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Structural equation modelling of building information modelling (BIM) adoption framework in New Zealand

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Abstract

Purpose – Building information modelling (BIM) adoption in the construction industry has increased, driven by its potential to revolutionise project outcomes through improved efficiency and collaboration. However, New Zealand's BIM adoption is still in its early stages, hindered by unique challenges such as a lack of comprehensive, tailored guidelines. While other countries have developed BIM frameworks to address their specific needs, a critical gap exists in New Zealand for a structured framework tailored to its context. This research aims to fill this gap by examining the key factors influencing BIM adoption in New Zealand, addressing the unique local challenges and opportunities.

Design/methodology/approach – This research employed a questionnaire to collect data from New Zealand construction professionals experienced in BIM. The data were analysed using partial least squares – structural equation modelling (PLS-SEM) to assess measurement and structural models.

Findings – The study identifies seven critical categories, encompassing 31 factors, that significantly impact BIM adoption in the region. Among these, leadership emerged as the most influential category, underscoring the importance of clear BIM leadership roles and regular reviews of strategic plans.

Originality/value – This research systematically integrates qualitative and quantitative insights to develop a comprehensive, empirically validated framework specifically for New Zealand. This study uniquely employs PLS-SEM to test interrelationships between 31 factors across seven categories, offering a structured decision-making model for policymakers and industry professionals. The framework not only addresses New Zealand's context-specific barriers but also provides a scalable model that can inform BIM adoption strategies in other countries facing similar challenges.

Keywords Building information modelling (BIM), Structural equation modelling (SEM), Partial least squares (PLS), SmartPLS, New Zealand

Paper type Research article

1. Introduction

Building Information Modelling (BIM) has a wide range of potential benefits that can transform the construction industry (Crotty, 2013). Its widespread adoption has gained the attention of both scholars and industry professionals, leading to increased global efforts to

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integrate BIM across construction sectors. Several countries, including Finland, Norway, Denmark, the Netherlands, and the United Kingdom, have mandated BIM for public sector projects, reinforcing its importance in modern construction practices (Smith, 2014).

Governments, being major beneficiaries of BIM implementation, play a pivotal role in promoting its adoption through various policies and initiatives. Marzouk *et al.* (2022) categorised these strategies into three main approaches: government-driven, industry-driven, and mixed approaches. The government-driven approach involves the issuance of policies or mandates that compel the construction industry to adopt BIM applications. This top-down strategy can significantly accelerate BIM adoption by creating a regulatory environment that supports and incentivises its use. Countries like Singapore, the UK, and the US have seen significant improvements in BIM implementation due to well-defined roadmaps supported by government initiatives (Jiang *et al.*, 2022).

Despite these strategic efforts, BIM implementation continues to face significant challenges worldwide. Oyewole and Dada (2019) stressed the critical need for training among Nigerian construction professionals to maximise the benefits of BIM technologies. Taib *et al.* (2023) presented a case study on BIM adoption in Southern China, emphasising stakeholder involvement in successful implementation. Casasayas *et al.* (2021) argued that integrating BIM into higher education curricula is essential to ensuring future professionals are equipped with necessary skills. Marzouk *et al.* (2022) revealed that in Egypt, despite efforts to provide finances and develop an agenda to respond to national demands, the lack of a construction sector mechanism for organised BIM implementation remains problematic. This underscores the need for a well-structured implementation strategy to ensure that the benefits of BIM are fully realised. In Iran, the AEC community faces specific barriers that require tailored strategies for effective BIM adoption (Hatami and Rashidi, 2023). These studies collectively highlight the need for tailored strategies, training, stakeholder collaboration, and legal considerations to promote effective BIM adoption worldwide.

The importance of region-specific BIM adoption frameworks has been further emphasised in recent studies. Ben Mahmoud *et al.* (2022) proposed a framework for BIM implementation in prefabrication SMEs in Quebec, highlighting critical barriers and strategies specific to this sector. Stride *et al.* (2020) focused on the role of BIM in facilities management (FM) and supporting quantity surveyors' roles in FM, suggesting the development of strategies to enhance BIM adoption in these specific areas. Hatami and Rashidi (2023) identified 26 BIM barriers in the Iranian AEC community and provided practical strategies for improving BIM adoption, highlighting the necessity of frameworks tailored to specific regulatory, economic, and industry conditions.

Following this global trend, New Zealand has begun to explore BIM adoption, motivated by the potential enhancements it offers to the local construction industry (EBOSS, 2017). Despite the enthusiasm surrounding BIM, its adoption in New Zealand is still in the early stages, faced with significant barriers and challenges. According to Kordestani Ghalenoei *et al.* (2024), these challenges include a lack of knowledge, insufficient training, financial constraints, and the absence of standardisation, which significantly hinder BIM adoption. Additionally, issues such as limited collaboration, immature industry capacity, and inadequate planning exacerbate these barriers in New Zealand's construction sector. Doan *et al.* (2021) highlighted that the lack of a comprehensive understanding and detailed guidelines for BIM implementation remains a critical obstacle.

In previous research specific to New Zealand, 39 critical factors influencing BIM adoption were identified using a qualitative approach (Doan *et al.*, 2024). This involved conducting 21 semi-structured interviews with industry experts and performing a comprehensive literature review focusing on the three most well-known global Building Excellence Models (BEMs). By combining insights from the literature review and interviews, seven main categories were identified: Leadership, Clients and Other Stakeholders, Strategic Planning, People, Resources, Process, and Results. Within these categories, 39 specific indicators were established, providing a comprehensive understanding of the factors influencing BIM adoption.

