automatic linear modelling (ALM) to identify predictive digital-adoption factors.

Findings – ALM revealed five significant predictors of competitiveness variance: investment in digital technologies, ethical compliance, knowledge sharing, employee training and supportive digital mindsets.

Research limitations/implications – The study used a cross-sectional survey design, which limits causal interpretation between digital adoption factors and competitiveness outcomes. The analysis focused solely on subcontracting organisations within New Zealand's residential construction sector; therefore, generalisability to other construction contexts or countries should be approached cautiously. Future research could adopt longitudinal or mixed method approaches to validate the predictive relationships identified through PCA and ALM and to explore qualitative dimensions such as leadership behaviour and organisational culture in digital transformation processes.

Practical implications – The findings suggest that competitiveness among subcontracting organisations depends on technological investment, ethical compliance, organisational learning and workforce capability. They highlight that digital transformation should be viewed as a socio-technical process, requiring not only technology adoption but also supportive mindsets, effective knowledge-sharing mechanisms and sustained capability development. These insights can guide policymakers and managers in promoting digital readiness, fostering ethical governance and strengthening organisational learning to enhance long-term competitiveness in the construction sector.

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Originality/value – This paper is the first to apply data-driven ALM to model the digital-competitiveness nexus within New Zealand's subcontracting organisations, providing a statistically grounded recommendation for targeted digital-transformation strategies.

Keywords Digital technologies, Digital transformation, Construction innovation, Smart construction, Building information modelling (BIM), Internet of Things (IoT)

Paper type Research paper

1. Introduction

The construction industry is a major contributor to national economies, driving growth through the development of essential infrastructure and the creation of employment opportunities (Abdul-Samad *et al.*, 2024; Ernstsen *et al.*, 2021). As one of the world's largest sectors, it encompasses diverse activities ranging from residential and commercial projects to large-scale infrastructure developments (Musarat *et al.*, 2024). Despite its economic significance, the industry remains characterised by fragmentation, inefficiencies and limited productivity gains. Construction projects involve multiple stakeholders, architects, engineers, contractors and subcontractors, each with distinct roles and objectives, leading to coordination difficulties, cost overruns and reduced quality outcomes (Long *et al.*, 2024; Zhang *et al.*, 2023). Moreover, the industry continues to rely heavily on labour-intensive and traditional practices that hinder innovation and performance improvements (Wuni *et al.*, 2024).

The emergence of digitalisation has provided opportunities to address these persistent challenges. Digital technologies such as building information modelling (BIM), the Internet of Things (IoT), artificial intelligence (AI) and big data analytics, propose new means of improving efficiency, collaboration and sustainability (Manderson *et al.*, 2015; Abu-Khader, 2023). Digital tools enable real-time communication, data-driven decision-making and enhanced integration across the project lifecycle (Teisserenc and Sepasgozar, 2021). For example, BIM supports coordinated design and information sharing, while IoT and AI enable predictive management of resources and project risks (Jemal *et al.*, 2023; Waqar *et al.*, 2023). Digital transformation, therefore, has the potential to reshape construction practices by promoting transparency, reducing waste and achieving sustainability objectives (Oke *et al.*, 2023).

In New Zealand, the construction industry is one of the nation's largest economic sectors, contributing approximately 6.7% to gross domestic product (GDP) and employing nearly 300,000 people (Business Council, 2019; Kirby *et al.*, 2025). Despite its size, the sector continues to face growing demand for housing and infrastructure alongside persistent productivity challenges (Chowdhury *et al.*, 2019; Kirby *et al.*, 2025). Efforts to enhance innovation and efficiency have encouraged the adoption of digital technologies; however, uptake remains uneven across firm sizes (Kirby *et al.*, 2022). Small and medium-sized enterprises (SMEs), particularly subcontractors that constitute the operational backbone of the industry and account for up to 70% of project value (Kirby *et al.*, 2025; Takim *et al.*, 2013), lag behind larger organisations due to limited financial resources, technical capacity and digital skills (Tezel *et al.*, 2020). Operating under resource constraints and project uncertainty often restricts their ability to invest in technological innovation (Adeitan *et al.*, 2019; Kamal and Flanagan, 2014; Musarat *et al.*, 2024), while the lack of integration of digital systems across subcontracting networks perpetuates inefficiencies and undermines competitiveness (Bingol and Polat, 2020). Residential construction is a particularly relevant context for examining these challenges, as it is highly subcontractor-dependent and characterised by fragmented delivery, tight margins and recurrent coordination demands (Kirby *et al.*, 2022; Lekan *et al.*, 2022).

While digital transformation has been widely discussed in relation to large firms, limited empirical research has focused on subcontracting organisations and the specific enablers that facilitate their effective adoption of digital technologies. Existing studies often isolate technological or managerial aspects without considering their combined impact on competitiveness (Brozovsky *et al.*, 2024; Trask and Linderoth, 2023). Given the dominance of SMEs in New Zealand's construction sector, understanding how these organisations could adopt and benefit from digital technologies is important. Therefore, this study aims to identify the key factors that enable the effective implementation of digital technologies to improve competitiveness among subcontracting organisations in New Zealand's residential construction industry. To address this aim, the research is guided by three questions:

RQ1. What relationships exist between the key indicators of organisational competitiveness among subcontracting organisations in the New Zealand construction industry?

RQ2. What underlying dimensions can summarise these competitiveness indicators through data reduction techniques?

RQ3. Which digital technology adoption factors significantly predict organisational competitiveness?

The remainder of this paper is structured as follows: Section 2 reviews the literature, Section 3 outlines the methodology, Section 4 presents the results, Section 5 discusses the findings and Section 6 concludes the study.

2. Literature review

This section examines existing scholarship on digital transformation and competitiveness within the construction industry, with particular attention to subcontracting SMEs in New Zealand. It explores how digital technologies influence organisational performance, identifies barriers and enablers of adoption and situates the present study within broader debates on innovation and capability development in construction.

2.1 Digital transformation and technological adoption in construction

Across economies, construction remains a major engine of growth and essential infrastructure delivery. However, it continues to operate with persistent inefficiencies and coordination problems that stem from project complexity, stakeholder fragmentation and labour-intensive methods (Abdul-Samad *et al.*, 2024; Al-kayed *et al.*, 2024; Ernstsen *et al.*, 2021; Long *et al.*, 2024; Musarat *et al.*, 2024; Zhang *et al.*, 2023). A large and growing literature has investigated how digitalisation can address these frictions by improving information flow, reducing errors and enabling predictive, data-driven decisions (Jemal *et al.*, 2023; Teisserenc and Sepasgozar, 2021). Much of this work converges on digital technologies, BIM, IoT, AI, big data analytics and cloud platforms, as levers for coordination, productivity and sustainability (Manderson *et al.*, 2015; Abu-Khader, 2023; Waqar *et al.*, 2023).

