E-BOOK OF EXTENDED ABSTRACT

THE 14TH INTERNATIONAL INVENTION, INNOVATION & DESIGN COMPETITION 2025

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UNVEILING THE DIGITAL HORIZON - BRIDGING THE REALMS OF DIGITAL TWINNING AND CONSTRUCTION PROJECT MANAGEMENT PERFORMANCE

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ABSTRACT

The digitalisation of the construction industry is deemed a crucial element in Construction 4.0's vision, attainable through the implementation of digital twinning. It is perceived as a virtual strategy to surmount the constraints linked with traditional construction projects, thereby augmenting their productivity and effectiveness. However, the neglect to investigate the causal relationship between implementation and construction project management performance has resulted from a lack of understanding and awareness regarding the consequences of digital twinning implementation, combined with a shortage of expertise among construction professionals. Consequently, this paper extensively explores the relationship between digital twinning implementation and construction project management performance. The Innovation Diffusion Theory (IDT) is employed to investigate this relationship, utilising a quantitative research approach through document analysis and questionnaire surveys. Additionally, partial least squares structural equation modelling (PLS-SEM) with SmartPLS software is employed to deduce the relationship. The results underscore that digital twinning implementation significantly improves construction project management performance. Despite recognising various challenges in digital twinning implementation, when regarded as moderating factors, these challenges do not significantly impact the established causal relationship. Therefore, this investigation aligns with the national push toward the digitalisation of the construction sector, highlighting the positive impacts of digital twinning implementation on construction project management performance. Moreover, this study details the impacts of implementing digital twinning from the construction industry's perspective, including positive and negative impacts. Afterwards, this paper addresses the existing research gap, providing a more precise understanding and awareness among construction industry participants, particularly in developing nations.

Keywords: digital twinning, digital twins, Industry 4.0, Construction 4.0, construction project management performance, Innovation Diffusion Theory (IDT)

1. INTRODUCTION

This study highlights the importance of the construction industry in driving a nation's technological and economic progress, focusing on the design, construction, and maintenance of infrastructure (Paz et al., 2020; Hussain et al., 2022). Despite its significance, the industry faces ongoing issues with inefficiency and low productivity (Andric et al., 2019). To address these problems, Construction 4.0 introduces technological advancements from Industry 4.0, such as digitisation and automation of construction processes, with the goal of improving productivity and efficiency (Forcael et al., 2020; Olsson et al.,

2021). One key aspect of Construction 4.0 is digital twinning, which involves creating digital replicas of physical assets and processes to optimise performance through real-time data analysis (Zuhairi at al., 2020). Countries like the U.K., China, and Malaysia have embraced digital twinning, launching initiatives to support its adoption in the construction sector. In Malaysia, the Construction Industry Development Board (CIDB) has introduced the Construction 4.0 Strategic Plan (2021-2025), encouraging the widespread use of digital twinning. However, the implementation of digital twinning in the construction industry faces challenges due to a lack of knowledge, training, and resistance to change (Matthews et al., 2015; Olsson et al., 2019; Nnaji and Karahan, 2020). Additionally, there is limited research on how digital twinning impacts construction project management performance. This study aims to investigate the effects of digital twinning on project management performance in Malaysia's construction industry.

2. METHODOLOGY

2.1 Research Model

This study examines the implementation of digital twinning in the construction industry, focusing on the acceptance process and individuals' attitudes toward innovation. The paper introduces a research model that integrates Innovation Diffusion Theory (IDT) with construction project management performance criteria to explore the relationship between digital twinning implementation and project management performance. The framework, based on IDT, evaluates factors such as relative benefits, complexity, compatibility, trialability, and observability to assess the readiness of potential adopters. Additionally, construction project management performance is measured through quality, cost, time, contract, and external factors. The research model, depicted in Figure 1, incorporates these elements while addressing challenges in implementing digital twinning as moderating variables. This study uses partial least squares structural equation modelling (PLS-SEM) to analyse the identified factors and their impact on project management performance.