While other countries have developed context-specific BIM adoption guidelines, New Zealand still lacks a comprehensive, empirically validated framework that outlines essential success factors and their interdependencies. Therefore, it is crucial to develop a comprehensive, empirically validated framework specifically designed for the New Zealand construction industry. This study addresses this gap by building on the qualitative findings from Doan *et al*. (2024) and employing a robust quantitative approach using Partial Least Squares - Structural Equation Modelling (PLS-SEM) to validate and refine the BIM adoption framework. This method allows for the validation and refinement of the BIM adoption framework, providing empirical evidence and actionable insights tailored to New Zealand's unique context. To guide this research, the following questions were formulated:

(1) What are the critical categories and factors influencing BIM adoption in New Zealand?

(2) How does leadership influence the overall BIM adoption framework in New Zealand?

(3) How do the identified factors interrelate within the BIM adoption framework?

By identifying and analysing key factors and their interactions, this research is poised to significantly contribute to the discourse on BIM adoption. It intends to provide both theoretical insights and practical guidance to stakeholders within the construction industry, facilitating more effective and widespread adoption of BIM practices. Ultimately, this research aims to enhance the quality and efficiency of construction projects in New Zealand and potentially serve as a model for other countries facing similar adoption challenges.

2. Research methodology

To enable comprehensive analysis of factors influencing BIM adoption, surveys are an effective tool for gathering data from many participants. They facilitate the collection of quantitative data, which is essential for subsequent statistical analysis (Babatunde *et al*., 2021). In the context of BIM adoption, surveys have been recognised as efficient for quantitative research, allowing for a systematic examination of influencing factors (Babatunde *et al*., 2021). Additionally, surveys provide reliable insights from large groups, which are crucial for assessing BIM adoption success within organisations (Won *et al*., 2013).

SEM was adopted to confirm the developed BIM adoption framework. According to Lomax and Schumacker (2004), SEM is a popular technique for research using multiple observed variables allowing "complex phenomena to be statistically modelled and tested." Also, it can provide "the validity and reliability of observed scores from measurement instruments." SEM has been effectively used in various BIM adoption studies (Ahmed and Suliman, 2020; Olugboyega and Windapo, 2022). Therefore, SEM was deemed appropriate for this research to analyse the relationships between 39 factors and 7 categories.

Figure 1 shows the research stages. Firstly, the survey was distributed to construction professionals in New Zealand to collect data for SEM. The data was then screened to remove inappropriate cases and check the normal distribution of the collected data. Next, SEM was conducted with two rounds in which the measurement and structural models were assessed, respectively. Finally, the findings and discussion were drawn from SEM.

3. Data collection

Based on the categories and factors revealed in Doan *et al*. (2024), a questionnaire survey was developed. It comprises two parts, demographics and the BIM adoption framework. Thirty-

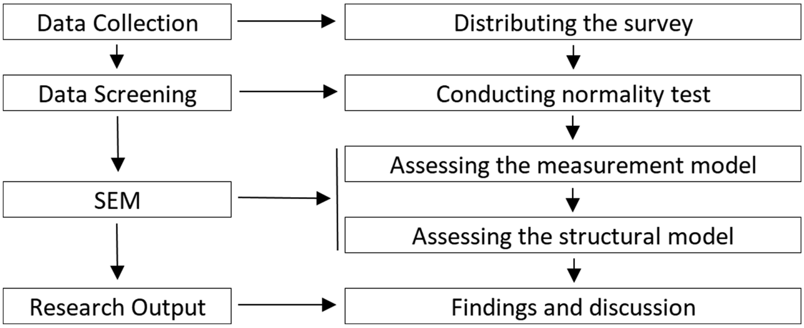

Figure 1. Research stages. Source: Authors' own work

nine statements, see Table 1, were prepared for the BIM adoption framework part using a 5-point Likert scale where 1 = Strongly Disagree; 2 = Slightly Disagree; 3 = Neutral; 4 = Slightly Agree; 5 = Strongly Agree.

This research adopted mixed-method sampling techniques, a common approach in quantitative research (Teddlie and Yu, 2007). The questionnaire was developed using Qualtrics and distributed on LinkedIn groups, a recognised platform for professional networking (Schneiderman, 2016). As stated by Doan *et al.* (2024) that BIM adoption in New Zealand is still in its early stages, a limited number of construction professionals might respond to the survey. To maximise participation, emails were sent simultaneously to potential respondents identified through LinkedIn and Architectural Designers New Zealand (ADNZ). The selection criteria for respondents were based on their professional experience. The respondents should have a minimum of three years' experience in the New Zealand construction industry. Additionally, it was essential for them to have been involved in at least one BIM project. The data collection process was approved by the Auckland University of Technology Ethics Committee, Reference number 17/309. Sixty-six responses were received after two months of distributing the survey.

4. Data screening

The demographics of the responses collected were reviewed to ensure all respondents met the selection criteria, and it was confirmed that every respondent satisfied the criteria. The normal distribution of data was then assessed, as suggested by Ali *et al.* (2018), to avoid reducing the statistical power. According to Griffin and Steinbrecher (2013) and Schneider and Wheeler-Kingshott (2014), data is normal distribution when skewness and kurtosis values are within the range ± 2 and $\pm$ 3, respectively. None of the collected data values is outside the mentioned range, proving that the data is appropriate for SEM.