Studies consistently report that BIM enhances design coordination and stakeholder communication, while IoT and sensing provide real-time site visibility that supports safety, resource control and maintenance (Al-kayed *et al.*, 2024; Jemal *et al.*, 2023; Teisserenc and Sepasgozar, 2021). AI-enabled analytics and forecasting further support schedule and risk management, and when integrated with supply-chain data, can streamline procurement and logistics (Waqar *et al.*, 2023). Collectively, these findings suggest a pathway from fragmented, document-centric practice to integrated, model- and data-centric delivery with measurable gains in efficiency, quality and carbon performance (Abdul-Samad *et al.*, 2024;

Oke *et al.*, 2023). However, several authors caution that benefits are contingent on organisational readiness and cross-firm interoperability; without these, technology deployments reproduce existing silos in digital form (Ng *et al.*, 2023; Sigalov *et al.*, 2021).

At the same time, the literature highlights persistent barriers that help explain construction's relatively slow diffusion of innovation compared with other sectors (Li *et al.*, 2023; Oke *et al.*, 2023; Olanrewaju *et al.*, 2020). Common barriers include high upfront costs, uncertain return on investment, workflow disruption, limited digital skills and perceived job-security risks (Abdul-Samad *et al.*, 2024; Snyder, 2019). Methodologically, many studies prioritise technology capabilities and case exemplars; fewer evaluate longitudinal change across multiple projects or examine how contractual structures, procurement routes and risk allocation shape adoption incentives (Ng *et al.*, 2023; Sigalov *et al.*, 2021). As a result, generalisability remains problematic; reported gains are strong in digitally mature firms and integrated delivery models, but less consistent in fragmented supply chains where coordination costs and data reliability issues persist (Long *et al.*, 2024; Zhang *et al.*, 2023).

The sustainability literature adds a complementary rationale for digitalisation. By supporting lifecycle asset management, energy optimisation and material tracking, digital tools can reduce waste and improve whole-life performance, aligning project delivery with environmental and economic goals (Abdul-Samad *et al.*, 2024; Oke *et al.*, 2023). Despite robust theoretical pathways, adoption remains uneven across firms and regions, and empirical studies often under-specify the organisational mechanisms such as governance, incentives and training that translate technical functionality into consistent project-level outcomes (Jemal *et al.*, 2023; Teisserenc and Sepasgozar, 2021). Overall, the evidence indicates clear potential for digital transformation to mitigate lasting coordination problems in construction, but points to a need for research that focuses on implementation enablers, capability building and cross-firm alignment rather than technology features alone.

2.2 Subcontracting organisations and competitiveness in the New Zealand construction context

In New Zealand, construction is a significant contributor to GDP and employment, with recent growth driven by residential and infrastructure demand. However, productivity and cost pressures remain persistent (Business Council, 2019; Chowdhury *et al.*, 2019; Kirby *et al.*, 2025). The national conversation mirrors global debates on digitalisation and innovation, but adoption varies by firm size, larger enterprises tend to advance faster than SMEs, which comprise the majority of firms and a substantial share of site execution through subcontracting (Business Council, 2019; Tezel *et al.*, 2020). This structure matters, subcontractors specialise in trades (e.g. mechanical, electrical and finishing), account for up to 70% of project value on some schemes and operate under tight margins and time constraints with limited bargaining power (Akintan and Morledge, 2013; Takim *et al.*, 2013; Tezel *et al.*, 2020). Consequently, even modest coordination or information losses can spread into significant project-level inefficiencies.

International and NZ-focused studies suggest that digital tools offer subcontractors tangible benefits, clearer interfaces with main contractors, improved visibility of workflows, reduced rework and better schedule adherence (Craveiro *et al.*, 2019; Kim *et al.*, 2021; Zheng *et al.*, 2021). Nevertheless, the diffusion of these tools within subcontracting SMEs remains constrained by limited capital for systems investment, restricted digital literacy and the difficulty of justifying ongoing software and training costs against uncertain pipeline continuity (Adeitan *et al.*, 2019; Jemal *et al.*, 2023; Kamal and Flanagan, 2014; Sodangi, 2019). Moreover, multilayer subcontracting intensifies fragmentation, creating data-handover gaps and versioning risks that can offset the nominal gains of model-based coordination unless standards, responsibilities and incentives are clearly defined (Bingol and Polat, 2020).

The literature therefore points to a dual challenge for SMEs, acquiring and sustaining digital capabilities and embedding them within inter-firm processes that they do not fully control.

Competitiveness for construction SMEs is typically framed through resource-based and capability perspectives, emphasising innovation, skilled labour, process efficiency and strategic positioning as sources of advantage (Friesenbichler and Reinstaller, 2021; Prabhakar *et al.*, 2023; Yilmaz *et al.*, 2023). Within this frame, digital technologies act as enablers that can lift operational performance (through fewer errors, better sequencing and faster decisions) and strategic performance (through reputation gains, data-rich bids and value-adding services) (Chen and Chen, 2021; Latifah *et al.*, 2021; Tan *et al.*, 2017). However, several studies note that technology alone does not yield a robust advantage unless accompanied by complementary assets such as managerial commitment, workforce upskilling, interoperable workflows and governance practices that align subcontractor incentives with project-wide outcomes (McNamara and Sepasgozar, 2021; Tezel *et al.*, 2020).

Synthesising these strands for the New Zealand residential context suggests three conclusions and a gap. Firstly, subcontracting SMEs are vital to delivery and bear much of the coordination risk, making them prime beneficiaries of well-targeted digital adoption (Akintan and Morledge, 2013; Takim *et al.*, 2013; Tezel *et al.*, 2020). Secondly, barriers are more organisational and capability-driven than purely technical, capital constraints, skills deficits and weak standardisation hamper uptake despite clear potential benefits (Adeitan *et al.*, 2019; Bingol and Polat, 2020; Kamal and Flanagan, 2014; Sodangi, 2019). Thirdly, competitiveness improvements linked to digitalisation depend on integrating tools with processes and incentives across firm boundaries (Chen and Chen, 2021; Latifah *et al.*, 2021). The enduring gap is that, while individual technologies (e.g. BIM, AI and IoT) are well studied, there is limited empirical work that isolates and tests the enabling factors that allow subcontracting SMEs operating in resource-constrained, multilayered supply chains to implement digital technologies effectively and translate them into measurable competitiveness gains (Brozovsky *et al.*, 2024; Trask and Linderoth, 2023). Given the predominance of SMEs in New Zealand and their central role in residential delivery, this gap is significant. The present study addresses it by empirically identifying and assessing the key enablers of effective digital technology implementation for competitiveness among subcontracting organisations in New Zealand's residential construction industry, thereby linking adoption conditions to outcomes that matter for firms and projects.

