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The Interplay of Digital Transformation, Organizational Agility, and Knowledge Management in Optimizing Construction Project Management

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Abstract

While digital transformation (DT) promises significant advancements in the construction sector, many firms report a disconnect between technological investment and realized project performance. This study investigates the mechanisms through which DT drives project management optimization (PMO), hypothesizing that organizational agility (OA) and knowledge management capability (KMC) serve as critical mediating factors. We propose and test a conceptual model in which DT directly enhances PMO and also exerts indirect influence through the parallel pathways of OA and KMC. Data from a survey of 312 construction professionals were analyzed using structural equation modeling. The results confirm a significant direct effect of DT on PMO. Furthermore, both OA and KMC are identified as complementary and significant partial mediators. This finding underscores that the efficacy of digital technologies is contingent upon supportive organizational structures and systematic knowledge processes. The study provides a nuanced theoretical framework explaining how DT translates into improved project outcomes and offers strategic guidance for practitioners: to fully capitalize on digital investments, construction firms must concurrently cultivate adaptive capabilities and robust knowledge management systems.

Keywords: digital transformation; construction project management; information collaboration; decision support; process optimization

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1. Introduction

The construction industry is experiencing a paradigm shift driven by the rapid advancement of digital technologies. As one of the most complex and resource-intensive sectors, construction faces increasing pressure to improve productivity, reduce costs, and manage uncertainty across project lifecycles [1]. Traditional project management approaches, often reliant on fragmented systems and manual coordination, are no longer sufficient in meeting the demands of today's dynamic project environments [2]. In this context, digital

transformation (DT) emerges not only as a technological upgrade but as a fundamental change in how construction projects are planned, executed, and optimized.

Digital transformation in construction encompasses the adoption of technologies such as Building Information Modeling (BIM), Internet of Things (IoT), artificial intelligence, and cloud-based platforms [3]. These tools enable real-time collaboration, predictive analytics, and integrated data management, thereby enhancing decision-making and operational efficiency [4]. However, while many firms have invested heavily in digital tools, the expected improvements in project performance have not always materialized [5]. This gap suggests that digital transformation alone is not a panacea; its effectiveness depends on how well it is integrated with the organization's internal capabilities and strategic responses.

In particular, organizational agility (OA) has emerged as a critical dynamic capability in the digital age. Agility reflects an organization's ability to rapidly adapt to changes, reconfigure resources, and maintain responsiveness in uncertain environments [6]. In construction, where project conditions can shift due to regulatory, environmental, or client-driven factors, agility enables teams to make timely decisions and recalibrate project plans [7]. Digital tools may enhance this capability by increasing transparency, improving communication, and enabling faster feedback loops.

Another essential factor is knowledge management capability (KMC), which refers to the processes of acquiring, sharing, and applying knowledge within an organization. In project-based industries, the ability to leverage accumulated experience, access technical know-how, and disseminate critical information can significantly influence project success [8]. Digital transformation facilitates KMC by enabling real-time data collection and providing platforms for collaborative learning [9]. However, if organizations lack the capacity to transform data into actionable knowledge, the benefits of digital tools remain limited.

Despite growing interest in digital transformation in construction, few empirical studies have systematically examined how DT translates into project management optimization (PMO) through organizational response mechanisms. Existing research often focuses narrowly on technological adoption or implementation barriers, without fully considering the complementary organizational capabilities that enable firms to extract value from digital investments. Consequently, there is a limited understanding of the pathways through which DT impacts project outcomes in construction settings, which are typically characterized by high uncertainty, interdependence, and the need for extensive coordination among multiple stakeholders.

This research addresses this critical gap by developing and empirically testing a conceptual model that investigates the direct effect of digital transformation on project management optimization, as well as the mediating roles of organizational agility and knowledge management capability. By doing so, it moves beyond a purely technological perspective and emphasizes the strategic and organizational enablers that amplify the effectiveness of digital initiatives. Drawing on dynamic capabilities theory, the study posits that firms must integrate and reconfigure internal competencies to remain competitive, and that OA and KMC are key mechanisms through which DT contributes to improved project outcomes.