5. SEM

Based on the characteristics of the 39 factors affecting BIM adoption and the number of responses received, partial least squares (PLS) SEM is considered the most appropriate technique. Firstly, the formative measurement model was developed from 39 factors of the BIM adoption framework rather than the reflective measurement model. If factors are not interchangeable and represent the causes of the categories, a formative measurement model is recommended (Hair *et al.*, 2016). PLS-SEM is the most appropriate technique for the formative measurement model (Alpert *et al.*, 2001). Secondly, "PLS is a more rigorous approach . . . avoids small sample size problem" (Henseler *et al.*, 2009; Mintu-Wimsatt and

Table 1. BIM adoption framework statements

Categories (Codes)	Factors
Leadership (LEA)	LEA1. Our organisation has a clear BIM leadership role LEA2. Our BIM leadership team plays a strategic role (with goals and objectives) that will guide our organisation towards BIM adoption LEA3. Our BIM leadership team monitors and reviews the strategic plan regularly for BIM adoption LEA4. Our BIM leadership team communicates openly with and engages employees for BIM adoption LEA5. Our BIM leadership team is committed to continuous improvement in their own BIM skills LEA6. Our BIM leadership team is committed to continuous improvement in employees' own BIM skills
Clients & Other Stakeholders (e.g., architects, contractors, MEP, QS, suppliers) (CLI)	CLI1. Our organisation determines clients' expectations for planning the BIM adoption CLI2. Our organisation determines stakeholders' expectations for BIM adoption CLI3. Our organisation has a clear approach to collect clients' feedback after completing BIM projects CLI4. Our organisation has a clear approach to collect stakeholders' feedback after completing BIM projects CLI5. Our organisation educates clients on BIM CLI6. Our organisation employs a standard form of contract for the procurement of BIM CLI7. Our organisation is not reluctant to share information concerning BIM adoption with other stakeholders
Strategic Planning (STR)	STR1. Our organisation has a BIM strategic plan (e.g., BIM standards, BIM specifications, policies) STR2. Our organisation involves all stakeholders in developing the BIM strategic plan STR3. Our organisation allocates the resources effectively to ensure the success of BIM adoption STR4. Our organisation translates the strategic plan for BIM adoption into specific requirements for each stakeholder STR5. Our organisation uses a formal process to track the effectiveness of the BIM strategic plan STR6. Our organisation has its BIM strategic plan reviewed and updated regularly
Resources (RES)	RES1. Our organisation has available software for BIM adoption RES2. Our organisation has available hardware for BIM adoption RES3. Our employees have the required skills needed for BIM adoption RES4. Our organisation has the financial resources for further BIM investment
People (PEO)	PEO1. Our organisation provides the necessary training for BIM adoption (before implementing BIM) PEO2. Our organisation creates an environment conducive for the employees to improve their BIM skills PEO3. Our organisation encourages employees to share their ideas to improve BIM adoption PEO4. Our employees are committed to the strategies for BIM adoption within our organisation

(*continued*)

Table 1. Continued

Categories (Codes)	Factors
Process (PRO)	PRO1. Our organisation provides adequate training to improve our employees' BIM skills (during the BIM implementation process) PRO2. Our organisation develops a comprehensive BIM Execution Plan for each BIM project PRO3. Our organisation uses a formal process to track the effectiveness of implementing BIM PRO4. Our organisation reviews the BIM implementation process regularly PRO5. Our organisation communicates changes in our BIM implementation process to all employees involved in the process
Results (RE)	RE1. In our organisation, projects implemented using BIM generally satisfy the clients' expectations RE2. In our organisation, projects implemented using BIM generally satisfy the stakeholders' expectations RE3. Our BIM leadership team is effective in BIM adoption RE4. Our organisation developed an effective BM plan for BIM adoption RE5. Our organisation developed an effective BIM implementation process for BIM adoption RE6. Our employees became capable of implementing BIM RE7. Our organisation has a positive return on investment for BIM adoption

Source(s): Authors' own work

Graham, 2004), with 66 collected responses in this research. Therefore, SmartPLS was selected for the analysis.

Although the PLS-SEM technique does not require the sample size and normally distributed data (Julien and Ramangalahy, 2003), they were tested in this research to ensure the validity and reliability of the collected data. The normal distribution of the data was checked with the values of skewness and kurtosis above while the 10-times rule method, the most widely adopted (Kock and Hadaya, 2018), was used to check whether the sample size was appropriate for PLS-SEM. There are seven categories in the BIM adoption framework, meaning there is a potential of having a category impacted by six other ones. In other words, the sample size required for the PLS-SEM technique should be greater than 60. Therefore, 66 collected responses are appropriate for further data analysis.

The PLS-SEM was developed based on the BIM adoption framework, see Table 1. It is clear from Figure 2 that CLI and RE have the most observed variables, with seven ones for each. Six measurement factors are used for LEA, which is the same for STR. The least observed variables belong to RES and PEO while five factors are used to measure PRO. According to Doan *et al*. (2024), LEA is the most important category, impacting all other categories, including CLI, STR, RES, PEO, PRO, and RE. STR is affected by both LEA and CLI while PEO depends on LEA and RES. PRO is influenced by LEA, CLI, and PEO. LEA, STR, and PRO significantly impact RE.

A two-step approach should be conducted to assess the BIM adoption PLS-SEM, including assessing the measurement model and the structural model (Ali *et al*., 2018), described in the following sections.