2.3 Indicators of organisational competitiveness and digital technology adoption

The literature consistently recognises organisational competitiveness and digital technology adoption in the construction industry as multidimensional constructs that require clearly defined indicators for reliable empirical assessment. Given the diversity of organisational structures, project roles and operating conditions within construction, prior studies have relied on structured indicator sets to ensure conceptual clarity and comparability across firms and contexts (Orozco *et al.*, 2013; Oyewobi *et al.*, 2016; Tan *et al.*, 2012).

Organisational competitiveness and digital technology adoption in the construction industry are complex concepts that cannot be captured using a single measure. For this reason, clearly defined indicators are required to support reliable empirical analysis. In this study, the indicators used to measure organisational competitiveness were drawn from a recent systematic review by Al-kayed *et al.* (2024), which provides a comprehensive overview of factors affecting competitiveness in the construction sector. The review examined 27 studies, of which 11 explicitly assessed competitiveness at the organisational level. The competitiveness indicators adopted in this research were therefore based on the measurement approaches used in these studies and are presented in Table 1.

Table 1. Indicators of organisational competitiveness in the construction organisations

Indicator	Authors
Project delivery	Dilkhaz Salahaddin (2016), Giménez *et al.* (2019), Khoa and Chinda (2023), Orozco *et al.* (2013) and Oyewobi *et al.* (2019)
Financial performance	Dilkhaz Salahaddin (2016), Oyewobi *et al.* (2016, 2019) and Tan *et al.* (2012)
Client satisfaction	Khoa and Chinda (2023), Mohamad and Mat Zin (2019), Oyewobi *et al.* (2019) and Zhang *et al.* (2019)
Competitive strategy	Deng *et al.* (2013), Dilkhaz Salahaddin (2016), Oyewobi *et al.* (2019) and Tan *et al.* (2012)
Operational efficiency and risk management	Orozco *et al.* (2013), Oyewobi *et al.* (2016) and Tan *et al.* (2012)
Health and safety standards	Giménez *et al.* (2019), Khoa and Chinda (2023) and Orozco *et al.* (2013)
Employee development and culture	Giménez *et al.* (2019), Khoa and Chinda (2023), Mohamad and Mat Zin (2019) and Zhang *et al.* (2019)
Leadership and management	Dilkhaz Salahaddin (2016), Lee and Park (2022), Mohamad and Mat Zin (2019), Oyewobi *et al.* (2016) and Zhang *et al.* (2019)
Adoption of digital technologies and innovation	Dilkhaz Salahaddin (2016), Giménez *et al.* (2019), Lee and Park (2022) and Oyewobi *et al.* (2016, 2019)
Market adaptability	Tan *et al.* (2012) and Zhang *et al.* (2019)
Regulatory compliance	Giménez *et al.* (2019) and Tan *et al.* (2012)
Reputation and stakeholder relationships	Orozco *et al.* (2013) and Oyewobi *et al.* (2019)
Sustainability and CSR	Giménez *et al.* (2019), Orozco *et al.* (2013) and Oyewobi *et al.* (2019)

Similarly, the indicators used to measure the level of digital technology adoption were identified through a focused review of recent empirical studies that examined digital transformation within construction organisations. These studies were selected because they assessed digital technology adoption at the organisational level and applied structured indicators to evaluate adoption levels and implementation practices. In total, nine relevant studies were identified, and the digital technology adoption indicators drawn from these studies were adopted for the present research. The selected indicators and their corresponding sources are summarised in Table 2.

3. Methodology

This study was conducted in New Zealand, where the construction industry is a key contributor to the national economy and is characterised by a strong reliance on small and medium-sized subcontracting organisations, particularly in residential construction (Chowdhury *et al.*, 2019a; Kirby *et al.*, 2022). Construction activity is geographically dispersed across urban and regional areas and operates within a nationally regulated building and safety framework. These characteristics make New Zealand an appropriate context for examining digital technology adoption and organisational competitiveness among subcontracting firms (Kirby *et al.*, 2022).

3.1 Research design and data collection

A quantitative research design was adopted to address the study's research questions, which focus on measuring relationships, identifying underlying dimensions and testing predictive effects between digital technology adoption and organisational competitiveness among subcontracting organisations in New Zealand's residential construction industry. A quantitative approach is appropriate in this context because the study seeks to examine patterns and

Table 2. Indicators of digital technology adoption in construction organisations

Indicator	Authors
Clear, organized strategy and long-term plan for digital technologies	Chathuranga *et al.* (2024), Chen *et al.* (2023), Chomistriana *et al.* (2024), Foroozanfar *et al.* (2017) and Lou and Lee (2018)
Active involvement and support from top management	Lou and Lee (2018) and Zhang *et al.* (2023)
Investment or plans to invest in digital technologies following trends	Foroozanfar *et al.* (2017), Lou and Lee (2018) and Zhang *et al.* (2023)
Budget dedicated to digital technology implementation and R&D	Foroozanfar *et al.* (2017), Lou and Lee (2018), Sajjad *et al.* (2023) and Schnell *et al.* (2022)
Employees are well-trained and equipped with necessary digital skills	Chomistriana *et al.* (2024), Jahanger *et al.* (2022), Schnell *et al.* (2022) and Zhang *et al.* (2023)
Comprehensive training programs for digital technologies	Chomistriana *et al.* (2024), Lou and Lee (2018) and Zhang *et al.* (2023)
Culture of innovation and digital skills development	Lou and Lee (2018), Schnell *et al.* (2022) and Zhang *et al.* (2023)
Mindsets of employees towards digital technology adoption	Jahanger *et al.* (2022), Lou and Lee (2018) and Schnell *et al.* (2022)
Infrastructure including hardware, software and tools	Chomistriana *et al.* (2024), Foroozanfar *et al.* (2017), Lou and Lee (2018) and Zhang *et al.* (2023)
Culture that values and embraces digital transformation	Chomistriana *et al.* (2024) and Lou and Lee (2018)
Effective change management processes	Chomistriana *et al.* (2024), Jahanger *et al.* (2022) and Lou and Lee (2018)
Knowledge sharing across departments	Chomistriana *et al.* (2024), Lou and Lee (2018) and Zhang *et al.* (2023)
Compliance with legal and ethical regulations	Chomistriana *et al.* (2024), Lou and Lee (2018) and Schnell *et al.* (2022)

associations across a large population of subcontracting organisations, rather than explore individual experiences or meanings in depth (Garbarino and Holland, 2009; McNabb, 2015). Quantitative methods are also widely applied in construction research because they enable objective measurement and statistical analysis of organisational performance and technology adoption across complex construction systems. Prior studies show that quantitative approaches support rigorous evaluation of construction practices and allow relationships between variables to be tested and generalised across organisations (Briskorn and Dienstknecht, 2018; Waqar *et al.*, 2025).