2. Literature Review and Hypothesis Development

2.1. Digital Transformation

Digital transformation (DT) refers to the strategic integration of digital technologies into all areas of an organization, fundamentally reshaping how value is created, delivered, and sustained [10]. It extends beyond mere technology adoption to include changes in organizational culture, business models, and operational processes. Prior studies suggest

that DT enhances operational efficiency, improves customer responsiveness, and facilitates data-driven decision-making [11]. In project-based environments, DT enables real-time communication, remote collaboration, and predictive analytics, which in turn foster better project execution and control [12]. Moreover, the adoption of digital tools such as cloud platforms, AI-driven project management systems, and digital dashboards is increasingly linked to improved scheduling, resource utilization, and risk management [13]. While these studies collectively affirm the potential benefits of DT, many tend to adopt a descriptive or tool-centric perspective, focusing primarily on the technologies themselves rather than the organizational mechanisms that enable successful transformation. Particularly in construction, where projects are dynamic and highly complex, the assumption that technology alone can lead to improved outcomes may oversimplify the nature of digital transformation. Existing models often emphasize the direct impact of DT on performance, yet offer limited insight into the internal conditions under which such transformation becomes effective. This creates a theoretical gap in understanding the role of organizational capabilities that mediate or facilitate this process. In response to this gap, the present study builds upon existing literature by proposing a dual-path framework in which organizational agility and knowledge management capability act as mediating mechanisms. This approach extends beyond the notion of DT as a standalone driver of performance, and instead positions it within a broader system of interrelated organizational competencies that determine its effectiveness.

Thus, this research contributes not only by validating DT's performance link in a project management context, but also by advancing the theoretical conversation toward a more capability-driven understanding of digital transformation in the construction industry.

H1. *Digital Transformation has a positive effect on Project Management Optimization.*

2.2. Project Management Optimization

Project Management Optimization (PMO) involves enhancing the efficiency, quality, and outcomes of project execution through structured processes, agile methodologies, and strategic alignment [14]. Effective PMO ensures that projects are delivered on time, within budget, and aligned with business objectives [15]. Recent research highlights that digital technologies provide critical support to PMO by automating repetitive tasks, enabling real-time tracking, and enhancing stakeholder engagement [16]. Consequently, digital transformation is increasingly viewed as a catalyst for optimized project management, with empirical studies reporting improvements in productivity, flexibility, and decision accuracy [17].

2.3. Organizational Agility

Organizational Agility (OA) refers to an organization's ability to sense changes in the environment and respond effectively and rapidly [18]. It involves dynamic capabilities that enable firms to reconfigure resources and processes in the face of uncertainty. Digital transformation contributes to OA by increasing transparency, accelerating information flows, and enabling decentralized decision-making [19]. In turn, agile organizations are better positioned to manage projects in turbulent environments, adapting plans and strategies in response to emerging risks and opportunities. Some scholars have proposed that OA may function as a critical mediator between digital initiatives and project-level outcomes, especially in contexts characterized by high complexity and uncertainty [20]. From the perspective of Dynamic Capabilities Theory, OA primarily operationalizes the sensing and seizing dimensions [21]. Agile organizations continuously monitor environmental signals, stakeholder needs, and technological changes (sensing), and are capable of rapidly mobilizing resources, adjusting priorities, and executing timely decisions in response (seizing).

These capabilities allow organizations to identify digital opportunities and act upon them efficiently, particularly within the dynamic contexts of project delivery [22]. Therefore, it is plausible to hypothesize that OA mediates the relationship between DT and PMO.