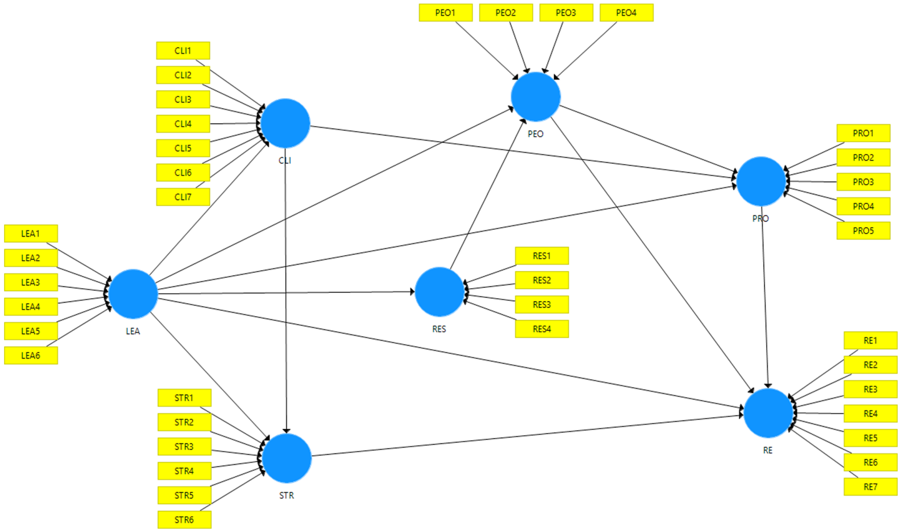

Figure 2. The BIM adoption PLS-SEM model. Source: Authors' own work

5.1 Assessing the measurement model

According to Lowry and Gaskin (2014), "no single technique is universally accepted for validating formative measures." Therefore, this research adopted the most popular approach for testing the construct validity of formative indicators, which was used in 29 studies during 2001–2015, revealed by Ali *et al.* (2018). A 3-step approach, which was also suggested by Lowry and Gaskin (2014), includes testing the variance inflation factors (VIFs), checking the indicator weights, and checking the significance of the indicator weights. According to Hair *et al.* (2016), non-significant indicator weights should be retained if their outer loadings exceed 0.5. Therefore, checking the significance of the indicator weights was replaced by checking the outer loadings.

Andreev *et al.* (2009) stated that the VIF values for the observed variables should be less than 10 to avoid multicollinearity while Hair *et al.* (2016) suggested using 5.0 as the cut-off point for VIF values in the context of PLS-SEM. Initial analysis revealed VIF values greater than 5.0 for the following variables: LEA1, LEA2, and LEA6; CLI3 and CLI4; STR5 and STR6; RE1 and RE2; RE4 and RE5. Because "multicollinearity causes redundant information" (Yoo *et al.*, 2014), those observed factors were checked to consider whether they should be removed from the model.

LEA2 was removed due to redundancy with LEA1, which sufficiently captured the importance of clear BIM leadership roles. Doan *et al.* (2024) emphasised the need for a clear BIM leadership role, which is well-captured by LEA1. The removal of LEA2 helps streamline the leadership category without losing the critical essence of effective leadership within the framework. LEA1 and other leadership factors, such as LEA3 and LEA4, ensure that the strategic aspects are still adequately covered.

Regarding CLI, CLI3 and CLI4 both focused on feedback collection. CLI4 was removed to reduce redundancy, concentrating on clients' feedback (CLI3), which is crucial as per Doan *et al.* (2024). By focusing on CLI3, the framework maintains its emphasis on client satisfaction and feedback, which are essential for BIM adoption. Other CLI factors, like CLI5 and CLI6, support this focus, ensuring a comprehensive approach to client and stakeholder management.

About STR, STR5 and STR6 were both about strategic planning processes. STR5 was removed to prioritise STR6, which emphasises the need for regular reviews and updates of the

BIM strategic plan. This aligns with the dynamic nature of BIM projects where continuous improvement and adaptation are critical. STR1 and STR3 remain, ensuring that strategic planning is comprehensively addressed.

RE2 and RE4 had high VIF values. RE2 was removed to highlight clients' expectations (RE1), which is more specific and aligns with the focus on client satisfaction. RE5 was retained to emphasise the importance of having a robust process for BIM adoption. RE3 and RE7 ensure that the results category comprehensively covers the outcomes and impacts of BIM adoption.

After removing LEA2, CLI4, STR5, RE2, and RE4, the model was rerun to detect the multicollinearity. All VIF values were below 5.0, satisfying the first condition for validating formative indicators, see Table 2. After running the model to check the outer weight for each factor, the values of CL2, STR4, and RES4 are negative. They, therefore, were removed, suggested by Ringle and Sarstedt (2016). Finally, the outer loadings along with their significance were determined with a bootstrapping procedure with 10,000 subsamples. Table 2 shows that all outer loadings are greater than 0.5 and are significant, with *p*-values equal 0.000. The reliability and validity of the construct measures of the BIM adoption PLS-SEM model with 31 factors were ensured after testing the VIFs, outer weights, and outer loadings.

5.2 Assessing the structural model

After confirming the reliability and validity of the construct measures of the model, the predictive capabilities and the relationships amongst the constructs were examined in this section. A 5-step approach, including assessing the coefficient of determination (R^2), the path coefficient, the f^2 effect size, the predictive relevance (Q^2), and the q^2 effect size, is a common approach suggested by many researchers to assess the structural model (Ali *et al.*, 2018; Hair *et al.*, 2016; Henseler *et al.*, 2009).