Data were collected using a structured online questionnaire administered through Qualtrics, chosen for its secure management, usability and ability to reach geographically dispersed respondents (Grassini and Laumann, 2020; Hamed Taherdoost and Lumpur, 2016). Online surveys are efficient for obtaining objective data from professionals while maintaining anonymity and ethical standards. The approach was therefore appropriate for capturing cross-sectional evidence from subcontracting organisations operating under time and location constraints. An ethics application was submitted and received approval from the AUT ethics committee under reference number Autec 24/188 for this study.

The target population for this study comprised subcontracting organisations operating within the New Zealand construction industry. As official statistics do not distinguish subcontractors by project type or contractual role, an industry-based definition was adopted. Business demography data published through Figure.NZ indicate that 26,478 construction-industry businesses with employees less than 100 were active in New Zealand (Figure.NZ, 2025), and this group was therefore considered the population relevant to this study. Due to reliance on publicly available professional listings and industry directories, valid contact information was identified for 1,020 organisations, which formed the effective sampling frame. A random sampling approach was applied at the organisational level, with one survey invitation issued per organisation to ensure equal opportunity for participation and to capture organisational rather than individual views (Rahman, 2013; Greening, 2019). Based on standard sample size determination procedures for finite populations, assuming a 95% confidence level, a strict 7.5% margin of error and a population of 26,478 organisations, the minimum required sample size was calculated as 170 responses (Roopa and Rani, 2012). In total, 172 responses were received, of which 142 valid responses were retained for analysis after excluding incomplete submissions. The achieved sample size was sufficient to support the quantitative analyses conducted, with limitations related to coverage and generalisability acknowledged:

$$n_0 = \frac{Z^2 p(1-p)}{e^2} = \frac{1.96^2 \times 0.5 \times 0.5}{0.075^2} = 170.74$$

To account for the finite population size, the finite population correction was applied:

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}} = \frac{96.04}{1 + \frac{95.04}{26478}} \approx 170$$

Although the study focuses on subcontracting organisations involved in residential construction, firms were included if they had direct experience delivering residential projects, regardless of whether they also operated in commercial or other construction sectors. This approach was adopted because it is difficult to identify organisations operating exclusively within the residential sector while maintaining an adequate organisational-level sample. It also reflects the structure of the New Zealand construction industry, where subcontracting organisations commonly operate across multiple project types.

The survey instrument consisted of three structured sections. Section A gathered demographic information including job role, years of experience and educational background. Section B measured organisational competitiveness using 13 indicators derived from the competitive dimensions synthesised in the systematic literature review. Section C assessed digital technology adoption through 13 indicators reflecting investment patterns, legal and ethical compliance, knowledge sharing, skills development, readiness for change, innovation orientation, technological capability and leadership involvement. All items in Sections B and C were rated on a seven-point Likert scale, where 1 = strongly disagree and 7 = strongly agree, with higher values indicating stronger agreement with the statement, ensuring comparability and supporting subsequent multivariate analysis.

3.2 Measures and variables

Organisational competitiveness served as the dependent construct and was assessed using 13 indicators derived from the competitive dimensions previously synthesised in the systematic literature review (Al-kayed *et al.*, 2024). These indicators captured operational effectiveness, financial performance, strategic positioning, risk management capability, innovation capacity, client satisfaction and sustainability orientation. Respondents rated their organisation's performance over the previous three years, generating a multidimensional data set suitable for evaluating competitiveness. These items were subsequently subjected to correlation analysis and principal component analysis (PCA) to validate dimensionality and to create a statistically robust representation of competitiveness for modelling.

Digital technology adoption was the independent construct and consisted of 13 indicators developed from established literature on digital transformation and technology adoption in construction and related sectors. These indicators reflected investment patterns, compliance with legal and ethical standards, knowledge-sharing processes, digital skills development, readiness for organisational change, innovation culture, technological infrastructure and leadership involvement in digital initiatives. Together, these indicators captured the breadth of digital adoption within subcontracting organisations and served as predictor variables in the modelling undertaken through automatic linear modelling (ALM).

3.3 Analytical procedures

To identify the predictors of organisational competitiveness, three analytical stages were implemented. Firstly, a correlation matrix assessed the strength and direction of relationships among competitiveness indicators, ensuring suitability for multivariate analysis. Secondly, PCA was applied to reduce the 13 competitiveness indicators into uncorrelated components, improving model clarity and avoiding multicollinearity. Thirdly, ALM was used to determine which digital adoption factors best predict competitiveness.

3.3.1 Correlation analysis of competitiveness indicators. Correlation analysis was conducted to evaluate the strength and direction of relationships among the competitiveness indicators prior to applying factor analysis. Pearson's product–moment correlation technique was used, as it is widely recognised for identifying linear associations between continuous variables and assessing the suitability of data sets for multivariate procedures (Franzese and Iuliano, 2018; Gogtay and Thatte, 2017). Establishing sufficient interrelationships among variables is a critical prerequisite for applying PCA, which assumes that the measured indicators share common variance (Luo *et al.*, 2021).

This analysis served as a diagnostic step to confirm the absence of multicollinearity and to ensure that each indicator contributed distinct information to the data set. By validating the presence of meaningful correlations, the procedure provided empirical justification for proceeding with PCA to extract latent dimensions of organisational competitiveness.

3.3.2 Principal component analysis for competitiveness dimensions. PCA was used to identify latent constructs underlying the competitiveness indicators and to reduce the data set into a smaller, interpretable structure while retaining most of the variance. PCA is widely recognised as an effective multivariate statistical technique for revealing clusters of interrelated variables and simplifying complex data structures (Odediran and Babalola, 2014; Wyke *et al.*, 2024). This method is particularly suitable for identifying the core dimensions of organisational competitiveness, which encompass multiple, interdependent operational and strategic factors.

Before conducting PCA, the suitability of the data was assessed using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. The KMO index evaluates whether the correlations among variables are sufficient for reliable factor extraction, with values above 0.5 considered acceptable for proceeding with PCA (Wyke *et al.*, 2024). Bartlett's test of sphericity tests the null hypothesis that the correlation matrix is an identity matrix, indicating no relationships among variables; a significant result demonstrates that the data set is appropriate for factor analysis (Akinradewo *et al.*, 2022).

PCA was then applied to extract the principal components based on eigenvalues greater than one, in accordance with the Kaiser criterion. This approach allows the identification of key underlying dimensions that explain the majority of variance among the competitiveness indicators (Guo and Lu, 2023; Pham *et al.*, 2020).

In this study, PCA served as a data reduction tool to generate a composite representation of competitiveness dimensions that would be subsequently used as dependent variables in predictive modelling through ALM.