H2. *Organizational Agility mediates the relationship between Digital Transformation and Project Management Optimization.*

2.4. Knowledge Management Capability

Knowledge Management Capability (KMC) refers to an organization's ability to acquire, share, and apply knowledge effectively to support decision-making and innovation [23]. In the digital era, KMC is increasingly supported by intelligent systems, collaborative platforms, and big data analytics. DT enhances KMC by facilitating knowledge integration across departments, improving data accessibility, and enabling continuous learning [24]. In the context of project management, strong KMC ensures that project teams have timely access to relevant knowledge, lessons learned, and expert insights, which contribute to better planning, problem-solving, and execution [25]. Existing literature suggests that KMC may serve as a critical pathway through which digital transformation enhances project performance. Under the Dynamic Capabilities framework, KMC corresponds to the reconfiguring dimension [26]. By enabling organizations to systematically acquire, integrate, and apply knowledge, KMC supports the continuous transformation of processes, routines, and resource configurations [27]. This ensures project teams can adapt effectively to evolving requirements, disruptions, or innovation needs, thus reinforcing long-term organizational adaptability. Therefore, this research proposes the following hypothesis:

H3. *Knowledge Management Capability mediates the relationship between Digital Transformation and Project Management Optimization.*

Based on the above analysis, the theoretical framework is established as shown in Figure 1.

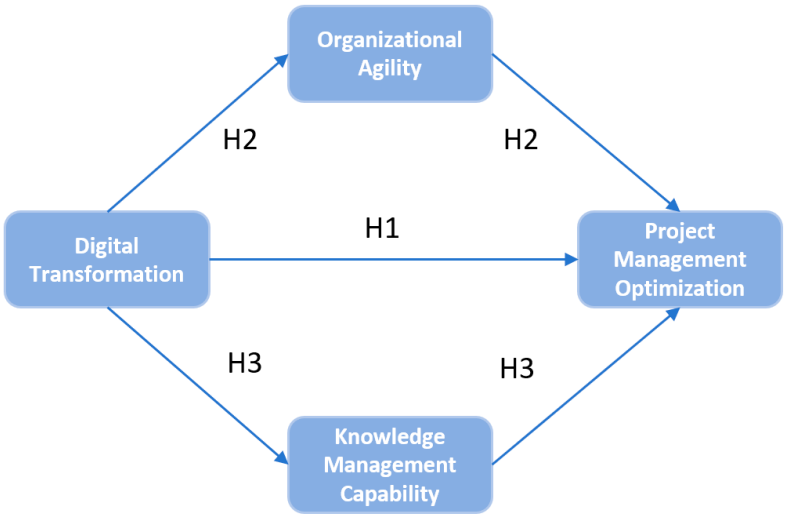


Figure 1. Theoretical model.

3. Research Design

3.1. Questionnaire Design

The questionnaire for this research was designed to capture the key variables related to digital transformation (DT), organizational agility (OA), knowledge management capability (KMC), and project management optimization (PMO). As shown in Table 1, each

construct was measured using four items designed to reflect respondents' experiences and perceptions in the context of construction project management. All items were adapted from established and validated measurement constructs in prior literature and refined through expert consultation, ensuring both conceptual validity and contextual relevance. This approach was guided by a comprehensive review of existing scales in related domains such as digital transformation, dynamic capabilities, and project performance.

Table 1. Construct Measurement Items.

Construct	Code	Measurement Item	References
Digital Transformation (DT)	DT1	Our organization integrates digital technologies (e.g., BIM, cloud systems, IoT) into project processes.	[10,12]
	DT2	Digital tools are widely used to improve coordination and communication in projects.	
	DT3	Real-time data collection and analysis support decision-making in our projects.	
	DT4	We have a clear strategic plan for digital transformation in project management.	
Organizational Agility (OA)	OA1	Our organization can quickly adapt project plans in response to unexpected changes.	[19,21]
	OA2	Decision-making processes in projects are flexible and responsive.	
	OA3	We can rapidly redeploy resources when project conditions change.	
	OA4	Project teams are empowered to make timely decisions without excessive hierarchy.	
Knowledge Management Capability (KMC)	KMC1	We systematically collect and document lessons learned from past projects.	[24–26]
	KMC2	Knowledge and best practices are effectively shared across project teams.	
	KMC3	Our project teams have access to integrated knowledge platforms and databases.	
	KMC4	Project members can quickly locate and apply relevant expertise or information.	
Project Management Optimization (PMO)	PMO1	Our projects are delivered on time and within budget through optimized management.	[15,16]
	PMO2	We continuously improve project processes based on performance feedback.	
	PMO3	Coordination among stakeholders in our projects is efficient and well-structured.	
	PMO4	Our project outcomes align well with predefined objectives and client expectations.	