Figure 3 shows the R^2 values and the path coefficients of the model, which measure how well the independent variables explain the variance in the dependent variables. The R^2 values for all categories exceed 0.33, indicating a substantial level of predictive accuracy (Henseler *et al.*, 2009). A bootstrapping procedure with 10,000 subsamples was performed to determine the appropriateness of the path coefficients. As shown in Table 3, all path coefficient values are significant, with p-values <0.05.

Table 4 shows the results of the f^2 effect sizes, which measure the relative impact of each independent variable on the dependent variable. According to Hair *et al.* (2016), effect sizes of 0.35, 0.15, and 0.02 represent large, medium, and small effects, respectively, for the exogenous latent factor. Except for the effect sizes of LEA on PRO and RE together with the effect size of PRO on RE are small, the other effect sizes are either large or medium. After evaluating the f^2 effect sizes, the predictive relevance Q^2 was examined with a blindfolding procedure. Table 4 shows that all the Q^2 values are greater than 0, indicating a good reconstruction of the observed values (Hair *et al.*, 2016; Henseler *et al.*, 2009). In other words, the model has predictive relevance.

Since SmartPLS does not directly provide q^2 effect sizes, they were calculated manually using the equation below (Hair *et al.*, 2016; Henseler *et al.*, 2009).

$$q^2 = \frac{Q^2_{included} - Q^2_{excluded}}{1 - Q^2_{included}}$$

The results shown in Table 4 indicate that the q^2 effect sizes of the relationships amongst the categories are either small or medium, which are higher than 0.02 and 0.15, respectively (Hair *et al.*, 2016; Henseler *et al.*, 2009).

Table 2. Results of VIFs, outer weights, outer loadings and *p*-values of the measurement model

	VIFs	Outer weights	Outer loadings	*p*-values
LEA1 → LEA	2.867	0.427	0.913	0.000
LEA3 → LEA	3.301	0.151	0.853	0.000
LEA4 → LEA	4.283	0.053	0.859	0.000
LEA5 → LEA	3.942	0.279	0.890	0.000
LEA6 → LEA	4.998	0.214	0.877	0.000
CLI1 → CLI	1.930	0.038	0.709	0.000
CLI3 → CLI	1.901	0.286	0.795	0.000
CLI5 → CLI	2.489	0.466	0.906	0.000
CLI6 → CLI	1.724	0.284	0.779	0.000
CLI7 → CLI	1.461	0.167	0.615	0.000
STR1 → STR	3.626	0.367	0.910	0.000
STR2 → STR	3.668	0.124	0.847	0.000
STR3 → STR	2.634	0.232	0.809	0.000
STR6 → STR	2.892	0.408	0.921	0.000
RES1 → RES	4.848	0.459	0.936	0.000
RES2 → RES	4.699	0.235	0.904	0.000
RES3 → RES	1.768	0.415	0.861	0.000
PEO1 → PEO	1.860	0.475	0.846	0.000
PEO2 → PEO	3.521	0.050	0.855	0.000
PEO3 → PEO	3.874	0.530	0.901	0.000
PEO4 → PEO	3.480	0.093	0.838	0.000
PRO1 → PRO	2.449	0.419	0.912	0.000
PRO2 → PRO	2.689	0.259	0.836	0.000
PRO3 → PRO	3.406	0.048	0.826	0.000
PRO4 → PRO	4.315	0.195	0.894	0.000
PRO5 → PRO	2.752	0.224	0.833	0.000
RE1 → RE	1.620	0.019	0.504	0.000
RE3 → RE	3.589	0.596	0.966	0.000
RE5 → RE	2.846	0.342	0.901	0.000
RE6 → RE	3.357	0.086	0.798	0.000
RE7 → RE	2.063	0.060	0.637	0.000

Source(s): Authors' own work

6. Discussion

The analysis of the BIM adoption framework using PLS-SEM has provided valuable insights into the critical factors influencing BIM adoption in New Zealand. Each category within the framework has been evaluated for its impact on BIM implementation, highlighting the significant roles of leadership, client engagement, strategic planning, resources, people, processes, and results.

The strong influence of leadership across the framework is evidenced by its significant impact on other categories. LEA1 (clear BIM leadership role) emerged as the most critical aspect within the LEA category, with an outer weight of 0.427 and an outer loading of 0.913. This finding aligns with Deutsch (2018), who emphasised that a clear leadership role is indispensable for successful BIM adoption. Moreover, the importance of strategic leadership and continuous improvement is reinforced by factors LEA3 and LEA4, further underlining that without strong leadership, BIM implementation efforts are likely to face resistance and fragmentation.

Educating clients on BIM (CLI5) was identified as a crucial factor, with a significant outer weight of 0.466 and an outer loading of 0.906. This reinforces the need to prioritise client understanding to improve BIM implementation, as supported by Rodgers *et al*. (2015). Additionally, incorporating client feedback (CLI3) is crucial for aligning BIM implementation