3.3.3 Automatic linear modelling for predicting competitiveness. ALM was used to statistically identify which digital technology adoption indicators best predict organisational competitiveness. ALM, implemented in IBM SPSS Statistics, is a robust predictive procedure that automates regression model building through advanced variable selection and data transformation processes (Yang, 2013). It extends conventional multiple regression by systematically testing all feasible combinations of predictors, applying information-theoretic criteria such as the corrected Akaike Information Criterion (AIC) and Bayesian information criterion (BIC) to identify the most parsimonious model while avoiding overfitting by retaining only predictors that contributed meaningfully to model fit (Dziak *et al.*, 2020; Isaac, U.C. and Ernest, 2025).

The procedure was applied to model the first principal component of competitiveness as the dependent variable, with all 13 digital technology adoption indicators entered simultaneously as candidate predictors. ALM automatically prepared and screened the data set by addressing outliers and multicollinearity, using built-in diagnostics such as Cook's distance and variance inflation factors to ensure data integrity (Dziak *et al.*, 2020). This approach is especially suited for organisational and behavioural research, where predictor intercorrelations are common, and human judgement in model selection may introduce bias.

Model selection within ALM relies on penalised likelihood estimation, in which smaller AIC and BIC values indicate better balance between model simplicity and explanatory power. By combining automation, information-criterion optimisation and diagnostic checks, ALM ensures transparency and reproducibility in identifying the digital adoption factors most associated with competitiveness (Yang, 2013).

In addition, the use of penalised information criteria and automated variable exclusion serves as an internal validation mechanism that reduces the risk of overfitting in exploratory modelling.

4. Results

4.1 Sample characteristics

A total of 142 valid responses were included in the final analysis, representing subcontracting organisations operating within New Zealand's residential construction sector. Among these, 115 participants were from organisations engaged in both residential and commercial projects, while 27 represented firms operating exclusively in the residential sector.

As shown in Table 3, most participants had substantial professional experience: 47.8% of those from mixed-sector organisations and 66.7% of those from residential-only organisations had more than 10 years of experience in the construction industry. This confirms that the responses reflect the views of knowledgeable and experienced professionals.

In terms of educational background, 61.7% of participants from mixed-sector organisations held higher education qualifications (university degree or postgraduate), compared with 37% among residential-only participants. The majority of respondents occupied senior management or technical roles, including general managers, directors, engineers and estimators, accounting for 72.2% of the total sample. This professional composition indicates that the data were obtained from individuals with sufficient strategic and operational insight into their organisations' digital adoption and competitiveness practices.

4.2 Correlation analysis

This section addresses Research Question 1 by examining the relationships between key organisational competitiveness indicators. Prior to conducting factor analysis, the interrelationships

Table 3. Profile of survey participants

Participant characteristics	Organisation type Profile of participants	Both residential and commercial ($n = 115$) Frequency	%	Residential ($n = 27$) Frequency	%
Years of experience	2–5 years	34	29.60	5	18.50
	6–9 years	26	22.60	4	14.80
	10+ years	55	47.80	18	66.70
Level of education	Low education (senior school and none)	16	13.90	9	33.30
	Intermediate education (trade certificate and diploma)	28	24.30	8	29.60
	Higher education (degree and postgraduate)	71	61.70	10	37
Role	Senior management (general manager, director, business owner)	37	32.20	18	66.70
	Middle management (construction manager, project manager, site manager, manager)	32	27.80	4	14.80
	Technical/engineering (engineer, QS/estimator, technician)	46	40	5	18.50

among the 13 competitiveness indicators were examined using a correlation matrix to confirm their suitability for multivariate analysis. As shown in Table 4, most indicators exhibited moderate to strong positive correlations, with coefficients ranging from 0.16 to 0.69. These results indicate that the variables are sufficiently interrelated to justify the application of PCA, which relies on meaningful associations among variables to identify latent constructs (Gogtay and Thatte, 2017).

No extreme correlations (above 0.80) were detected, confirming the absence of multicollinearity and ensuring that each variable contributed unique information to the data set. The correlation pattern also suggests that the competitiveness indicators share common underlying dimensions, such as operational efficiency, innovation and strategic adaptability, thereby supporting their dimensional reduction in the subsequent PCA procedure.

4.3 PCA results

This section addresses Research Question 2 by identifying underlying dimensions of organisational competitiveness using PCA. PCA was applied to reduce the 13 competitiveness indicators into a smaller set of uncorrelated components while retaining most of the variance in the data set. PCA is an objective multivariate technique that identifies latent constructs by extracting components based on eigenvalues and variable loadings (Gogtay and Thatte, 2017; Odediran and Babalola, 2014). This method is suitable for analysing complex constructs such as competitiveness, which are influenced by multiple, interrelated operational and strategic factors.

The suitability of the data for PCA was first examined. The KMO measure of sampling adequacy was 0.889, confirming excellent sample adequacy and Bartlett's test of sphericity was significant, verifying that the correlation matrix was not an identity matrix and that sufficient interrelationships existed among variables to justify PCA, as shown in Table 5.

Two components with eigenvalues greater than one were extracted, jointly explaining 56.64% of the total variance, as presented in Table 6. The scree plot, as shown in Figure 1, displayed a clear break after the second component, confirming that a two-factor solution

Table 4. Correlation matrix for competitiveness indicators

Correlation matrix	COMP1	COMP2	COMP3	COMP4	COMP5	COMP6	COMP7	COMP8	COMP9	COMP10	COMP11	COMP12	COMP13
COMP1	1												
COMP2	0.47	1	0.23										
COMP3	0.509	0.23	1										
COMP4	0.507	0.55	0.275	1									
COMP5	0.561	0.423	0.323	0.618	1								
COMP6	0.426	0.188	0.356	0.329	0.539	1							
COMP7	0.357	0.197	0.36	0.352	0.461	0.472	1						
COMP8	0.387	0.246	0.404	0.478	0.574	0.438	0.688	1					
COMP9	0.437	0.443	0.328	0.615	0.586	0.394	0.405	0.47	1				
COMP10	0.499	0.159	0.404	0.296	0.424	0.456	0.562	0.531	0.373	1			
COMP11	0.4	0.278	0.379	0.336	0.364	0.365	0.452	0.436	0.236	0.506	1		
COMP12	0.532	0.315	0.329	0.476	0.46	0.434	0.433	0.498	0.424	0.542	0.485	1	
COMP13	0.337	0.323	0.16	0.449	0.378	0.451	0.429	0.373	0.304	0.361	0.45	0.539	1

Table 5. Kaiser–Meyer–Olkin (KMO) and Bartlett's test of sphericity for competitiveness indicators

KMO and Bartlett's test	
Kaiser–Meyer–Olkin measure of sampling adequacy	0.889
Bartlett's test of sphericity	
Approx. chi-square	774.009
Df	78
Sig.	<0.001

Table 6. Total variance explained by principal component analysis

Total variance explained						
	Initial eigenvalues			Extraction sums of squared loadings		
Component	Total	% of variance	Cumulative (%)	Total	% of variance	Cumulative (%)
1	6.031	46.391	46.391	6.031	46.391	46.391
2	1.333	10.25	56.642	1.333	10.25	56.642
3	0.952	7.32	63.962			
4	0.884	6.797	70.758			
5	0.685	5.271	76.03			
6	0.577	4.436	80.466			
7	0.494	3.799	84.264			
8	0.452	3.477	87.741			
9	0.435	3.346	91.087			
10	0.355	2.733	93.82			
11	0.296	2.274	96.094			
12	0.276	2.126	98.22			
13	0.231	1.78	100			

was appropriate. As the purpose of this analysis was dimensional reduction rather than rotated interpretation, no rotation was applied.