The survey comprised several sections, each dedicated to one of the core variables. The DT section contained items related to the adoption and integration of digital tools such as BIM, cloud computing, and IoT within the organization. The OA section focused on organizational practices such as flexibility, rapid decision-making, and resource reconfiguration. KMC items assessed the processes of knowledge acquisition, dissemination, and utilization within the organization. Finally, the PMO section included questions related to project performance, specifically in terms of cost, time, quality, and stakeholder satisfaction. All items were measured using a five-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree," which allowed respondents to indicate their level of agreement with each statement.

To enhance the reliability and validity of the instrument, the initial draft of the questionnaire was pre-tested on a small sample of construction professionals. Specifically, the

pilot study involved 20 participants, including project managers, engineers, and site supervisors from medium to large construction firms in Taiwan. The participants represented diverse backgrounds in terms of age, experience, and organizational roles, ensuring a broad perspective on the questionnaire content. Feedback was gathered to ensure clarity, relevance, and comprehensibility of the questions. Based on this feedback, several minor adjustments were made, such as rephrasing ambiguous items, simplifying technical terms, and adding more industry-specific examples to enhance contextual alignment.

3.2. Data Collection and Sample Descriptive

The data for this research were collected through an online survey distributed to construction professionals across various roles, including project managers, engineers, and IT specialists. The target population was drawn from the construction industry in Taiwan, with a particular focus on firms that have made significant investments in digital transformation efforts. The survey was distributed via email and hosted on an online platform, ensuring easy access for participants and the ability to reach a broad geographic area. In total, 312 responses were collected over a four-week period, with a response rate of 70%.

The final sample size of 312 respondents is considered adequate for structural equation modeling (SEM), following the commonly cited rule of thumb by Hair et al. [28], which recommends a minimum of 200 cases or a ratio of at least 10 respondents per estimated parameter. Given the model complexity and number of indicators used, the current sample exceeds this requirement and ensures sufficient statistical power.

Purposive sampling was employed to specifically target professionals in firms with active digital transformation initiatives, ensuring that respondents possessed relevant knowledge and experience to address the research questions. This method was deemed more appropriate than random sampling, which may have included individuals lacking the necessary exposure to digital transformation practices.

The sample was purposively selected to ensure that respondents had relevant experience in digital transformation within construction projects. Demographic information was also collected to analyze the composition of the sample. Among the respondents, 65% were male, and 35% were female. The average age of participants was 38 years, with a range from 25 to 55 years. Respondents had varying levels of experience, with 40% having over 10 years of experience in the construction industry, 35% having 5–10 years, and the remaining 25% having less than 5 years of experience.

In terms of organizational characteristics, the majority of respondents (55%) worked for large construction firms with over 500 employees, while 30% were employed by medium-sized firms (100–500 employees) and 15% were from small firms with fewer than 100 employees. The distribution of respondents by role showed that 45% were project managers, 30% were engineers, and 25% held roles in IT and digital management. This diverse sample provides a comprehensive view of how digital transformation, organizational agility, and knowledge management practices are perceived and implemented across different roles and firm sizes in the construction industry.

4. Data Analysis and Results

4.1. Reliability and Validity Analysis

The questionnaire consisted of 16 items. Reliability refers to the internal consistency of the measurement results, encompassing both the stability of responses when the same participant completes the same items at different times and the agreement among different participants responding to identical items. A widely recognized indicator for assessing internal consistency is Cronbach's alpha, with values above 0.7 generally regarded as

satisfactory [28]. As indicated in Table 2, all five dimensions reported Cronbach's alpha coefficients exceeding 0.7, demonstrating robust reliability across the dataset.

Table 2. Reliability test.