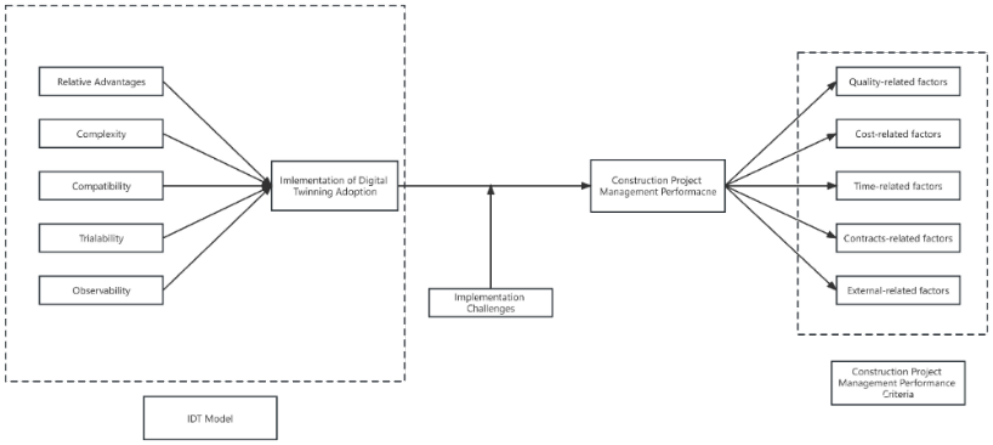

Figure 1 Research Model

2.2 Research Methodology

This study employed a quantitative research methodology, incorporating data collection through a literature review and questionnaire survey, followed by data analysis using Smartpls 4.0 software. The survey targeted specific individuals from the Malaysian construction industry using purposive sampling, with 66 valid responses collected from 210 distributed questionnaires, yielding a response rate of 31.4%. Data analysis was conducted using Partial Least Squares Structural Equation Modeling (PLS-SEM), a method well-suited for small sample sizes, limited theoretical background, and a focus on predictive accuracy.

3. FINDINGS

Initial findings reveal that the most reliable participants are Civil and Structural Engineers (30.6%), Project Engineers (7.4%), and Cost Engineers (6.5%). The majority of participants have either less than five years of experience or between five to ten years (33.3% each), with 10.6% having over 20 years of

experience. The study utilises a PLS-SEM hierarchical component model (HCM), featuring two higher-order and ten lower-order constructs, as illustrated in Figure 2. Figure 3 depicts the measurement model, and it was assessed for reliability and validity.