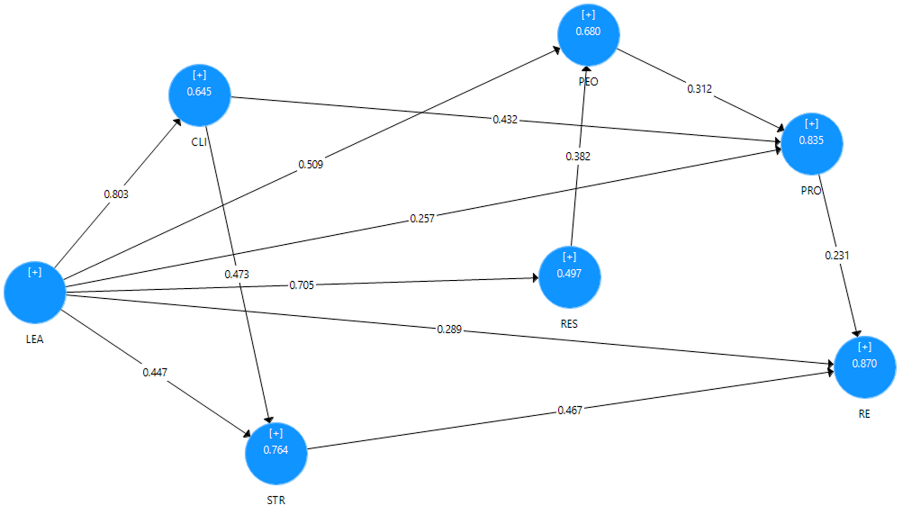

Figure 3. Results of the BIM adoption PLS-SEM model. Source: Authors' own work

Table 3. Significance testing results of the path coefficients

	Original sample	Sample mean	Standard deviation	*T* statistics	*p* values
LEA → CLI	0.803	0.813	0.048	16.668	0.000
LEA → STR	0.447	0.448	0.100	4.455	0.000
LEA → RES	0.705	0.723	0.061	11.615	0.000
LEA → PEO	0.509	0.525	0.102	4.970	0.000
LEA → PRO	0.257	0.250	0.100	2.578	0.010
LEA → RE	0.289	0.299	0.097	2.975	0.003
CLI → STR	0.473	0.479	0.095	4.966	0.000
CLI → PRO	0.432	0.441	0.094	4.581	0.000
STR → RE	0.467	0.448	0.089	5.261	0.000
RES → PEO	0.382	0.373	0.108	3.548	0.000
PEO → PRO	0.312	0.311	0.081	3.859	0.000
PRO → RE	0.231	0.241	0.101	2.283	0.022

Source(s): Authors' own work

with client expectations and project needs. Ensuring that clients are actively involved in the BIM process not only reduces resistance to adoption but also fosters greater collaboration across project stakeholders. These findings highlight the importance of proactive client education and engagement strategies, which can enhance trust, improve decision-making, and facilitate smoother BIM integration in construction projects.

Regularly reviewing and updating the BIM strategic plan (STR6) is essential, as indicated by its outer weight of 0.408 and outer loading of 0.921. This supports Chunduri *et al*. (2013), who highlighted the responsibilities of BIM champions in maintaining up-to-date strategic plans. Having a BIM strategic plan (STR1) and effective resource allocation (STR3) are also critical to the success of BIM projects. These findings suggest that adaptability in strategic planning is key to aligning with evolving project requirements.

Table 4. Results of the f^2 effect sizes, the predictive relevance Q^2, and the q^2 effect sizes

	CLI		STR		RES		PEO		PRO		RE		
	f^2	q^2	f^2	q^2	f^2	q^2	f^2	q^2	f^2	q^2	f^2	q^2	Q^2
LEA	1.817		0.301	0.042	0.988		0.408	0.187	0.102	0.024	0.150	0.025	
CLI			0.337	0.197					0.394	0.158			0.348
STR											0.431	0.044	0.522
RES							0.230	0.083					0.367
PEO									0.228	0.043			0.449
PRO											0.095	0.023	0.577
RE													0.479

Source(s): Authors' own work

The availability of BIM software (RES1) is a key factor in the resources category, with an outer weight of 0.459 and an outer loading of 0.936. This finding is consistent with Olatunji (2011), who found that software costs account for a significant portion of BIM implementation expenses. Adequate financial resources (RES4) and hardware (RES2) are also vital for supporting BIM adoption.

Encouraging employees to share ideas (PEO3) significantly improves BIM adoption success, with an outer weight of 0.530 and outer loading of 0.901. This aligns with Ho *et al*. (2013) and Farnsworth *et al*. (2015), who emphasised the importance of knowledge-sharing cultures in digital transformation efforts. Providing necessary BIM training (PEO1) was also identified as a key enabler, reinforcing that technical expertise must be continuously developed to ensure successful adoption.

Adequate training during the BIM implementation process (PRO1) is highlighted by its outer weight of 0.419 and outer loading of 0.912. Zhao *et al*. (2016) identified the lack of BIM expertise as a significant risk, underscoring the need for continuous training. Developing comprehensive BIM Execution Plans (PRO2) and communicating changes in the BIM implementation process (PRO5) are also important for successful BIM adoption.

The effectiveness of the BIM leadership team (RE3) is crucial for BIM adoption, with the highest outer weight of 0.596 and outer loading of 0.966. This finding reinforces the interconnected role of leadership in driving outcomes, particularly through the robust implementation of BIM processes (RE5), which is also critical for achieving positive results.

The BIM adoption framework and the five hypotheses proposed by Doan *et al*. (2024) were validated with significant path coefficients and high R^2 values, as shown in Figure 3. Specifically, the R^2 value of RE is 0.870, indicating that LEA, CLI, STR, RES, PEO, and PRO explain 87% of the variations in RE. The integration of these categories illustrates the comprehensive nature of the framework in predicting successful BIM adoption. It is noticed that the R^2 value of RES is lowest compared to the rest categories, 0.497. This reflects the dependency of resources on external factors beyond leadership, such as technological capabilities and industry maturity. Based on the results of the measurement model, RE depends mainly on the BIM software with significant and highest outer weight. However, the available BIM software still needs to be improved for specialised tasks for BIM adoption (Ignatova *et al*., 2018). Also, the need for the strong power of computers for BIM adoption was also mentioned by Tulenheimo (2015). These explained why RE has the lowest R^2 values.