Latent Variables	Observed Variables	Cronbach's α After Deleting Item	Cronbach's α
DT	DT1	0.842	0.849
	DT2	0.855	
	DT3	0.863	
	DT4	0.848	
PMO	PM1	0.878	0.867
	PM2	0.866	
	PM3	0.848	
	PM4	0.892	
OA	OA1	0.887	0.807
	OA2	0.886	
	OA3	0.878	
	OA4	0.890	
KMC	KM1	0.844	0.864
	KM2	0.856	
	KM3	0.871	
	KM4	0.887	

Validity reflects the extent to which the questionnaire items accurately and comprehensively represent the underlying constructs they are intended to measure. To assess construct validity, the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity were applied. According to standard criteria, KMO values are interpreted as follows: excellent (>0.9), good (>0.8), acceptable (>0.7), marginal (>0.6), and inadequate (>0.5) [29]. A significant result from Bartlett's test (Sig < 0.05) indicates that correlations among variables are sufficient for factor analysis. As shown in Table 3, the KMO statistic for the 16 items was 0.921, placing it in the "excellent" category, and Bartlett's test produced a significance value of 0.000, well below the threshold. These results confirm that the questionnaire provides a valid and rigorous measure of the intended theoretical constructs. All statistical analyses were conducted using IBM SPSS Statistics (Version 26) and AMOS (Version 24). SPSS was employed for descriptive statistics, reliability testing (Cronbach's alpha), and validity assessments (KMO and Bartlett's test), while AMOS was used for confirmatory factor analysis (CFA) and SEM.

Table 3. Validity test.

KMO value		0.921
Bartlett sphericity test	Approximate chi-square	2974.5
	Degree of freedom	198
	Significance level	0.000

4.2. Scale Correlation Testing

To examine the underlying structure of the measurement items, a Principal Component Analysis (PCA) with varimax rotation was conducted. As shown in Table 4, the rescaled component loadings revealed a clear three-factor solution consistent with the theoretical model. Items DT1-DT4 exhibited strong loadings on the first component (ranging from 0.725 to 0.813), indicating they reliably capture the construct of Digital Transformation. Items PM1–PM4 also loaded substantially on this component, suggesting a close empirical relationship between digital practices and perceived project management outcomes.

The second component was primarily defined by OA1–OA4 and KM1, with loadings above 0.70, supporting the distinctiveness of Organizational Agility within the model. Meanwhile, KM3 demonstrated a dominant loading (0.924) on the third component, reinforcing the construct validity of Knowledge Management Capability. Cross-loadings were minimal, and no significant overlaps were observed, suggesting that the items are well differentiated across factors. These results support the structural validity of the proposed measurement model.

Table 4. Rotated composition matrix.

Item	Original Ingredients			Rescale Ingredients		
	1	2	3	1	2	3
DT1	0.644	0.180	0.080	0.770	0.215	0.095
DT2	0.576	0.163	0.136	0.747	0.212	0.177
DT3	0.600	0.219	0.202	0.725	0.265	0.245
DT4	0.687	0.210	0.101	0.809	0.247	0.119
PM1	0.679	0.375	0.045	0.651	0.359	0.043
PM2	0.607	0.209	0.148	0.756	0.261	0.184
PM3	0.690	0.209	0.162	0.813	0.247	0.191
PM4	0.566	0.151	0.235	0.739	0.197	0.306
OA1	0.239	0.679	0.079	0.249	0.705	0.082
OA2	0.208	0.789	0.185	0.213	0.809	0.190
OA3	0.177	0.810	0.171	0.187	0.856	0.180
OA4	0.351	0.651	0.120	0.379	0.702	0.129
KM1	0.277	0.820	0.097	0.288	0.853	0.101
KM2	0.446	0.320	0.435	0.495	0.355	0.483
KM3	0.207	0.163	0.992	0.193	0.152	0.924
KM4	0.399	0.204	0.405	0.491	0.250	0.498

4.3. Theoretical Model Testing

To assess the construct validity of the measurement model, a Principal Component Analysis (PCA) was initially performed. The results supported a clear four-factor solution consistent with the proposed theoretical structure. Items loaded strongly onto their respective components with minimal cross-loadings, indicating adequate discriminant validity. Following this, Confirmatory Factor Analysis (CFA) was conducted to further validate the measurement model. As shown in Table 5, the model demonstrated a satisfactory overall fit: $\chi^2 = 246.609$, df = 99, $\chi^2/df = 2.491$, GFI = 0.925, AGFI = 0.894, CFI = 0.906, and RMSEA = 0.071. These indices meet or exceed commonly accepted thresholds, suggesting a reasonably good model fit [30].