The first component represented operational and performance-based competitiveness, encompassing project delivery, cost and risk management, client satisfaction and leadership effectiveness. The second component captured strategic and innovation-oriented competitiveness, including adaptability, technological innovation and sustainability performance.

Given that the first component accounted for the most significant proportion of variance and represented the dominant dimension of competitiveness, it was retained as the dependent variable in the subsequent ALM analysis to identify the digital adoption factors that best predict competitiveness.

4.4 ALM results

This section addresses Research Question 3 by identifying which digital technology adoption factors significantly predict organisational competitiveness using ALM. While the previous PCA isolated competitiveness as a measurable construct, the current stage examined how variations in this construct could be explained by digital technology adoption factors. To achieve this, the study used ALM in IBM SPSS Statistics, a predictive technique that automates regression analysis through variable selection, transformation and optimisation. ALM enhances traditional regression by systematically testing all possible predictor combinations and applying information criteria such as the AIC and BIC to achieve the best balance between model fit and simplicity (Oshima, 2016; Harris *et al.*, 2011; Dziak *et al.*, 2020; Isaac, U.C. and Ernest, 2025). In this study, the PCA-

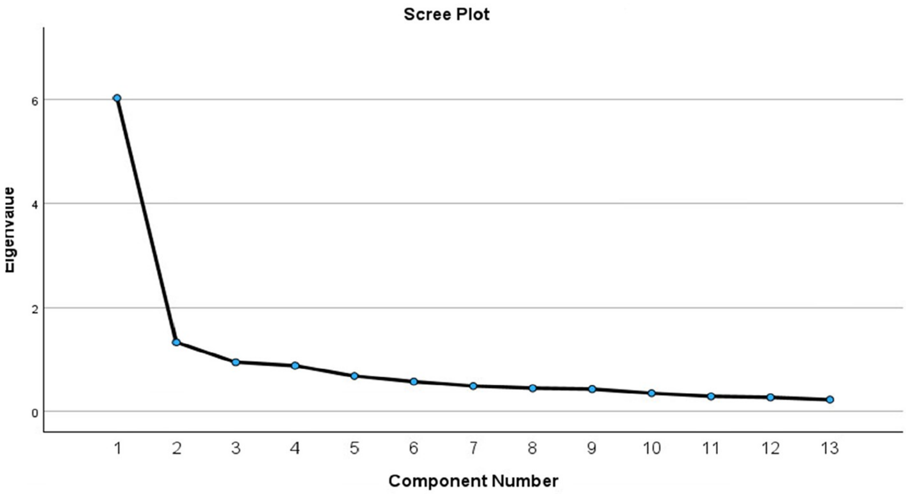

Figure 1. Scree plot for principal component analysis
Source(s): Authors' own work

derived competitiveness factor served as the dependent variable, while 13 digital adoption indicators were used as predictors, allowing the algorithm to objectively identify the most influential factors that explain competitiveness.

4.5 Model selection

Figure 2 summarises the model-building process. Ten competing models were automatically generated, with the information criterion progressively decreasing from −122.692 to −119.684, confirming incremental improvements in explanatory power and parsimony. The optimal model included five key predictors:

(1) Investment in digital technologies following trends.

(2) Compliance with legal and ethical technology use.

(3) Sharing digital knowledge across departments.

(4) Well-trained employees for digital adoption.

(5) Encouraging employee mindsets for digital adoption.

These variables collectively produced the lowest AIC/BIC values, indicating the best trade-off between model accuracy and simplicity. The remaining eight digital technology factors – such as top management support, clear strategy and effective change management – were excluded from the optimal model because they yielded no incremental explanatory contribution once the aforementioned predictors were included.

4.5.1 Model diagnostics. The ALM algorithm automatically evaluated regression assumptions. Multicollinearity diagnostics indicated acceptable independence among predictors (variance inflation factors < 5). Residual analysis confirmed approximate normality and homoscedasticity, demonstrating that the model assumptions were satisfied.

The ALM model's overall accuracy (65.3%), as shown in Figure 3, indicates that the retained predictors collectively explain two-thirds of the variation in competitiveness scores

Model Building Summary

Target: REGR factor score 1 for analysis 1

		Model									
		1	2	3	4	5	6	7	8	9	10
Information Criterion		-122.692	-122.568	-121.146	-120.889	-120.685	-120.471	-120.318	-120.017	-119.766	-119.684
Effect	investment_in_digital_technologies_following_trends_transformed	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	well_trained_employees_for_digital_adoption_transformed	✓	✓	✓	✓	✓	✓	✓	✓	✓	
	encouraging_employee_mindsets_for_digital_adoption_transformed	✓				✓		✓	✓		
	sharing_digital_knowledge_across_departments_transformed	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	compliance_with_legal_and_ethical_technology_use_transformed	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	clear_strategy_for_digital_technology_adoption_transformed			✓		✓				✓	
	top_management_support_for_digital_adoption_transformed			✓		✓	✓	✓			
	effective_change_management_for_digital_adoption_transformed				✓				✓		

The model building method is Best Subsets using the Information Criterion.
A checkmark means the effect is in the model.

Figure 2. Automatic linear modelling (ALM) – model-building summary
Source(s): Authors' own work

Model Summary

Target	REGR factor score 1 for analysis 1
Automatic Data Preparation	On
Model Selection Method	Best Subsets
Information Criterion	-122.692

The information criterion is used to compare to models. Models with smaller information criterion values fit better.

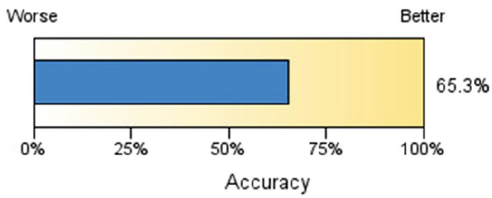

Figure 3. Model summary and accuracy of the ALM model
Source(s): Authors' own work

across subcontracting organisations. This level of predictive performance is consistent with comparable studies applying linear models to behavioural and organisational constructs within construction management (Hair *et al.*, 2019; Kissi *et al.*, 2016).

4.5.2 Predictor importance and coefficient effects. Figure 4 illustrates the predictor importance ranking of the five retained variables. Investment in digital technologies following trends was identified as the most influential factor, contributing approximately 38% of total model importance. Compliance with legal and ethical technology use ranked second (≈30%), followed by sharing digital knowledge across departments (≈22%). Well-trained employees and encouraging employee mindsets contributed modestly but positively (≈7% and 3%, respectively).