The reliability and validity of the BIM adoption PLS-SEM model were confirmed after examining the f^2 effect sizes, the predictive relevance Q^2, the q^2 effect sizes. The results show that all the categories have at least small effect sizes to the others while the value of Q^2 is positive, indicating that the observed values are well reconstructed and the model has predictive relevance. To sum up, the results of the model confirmed the BIM adoption framework developed by Doan *et al*. (2024).

It is clear from Table 5 that LEA is the most important category for BIM adoption, affecting all other categories in the BIM adoption framework. This is consistent with internationally recognised frameworks such as the Baldrige Excellence Framework (BEF), European Foundation for Quality Management Excellence Model (EFQMEM), and Australian Business Excellent Framework (ABEF) when LEA is the first and foremost factor for all of them (EFQM, 2018; NIST, 2015; SAI-Global, 2011). STR also plays a crucial role in supporting RE, alongside LEA. This emphasises the importance of focusing on strategic planning factors to improve a BIM project's quality.

The findings of this research provide significant practical value to multiple stakeholders in the construction industry, particularly in New Zealand. This study identified key success factors for BIM adoption and outlined specific ways for different stakeholder groups to apply these findings in practice. Policymakers can use the BIM adoption framework as a foundation for developing national BIM guidelines and policies, ensuring a structured and standardised approach to BIM implementation. Insights into leadership, strategic planning, and client engagement will help policymakers design targeted incentives, training programmes, and

Table 5. The effects amongst categories of the BIM adoption framework

	Original sample	Sample mean	Standard deviation	T statistics	*p*-values
LEA → CLI	0.802	0.813	0.048	16.690	0.000
LEA → STR	0.829	0.843	0.040	20.589	0.000
LEA → RES	0.704	0.731	0.058	12.146	0.000
LEA → PEO	0.779	0.795	0.055	14.288	0.000
LEA → PRO	0.847	0.856	0.036	23.395	0.000
LEA → RE	0.872	0.882	0.031	28.412	0.000
CLI → STR	0.462	0.469	0.098	4.724	0.000
CLI → PRO	0.430	0.443	0.095	4.528	0.000
CLI → RE	0.324	0.323	0.073	4.457	0.000
STR → RE	0.481	0.460	0.092	5.254	0.000
RES → PEO	0.392	0.379	0.110	3.573	0.000
RES → PRO	0.123	0.118	0.046	2.647	0.008
PEO → PRO	0.313	0.311	0.081	3.877	0.000
PEO → RE	0.075	0.077	0.038	1.971	0.049
PRO → RE	0.238	0.246	0.099	2.414	0.016
RES → RE	0.029	0.030	0.018	1.639	0.101

Source(s): Authors' own work

regulatory frameworks that facilitate industry-wide BIM adoption. By integrating these factors into policy development, governments can create a more cohesive and supportive environment for BIM adoption across the sector.

Construction professionals and project managers can integrate the framework's key factors into their project workflows. By establishing clear BIM leadership roles, conducting regular strategic reviews, and enhancing client education, they can improve collaboration, reduce inefficiencies, and streamline digital integration within their projects. These improvements will lead to better coordination between stakeholders, minimising delays and ensuring that BIM is effectively integrated into project lifecycles. Additionally, by following the framework's recommendations, construction firms can refine their internal processes and build greater BIM competency among their teams.

Educational institutions and training organisations can also benefit from these findings by embedding the framework into BIM courses and professional training programmes. By aligning curricula with the critical factors identified in this study, universities and training centres can ensure that students and industry practitioners acquire technical and managerial competencies for effective BIM adoption. The structured approach outlined in this research serves as a teaching tool, equipping future professionals with the knowledge required to navigate BIM implementation challenges. This, in turn, enhances industry readiness by fostering a workforce that is well-versed in BIM processes and best practices.

Technology providers can leverage the research findings to address industry-specific BIM adoption challenges, including software accessibility, interoperability, and usability. The insights related to client engagement and resource constraints can help guide the development of customised BIM solutions that better align with the needs of construction professionals. By refining their software offerings based on these insights, technology providers can enhance user adoption rates and facilitate smoother BIM implementation.

Beyond its practical applications, this research also makes a significant theoretical contribution to BIM adoption theory by integrating a region-specific perspective into global discussions on digital construction transformation. This study advances the discourse by developing and empirically validating a multi-dimensional adoption framework, reinforcing and expanding existing models. Specifically, the findings highlight the dominant role of leadership in BIM adoption success, the interdependence of strategic planning and stakeholder engagement in driving digital transformation, and the criticality of resource availability in overcoming adoption barriers. These insights bridge the gap between theoretical BIM adoption models and real-world industry applications, offering a framework that explains BIM adoption dynamics and provides actionable strategies for improving implementation outcomes. Additionally, this study's methodological approach—using PLS-SEM to quantify relationships among adoption factors—provides a replicable framework that can be adapted for future research in different national contexts. By validating the relationships between key adoption factors, this research offers a strong foundation for comparative studies and further exploration of BIM adoption across diverse construction markets.