Table 5. Model fitness index.

Fitness Indexes	χ^2	Df	χ^2/ Df	GFI	AGFI	CFI	RMSEA
Requirement	-	-	<3	>0.8	>0.8	>0.9	<0.10
Results	246.609	99	2.491	0.925	0.894	0.906	0.071

In Table 6, standardized factor loadings for all items exceeded 0.56 and were statistically significant ($p < 0.001$), indicating strong item reliability. Composite reliability (CR) values for each latent construct exceeded the acceptable threshold of 0.70, with values ranging from 0.774 to 0.880, and average variance extracted (AVE) values mostly surpassed the 0.50 benchmark, further supporting convergent validity. These results confirm that the measurement model exhibits both strong reliability and construct validity, providing a solid foundation for subsequent structural equation modeling.

Table 6. Results of CFA.

Facet	Path	Facet	UNSTD	STD	S.E.	C.R.	*p*	CR	AVE
OA1	<---	OA	1	0.666	-	-	-	0.859	0.606
OA2	<---	OA	1.242	0.817	0.109	11.386	***		
OA3	<---	OA	1.253	0.849	0.107	11.685	***		
OA4	<---	OA	1.112	0.77	0.102	10.872	***		
DT4	<---	DT	1	0.822	-	-	-	0.873	0.633
DT3	<---	DT	0.954	0.805	0.062	15.395	***		
DT2	<---	DT	0.867	0.786	0.058	14.876	***		
DT1	<---	DT	0.92	0.768	0.064	14.418	***		
KM4	<---	KMC	1	0.719	-	-	-	0.774	0.666
KM3	<---	KMC	1.029	0.56	0.121	8.495	***		
KM2	<---	KMC	1.213	0.787	0.104	11.714	***		
KM1	<---	KMC	1.058	0.643	0.109	9.717	***		
PM1	<---	PMO	1	0.663	-	-	-	0.880	0.649
PM2	<---	PMO	0.983	0.847	0.081	12.131	***		
PM3	<---	PMO	1.096	0.892	0.087	12.623	***		
PM4	<---	PMO	0.888	0.801	0.077	11.593	***		

Note: *** indicates $p < 0.001$.

Discriminant validity was assessed using the Fornell-Larcker criterion, which compares the square root of the average variance extracted (AVE) for each construct to its correlations with other constructs. As presented in Table 7, the square roots of the AVE values (bolded on the diagonal) range from 0.778 to 0.816, all of which exceed the corresponding inter-construct correlation coefficients in the lower triangle. For instance, the square root of AVE for Knowledge Management Capability (0.816) is higher than its correlations with Digital Transformation (0.721), Organizational Agility (0.684), and Project Management Optimization (0.702). These results indicate satisfactory discriminant validity, suggesting that each construct is empirically distinct from the others in the model.

Table 7. Correlation coefficient and discriminant validity.

Facet	AVE	OA	DT	KMC	PMO
OA	0.606	**0.778**	-	-	-
DT	0.633	0.687	**0.796**	-	-
KMC	0.666	0.684	0.721	**0.816**	-
PMO	0.649	0.632	0.648	0.702	**0.806**

Note: Bold diagonal values are the square root of AVE.

4.4. Hypothesis Testing

4.4.1. Main Effect Testing

The results of the structural model analysis provide empirical support for several hypothesized main effects. As shown in Table 8, Digital Transformation (DT) had a significant and positive effect on Organizational Agility (OA) (standardized path coefficient = 0.699, $p < 0.001$), supporting H1. Similarly, DT exhibited a strong and significant influence on Knowledge Management Capability (KMC) (standardized coefficient = 0.870, $p < 0.001$), as well as on Project Management Optimization (PMO) (standardized coefficient = 0.889, $p < 0.001$). These findings suggest that digital transformation directly enhances organizational agility, knowledge management capability, and project management performance.

Table 8. Main Effect Test.