Figure 5 illustrates the coefficient estimates of each predictor in the final ALM model. The diagram visualises the direction and magnitude of the predictors' influence on competitiveness, with blue lines indicating positive coefficients and orange lines indicating negative coefficients. The relative length of each line corresponds to the magnitude of effect, showing how strongly each variable contributes to the PCA-derived competitiveness factor (FAC1_1). The plot reveals that all five retained predictors exhibit positive coefficients (blue lines), confirming that increases in these digital adoption practices correspond to higher competitiveness scores. Among them, investment in digital technologies following trends shows the longest blue path, indicating the most substantial positive effect. Similarly, compliance with legal and ethical technology use and sharing digital knowledge across departments display strong positive coefficients, implying that ethical governance and collaborative knowledge flow significantly reinforce competitive advantage. Well-trained employees for digital adoption and encouraging employee mindsets for digital adoption show shorter yet positive blue lines, reflecting moderate but consistent effects. Collectively, the positive directionality across all predictors supports the conclusion that strategic, compliant and people-centred digital adoption practices act synergistically to strengthen organisational competitiveness in subcontracting firms.

In summary, the ALM analysis identified five statistically significant predictors that collectively explain approximately 65% of the variance in competitiveness among subcontracting organisations. The strongest determinants were investment in digital technologies, ethical

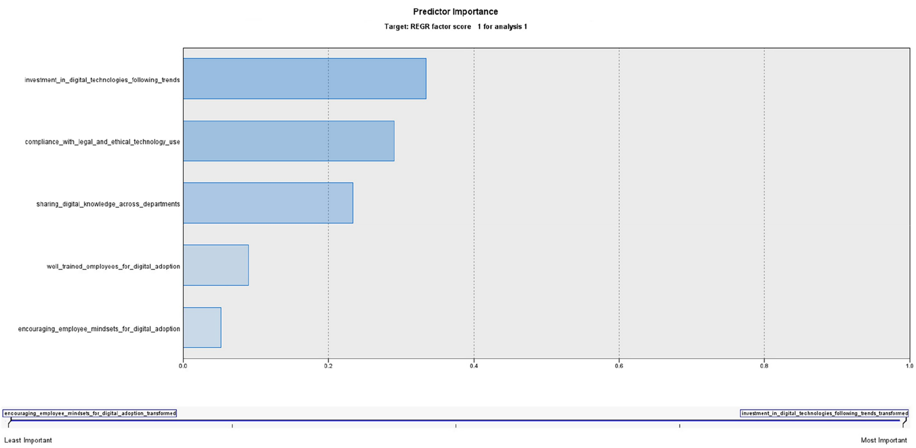

Figure 4. Predictor importance ranking
Source(s): Authors' own work

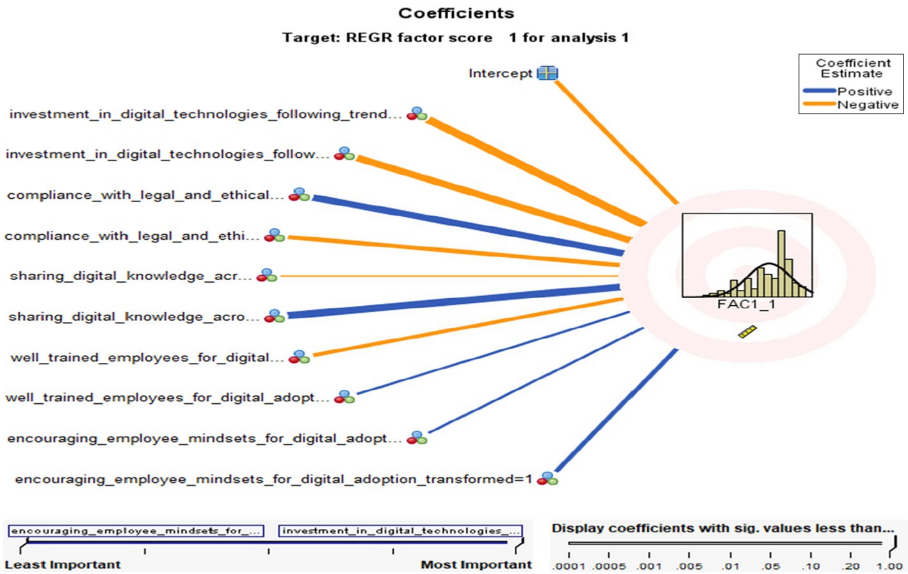

Figure 5. Coefficient estimates of the ALM predictors
Source(s): Authors' own work

compliance and knowledge sharing, with support from employee training and mindset development. The integration of ALM allowed the study to manage interrelated variables objectively and select the most parsimonious predictive model using data-driven criteria.

5. Discussion

5.1 Relationships and dimensions of competitiveness indicators

The interrelationships among the competitiveness indicators reveal that subcontracting organisations operate within an interconnected system of technological, organisational and human factors. The moderate yet consistent correlations among variables suggest that improvements in one area, such as leadership or client satisfaction, tend to reinforce performance in others. This finding is consistent with previous research showing that competitiveness in construction is cumulative and relational rather than additive (Chen and Chen, 2021; Tezel *et al.*, 2020). In fragmented subcontracting environments, these relationships highlight the need for alignment between operational processes and strategic learning to sustain performance improvements.

The PCA results indicate that competitiveness among subcontracting organisations is dominated by a single, integrated dimension, operational-performance competitiveness, which captures delivery efficiency, cost management, leadership and client satisfaction. This finding suggests that subcontractors' competitive strength continues to rest primarily on project execution and immediate performance rather than strategic innovation. This outcome supports earlier arguments that resource constraints, short project cycles and dependency on the main contractor limit subcontractors' ability to invest in long-term innovation (Adeitan *et al.*, 2019; Kamal and Flanagan, 2014). Unlike studies of larger contractors, where innovation capability often emerges as a separate strategic dimension (Tan *et al.*, 2017; Zhang *et al.*, 2019), the present findings suggest that resource constraints and project-based contracting structures limit the ability of subcontracting SMEs to decouple innovation from operational performance.

These findings extend existing theories by demonstrating that competitiveness among subcontracting SMEs evolves as a hierarchical process: operational stability enables the pursuit of innovation, and innovation, in turn, reinforces operational gains through improved coordination and adaptability. This interpretation aligns with Wuni *et al.* (2024), who argue that digital transformation in construction is effective only when operational readiness and strategic vision progress together. As such, the identified competitiveness dimension may not fully translate to subcontractors operating in infrastructure or commercial construction contexts.