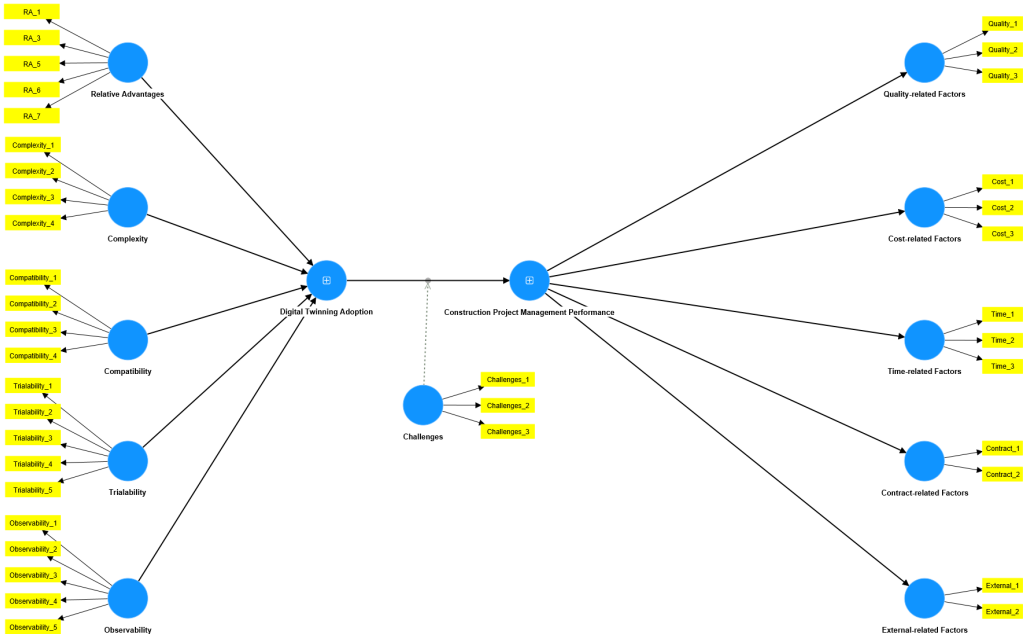

Figure 2 PLS-SEM measurement model with Lower Order Constructs (LOCs).

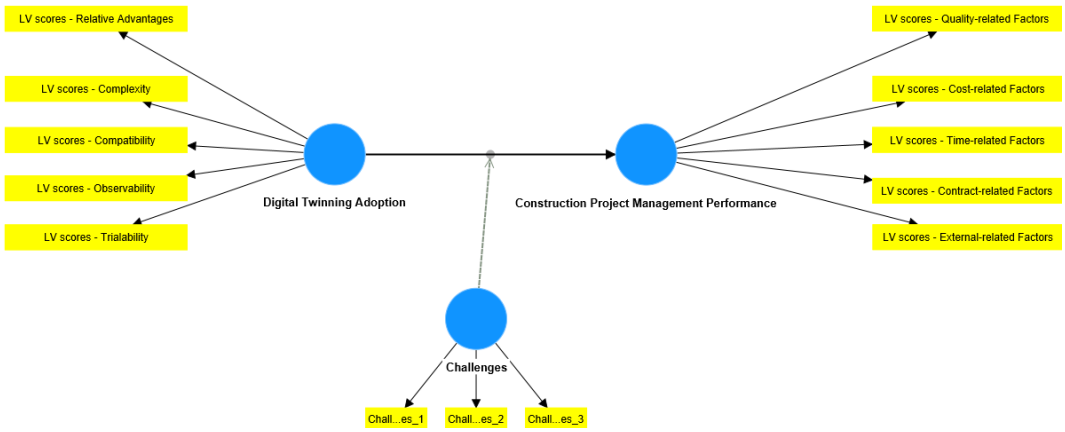

Figure 3 PLS-SEM measurement model.

The result of the evaluation of the measurement model showed an acceptable reliability, good convergent validity, non-concerning multicollinearity, and established discriminant validity, as shown in Table 1. However, three indicators were excluded due to low indicator loading (below 0.4).

Table 1 Results summary for evaluation of PLS-SEM measurement model.

Indicators	Indicator Loading	VIF	Cronbach's Alpha	Composite Reliability	AVE	*t* Value	*p* Value
LV Scores - Relative Advantages	0.712	1.487	0.800	0.715	0.516	3.140	0.002*
LV Scores - Complexity	0.286	1.598	0.800	0.715	0.516	1.141	0.254
LV Scores - Compatibility	−0.210	1.553	0.800	0.715	0.516	0.825	0.410
LV Scores - Trialability	0.422	2.752	0.800	0.715	0.516	2.089	0.037*

LV Scores - Observability	0.293	2.284	0.800	0.715	0.516	1.288	0.198
LV Scores - Quality-related Factors	0.830	1.680	0.684	0.730	0.439	7.654	0.000*
LV Scores - Cost-related Factors	0.464	1.335	0.684	0.730	0.439	2.485	0.013*
LV Scores - Time -related Factors	0.764	1.683	0.684	0.730	0.439	5.949	0.000*
LV Scores - Contract -related Factors	0.672	1.469	0.684	0.730	0.439	5.035	0.000*
LV Scores - External -related Factors	0.553	1.297	0.684	0.730	0.439	2.460	0.014*
Challenges_1	0.633	1.288	0.651	0.720	0.564	2.021	0.043*
Challenges_2	0.805	1.403	0.651	0.720	0.564	3.533	0.000*
Challenges_3	0.825	1.213	0.651	0.720	0.564	3.232	0.001*