Facet	Path	Facet	UNSTD	STD	S.E.	C.R.	*p*
OA	<---	DT	0.643	0.699	0.072	8.968	***
KMC	<---	DT	0.729	0.87	0.065	11.197	***
PMO	<---	DT	0.881	0.889	0.15	5.887	***
PMO	<---	OA	−0.044	−0.041	0.066	−0.659	***
PMO	<---	KMC	0.087	0.074	0.143	0.613	***

Note: *** indicates $p < 0.001$.

In contrast, the direct effects of OA and KMC on PMO were not statistically significant. Specifically, OA had a negligible and non-significant impact on PMO (standardized coefficient = −0.041, $p > 0.05$), and the effect of KMC on PMO was similarly weak (standardized coefficient = 0.074, $p > 0.05$). These results indicate that while DT plays a crucial direct role in improving project management outcomes, the mediating roles of OA and KMC may be limited or require further investigation through indirect effect testing.

Figures 2 and 3 illustrate the structural equation model results using unstandardized and standardized path coefficients, respectively. As shown in Figure 2, the unstandardized path from DT to OA is 0.64, to KMC is 0.73, and to PMO is 0.88. In contrast, the direct paths from OA to PMO (−0.01) and from KMC to PMO (0.09) are not statistically significant. Figure 3 presents the standardized path coefficients: DT → OA = 0.70, DT → KMC = 0.76, and DT → PMO = 0.89, while the paths OA → PMO = 0.04 and KMC → PMO = 0.07 remain weak and non-significant. These results are consistent with the findings reported in Tables 8 and 9, supporting the mediating role of OA and KMC.

Table 9. Mediated effects test results.

Path	Effect Type	Point Estimate	Product of Coefficients		Bootstrap 5000 Time 95%CI Bias Corrected		Bootstrap 5000 Time 95%CI Percentile		Note
			SE	Z	Lower	Upper	Lower	Upper	
DT→ OA→PMO	Indirect effect	0.045	0.039	0.141	0.067	0.121	0.063	0.144	H2 Valid
	Direct effect	0.545	0.187	3.254	0.387	0.605	0.425	0.776	
	Total effect	0.638	0.121	3.854	0.506	0.842	0.491	0.802	
DT→ KMC→PMO	Indirect effect	0.184	0.128	0.521	0.058	0.388	0.021	0.335	H3 Valid
	Direct effect	0.502	0.220	3.954	0.263	0.826	0.346	0.802	
	Total effect	0.641	0.209	4.603	0.572	0.905	0.423	0.826	

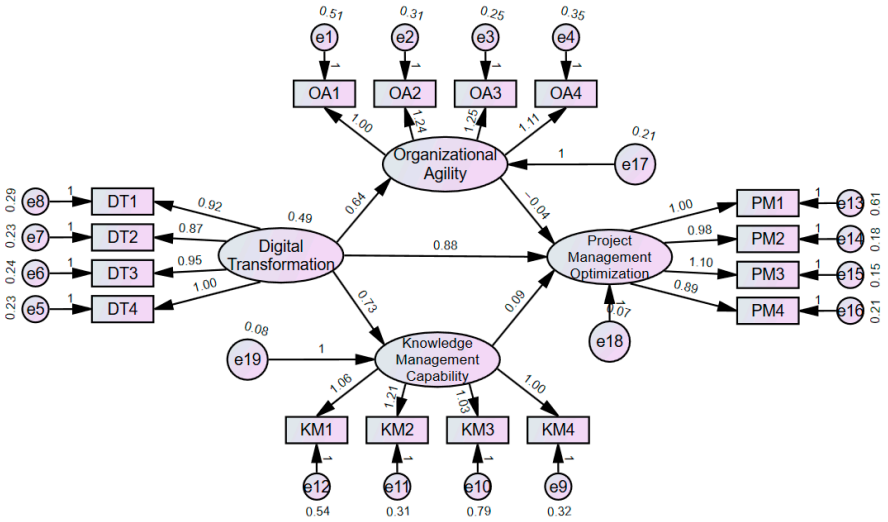


Figure 2. Non-standardized analysis results.