5.2 Predictors of competitiveness through digital adoption

The results identified five significant predictors of competitiveness: investment in digital technologies, compliance with ethical and legal standards, digital knowledge sharing, employee training and employee digital mindsets. These predictors collectively demonstrate that competitiveness arises from both technological capability and organisational readiness, a pattern widely reported in construction digitalisation studies (Chowdhury *et al.*, 2019a, 2019b; Faiz *et al.*, 2024; Kirby *et al.*, 2025; Sinenko *et al.*, 2021).

Investment in digital technologies following trends was the strongest predictor, reaffirming evidence from Rinchen *et al.* (2024) and Skibniewski (2025) that firms aligning their investments with industry trends enhance efficiency, data integration and innovation. This suggests that timely and trend-aligned investment enables subcontractors to respond effectively to evolving client and regulatory expectations.

Compliance with legal and ethical technology use also significantly predicted competitiveness, supporting studies by Firoozi and Firoozi (2025) and Shirwa *et al.* (2025), who found that transparent digital governance builds client trust and mitigates risks of data misuse. The result underscores that ethical and regulatory alignment is not merely procedural but a strategic enabler of competitiveness in digitalised construction environments.

Sharing digital knowledge across departments emerged as another strong predictor, in line with Leal *et al.* (2017) and Zhou *et al.* (2023), who observed that structured communication and leadership support improve coordination. This finding implies that subcontracting organisations benefit when internal knowledge flows translate digital capability into consistent project-level outcomes.

Well-trained employees for digital adoption significantly contributed to competitiveness, corroborating research by Gao *et al.* (2025), Mojtahed *et al.* (2014) and Rinchen *et al.* (2024), which linked workforce development to improved digital readiness. Training helps subcontractors meet technical and regulatory standards, reduces resistance to change and enhances confidence in using advanced tools.

Finally, encouraging positive employee mindsets towards digitalisation also influenced competitiveness. This aligns with Kratochvil (2025), who found that supportive attitudes enhance engagement and digital performance. Subcontracting organisations operate in demanding environments; therefore, fostering adaptive mindsets helps employees embrace innovation rather than resist it. Collectively, these findings affirm that digital competitiveness is a product of technological, behavioural and cultural alignment within firms.

While these predictors provide robust insights, the findings should be interpreted with careful attention to context and participation effects. The results reflect the perspectives of subcontracting SMEs operating within New Zealand's residential construction sector, and organisations with stronger digital engagement may have been more inclined to respond, introducing potential non-response bias. Consequently, the predictors identified here may not generalise directly to larger firms, other construction sectors or jurisdictions with different regulatory and market conditions.

5.3 Theoretical and practical implications

These findings suggest that a combination of technological investment, ethical governance, organisational learning and workforce capability shapes competitiveness in subcontracting organisations. The results may be taken to indicate that digital transformation operates as a socio-technical process in which technology, structure and human behaviour interact to produce competitive outcomes. An implication of this finding is the possibility that existing theoretical models of digital adoption may need to integrate compliance and mindset-related factors more explicitly, as these elements appear to play an important role in shaping performance. These results also provide support for the idea that knowledge flows within organisations may help us to understand how digital tools translate into operational gains in project-based environments. One of the issues that emerges from these findings is the extent to which subcontractors rely on incremental rather than systemic digital adoption, raising intriguing questions regarding the nature of digital maturity in small and medium-sized construction firms. The findings further suggest that digital capability building, ethical compliance and sustained investment may help organisations respond effectively to the increasing technological demands of the New Zealand construction industry.

6. Conclusion

This study set out to determine which digital technology adoption factors best predict organisational competitiveness among subcontracting organisations in New Zealand's residential construction industry. Five predictors were identified: investment in digital technologies, compliance with legal and ethical standards, cross-departmental digital knowledge sharing, well-trained employees and supportive employee mindsets, which together accounted for 65% of the variance in competitiveness. These findings suggest that digital transformation in subcontracting organisations is driven by more than technological acquisition; rather, it emerges from strategic governance, knowledge integration and workforce capability. The results advance current understanding by providing one of the first quantitative models that links digital adoption conditions to competitiveness outcomes in subcontracting SMEs, offering empirical clarity in an area where prior studies have been limited or mostly conceptual.

Taken together, the findings indicate that strengthening competitiveness requires a balanced approach that integrates technological, organisational and human elements. Digital investment aligned with industry trends appears particularly influential, while ethical compliance and effective knowledge-sharing systems play central roles in enabling productive digital practices. Workforce-related factors, skills development and employee openness to digital change, also contribute meaningfully, underscoring the multidimensional nature of digital readiness.

Despite these promising results, several questions remain. Further studies are needed to examine whether the same predictors hold across different construction sectors and organisational sizes, and to assess the longer-term impact of digital investment on competitiveness, particularly in environments where market conditions fluctuate rapidly. Additional research is also required to better understand how employee mindset influences digital uptake, including the mechanisms underpinning cultural readiness and the potential moderating role of leadership practices. Moreover, future investigations should explore how digital knowledge sharing operates within subcontracting networks characterised by temporary project teams, as well as how inter-organisational dynamics, supply-chain relationships and regulatory requirements shape compliance-driven digital strategies.

Longitudinal and cross-regional studies would help determine whether the predictors identified in this research exhibit similar effects in other contexts and over time. Together, these directions highlight the need for continued empirical research to validate the findings reported here and to further refine theoretical models of digital transformation in subcontracting organisations' construction.

7. Limitations

A limitation of this study is that only one participant was surveyed from each subcontracting organisation. Although this approach ensured that each response represented the organisation rather than an individual department, it may not fully reflect internal differences in digital adoption practices or competitiveness perceptions. The generalisability of these results is therefore subject to the possibility that organisational views are more heterogeneous than the single-respondent design could capture.

Although the sample size was acceptable for the exploratory analyses conducted, it may limit the stability and generalisability of the PCA solution, particularly for identifying weaker component structures. Replication of the analysis with a larger sample would strengthen confidence in the robustness and transferability of the identified components.

Although the achieved sample size was adequate for exploratory modelling, it may limit the ability to detect small effect sizes, particularly in multivariate analyses. As a result, relationships with weaker statistical influence may not have been identified and should be interpreted with caution. However, the rigour in statistical analysis offset these limitations.

The scope of this study was limited to subcontracting organisations operating in the residential construction sector. Being limited to this sector, the study lacks comparative evidence from commercial or infrastructure subcontractors, which may exhibit different digital-transformation behaviours. Nevertheless, this focus strengthens the internal relevance of the findings to residential construction.

Another issue that may affect the interpretation of the results is the uneven representation of subcontractor types within the sample. Some trades may be overrepresented while others appear less frequently, which makes these findings less generalisable to all subcontracting categories across the sector.

A further limitation relates to the quantitative phase of this study, which may not fully capture the nuanced perspectives, contextual influences and subjective experiences of participants.

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Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to ethical approval conditions.

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