7. Conclusion

This research examines the relationships among factors affecting BIM adoption in New Zealand. Specifically, a BIM adoption framework with 7 main categories along with 39 factors and five hypotheses developed by Doan *et al*. (2024) were examined. The framework was assessed through a rigorous analysis of the measurement model, including evaluations of VIFs, outer weights, outer loadings, and *p*-values. Additionally, the structural model was assessed using R^2, f^2, Q^2, and q^2 values. The results indicate that 31 factors amongst 39 are reliable and valid to evaluate a BIM project, see Table 6.

A key finding of this research is the essential role of leadership in advancing BIM adoption. The findings underscore the significance of clear leadership, reinforcing its criticality within the BIM adoption landscape. This research provides specific empirical evidence from New Zealand, addressing the critical gap in understanding BIM adoption in a less explored geographical context. The study develops a tailored BIM adoption framework by leveraging robust quantitative validation with qualitative insights, offering a unique contribution to the literature. The findings underscore the pivotal role of leadership and provide actionable strategies for overcoming region-specific challenges. These contributions advance both academic discourse and practical methodologies, enhancing the global understanding of BIM adoption strategies.

This study provides significant practical insights for various stakeholders. The findings offer a targeted guide for enhancing BIM implementation in construction projects, highlighting the importance of robust leadership, strategic foresight in planning, and improved client engagement with BIM processes. These actionable recommendations aim to refine project management methodologies and improve the overall efficiency of construction undertakings.

Although developed for New Zealand, the findings have broader implications for BIM adoption in regions with similar industry constraints. The leadership-driven adoption approach proposed in this study aligns with challenges observed in other emerging BIM markets, such as limited stakeholder engagement and resource allocation concerns. The framework's structural validation through PLS-SEM provides a methodological foundation for future research in international contexts, allowing for comparative studies and cross-regional adaptation. Policymakers and industry leaders in other countries can leverage this structured model to design targeted interventions that accelerate BIM implementation in their respective construction sectors. Moreover, the study highlights the evolving nature of construction technology, advocating for ongoing exploration into how advancements in digital tools might redefine the parameters of BIM adoption. The continuous adaptation to new technological paradigms underscores the need for sustained scholarly inquiry.

While this study provides valuable insights, certain limitations should be acknowledged. The relatively small sample size, although appropriate for PLS-SEM, may limit the generalisability of findings across the broader construction industry. Additionally, the study's focus on the New Zealand context may reduce its direct applicability to regions with differing construction practices, regulatory environments, and market conditions. Expanding the scope

Table 6. Final BIM adoption framework

Categories	Factors
Leadership	1. The organisation has a clear BIM leadership role 2. The BIM leadership team monitors and reviews the strategic plan regularly for BIM adoption 3. The BIM leadership team communicates openly with and engages employees for BIM adoption 4. The BIM leadership team is committed to continuous improvement in their own BIM skills 5. The BIM leadership team is committed to continuous improvement in employees' own BIM skills
Clients & Other Stakeholders (e.g., architects, contractors, MEP, QS, suppliers)	1. The organisation determines clients' expectations for planning the BIM adoption 2. The organisation has a clear approach to collect clients' feedback after completing BIM projects 3. The organisation educates clients on BIM 4. The organisation employs a standard form of contract for the procurement of BIM 5. The organisation is not reluctant to share information concerning BIM adoption with other stakeholders
Strategic Planning	1. The organisation has a BIM strategic plan (e.g., BIM standards, BIM specifications, policies) 2. The organisation involves all stakeholders in developing the BIM strategic plan 3. The organisation allocates the resources effectively to ensure the success of BIM adoption 4. The organisation has its BIM strategic plan reviewed and updated regularly
Resources	1. The organisation has available software for BIM adoption 2. The organisation has available hardware for BIM adoption 3. The employees have the required skills needed for BIM adoption
People	1. The organisation provides the necessary training for BIM adoption (before implementing BIM) 2. The organisation creates an environment conducive for the employees to improve their BIM skills 3. The organisation encourages employees to share their ideas to improve BIM adoption 4. The employees are committed to the strategies for BIM adoption within the organisation
Process	1. The organisation provides adequate training to improve their employees' BIM skills (during the BIM implementation process) 2. The organisation develops a comprehensive BIM Execution Plan for each BIM project 3. The organisation uses a formal process to track the effectiveness of implementing BIM 4. The organisation reviews the BIM implementation process regularly 5. The organisation communicates changes in the BIM implementation process to all employees involved in the process

(*continued*)

Table 6. Continued

Categories	Factors
Results	1. In the organisation, projects implemented using BIM generally satisfy the clients' expectations 2. The BIM leadership team is effective in BIM adoption 3. The organisation developed an effective BIM implementation process for BIM adoption 4. The employees became capable of implementing BIM 5. The organisation has a positive return on investment for BIM adoption

Source(s): Authors' own work

of future studies through larger-scale, longitudinal research could enhance the framework's validity and generalisability.

In essence, this study bridges critical gaps in understanding BIM adoption in New Zealand, with a particular emphasis on the centrality of leadership. It furnishes pragmatic guidance for industry stakeholders while charting a course for future scholarly inquiry. The tailored framework developed through this research serves as a valuable addition to academic discourse on technological integration in construction, providing actionable methodologies that can be adapted to other regions with similar challenges.

The BIM adoption framework was specifically developed for the New Zealand context. To enhance its applicability, adjustments may be required for implementation in other countries. Additionally, the current framework may not capture all aspects of BIM adoption. For example, limited technological resources were not fully addressed, contributing to the lower R^2 value for the "Resources" category. Addressing these gaps in future research could further enrich the understanding of BIM adoption.

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