Following validation of the measurement model, the structural model was analysed based on collinearity, R^2, f^2, Q^2, and path significance. According to Table 2, Collinearity has no issues, the value of R^2 indicates moderate determination, Q^2 value indicates the accepted predictive relevance, f^2 value ranges from moderate to large (0.259, 0.096, 0.004), and the path coefficient analysis shows that the implementation of digital twinning positively and significantly influences construction project management performance. Challenges also show a minor but significant positive relationship with performance, although their interaction with digital twinning implementation does not significantly affect the project management performance.

Table 2 Results summary for evaluation of PLS-SEM structural model

Indicators	**VIF**	***R*²**	***Q*²**
LV Scores - Relativ4e Advantages	1.415		0.000
LV Scores - Trialability	1.415		0.000
LV Scores - Quality-related Factors	1.680	0.263	0.085
LV Scores - Cost-related Factors	1.335	0.263	0.085
LV Scores - Time -related Factors	1.682	0.263	0.085
LV Scores - Contract -related Factors	1.467	0.263	0.085
LV Scores - External -related Factors	1.294	0.263	0.085
Challenges_1	1.288		0.000
Challenges_2	1.403		0.000
Challenges_3	1.213		0.000

Path Model	**Path Coefficient**	**f²**	**t Value**	**p Value**	**Significant Level**	**90% Confidence Level**
Digital twinning adoption → Construction project management performance	0.417	0.234	3.854	0.000	***	0.625
Challenges → Construction project management performance	0.274	0.095	2.004	0.045	**	0.466
Challenges x Digital twinning adoption → Construction project management performance	-0.021	0.001	0.186	0.853	NS	0.128

The findings suggest that while challenges exist in digital twinning implementation, such as inadequate resources or technical knowledge, these do not negate its benefits. Effective solutions and mitigation strategies can address these obstacles (Ammar et al., 2022; Greif et al., 2020; Lei et al., 2023; Oraee et al., 2019; Ramu et al., 2022; Redmond et al., 2012; Wang et al., 2020). Most adopters perceive that the

advantages of digital twinning implementation outweigh its challenges. Moreover, government policies and mandates, such as Singapore's Integrated Digital Delivery (IDD) initiative, significantly drive implementation.

4. CONCLUSION

This study explores the impact of the implementation of digital twinning in the construction industry, identifying seven positive and six negative effects, alongside five performance criteria for project management. SmartPLS software has been adopted to investigate the causal relationship between the implementation of digital twinning and the performance of construction project management, finding a strong, significant positive connection. While challenges in implementing digital twinning exist, they do not significantly diminish its positive impact on project management performance. Therefore, this study underscores the considerable benefits of digital twinning implementation, especially in enhancing construction project management despite its challenges.

This research contributes in several ways. This study supports the national goal of construction digitalisation by demonstrating that digital twinning can improve project management, contributing to the broader digital transformation of the industry. Besides that, it highlights how digitalisation can enhance the construction industry's competitiveness and sustainability, leading to economic growth. Moreover, this research provides a comprehensive analysis of the positive and negative effects of digital twinning, offering valuable recommendations to aid the industry's transition to digital methods. Furthermore, the findings are valuable for construction companies, government bodies, and research institutions, potentially shaping the future of intelligent construction. Lastly, by focusing on the impact of the implementation of digital twinning on construction project management performance, the study enhances understanding among stakeholders and promotes awareness of digital twinning, particularly in developing countries.

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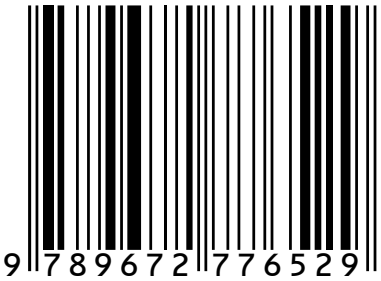

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