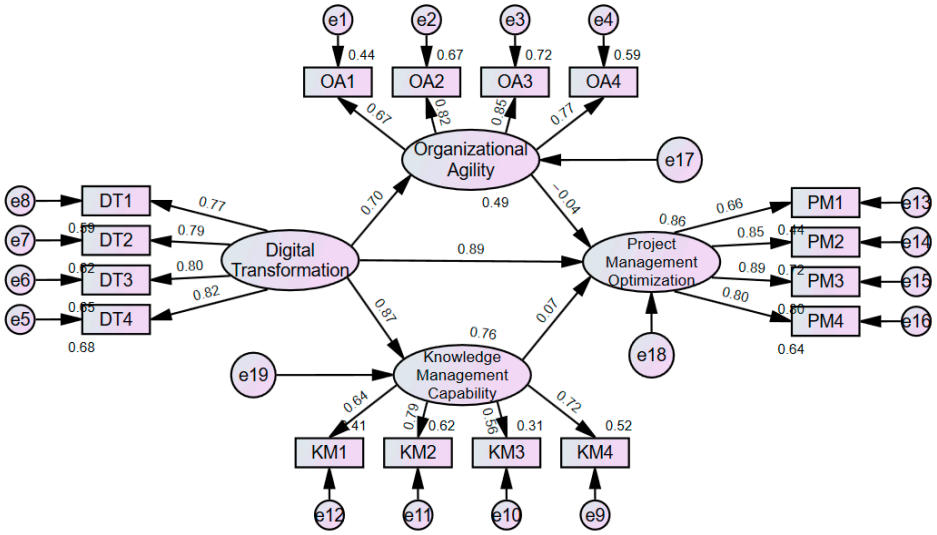


Figure 3. Standardized analysis results.

4.4.2. Mediation Effect Testing

To further examine the indirect mechanisms underlying the influence of Digital Transformation (DT) on Project Management Optimization (PMO), a bootstrap-based mediation analysis with 5000 resamples was conducted. As shown in Table 9, Organizational Agility (OA) was found to partially mediate the relationship between DT and PMO. The indirect effect of DT on PMO via OA was statistically significant (point estimate = 0.045, 95% bias-corrected CI [0.067, 0.121]; percentile CI [0.063, 0.144]), with the confidence intervals not containing zero. Additionally, the direct effect remained significant (0.545, $p < 0.001$), indicating partial mediation and supporting Hypothesis 2.

It is worth noting that although the direct paths from OA and KMC to PMO were not statistically significant (see Table 8), the mediation analysis still revealed significant indirect effects. This phenomenon is statistically plausible, particularly under bootstrap-based mediation testing, which does not require a significant direct path for mediation to exist [31]. The significant indirect effects indicate that DT enhances PMO through OA and KMC, even if OA and KMC alone do not independently predict PMO in the absence of DT. This supports the notion of full mediation, where the mediator transmits the entire effect of the independent variable to the dependent variable.

Similarly, Knowledge Management Capability (KMC) also served as a significant mediator in the DT-PMO relationship. The indirect effect through KMC was 0.184, with a 95% bias-corrected CI of [0.058, 0.388] and a percentile CI of [0.021, 0.335], both excluding zero. The direct path from DT to PMO (0.502, $p < 0.001$) remained significant, indicating that KMC also partially mediates this relationship. These findings confirm both H2 and H3 and underscore the importance of enhancing organizational agility and knowledge capability as mechanisms through which digital transformation improves project management outcomes.

In terms of effect magnitude, the indirect impact of DT on PMO through OA accounted for approximately 7.1% of the total effect (0.045/0.638), while the mediation through KMC explained about 28.7% of the total effect (0.184/0.641). These proportions indicate that, although the direct influence of DT on PMO remains dominant, a meaningful portion of DT's effect operates indirectly through organizational agility and knowledge management capability. Practically, this suggests that improving OA and KMC can substantially strengthen the positive outcomes of digital transformation on project management performance.

5. Discussion

This research set out to examine the mechanisms through which digital transformation (DT) contributes to the optimization of construction project management processes. The empirical results strongly support all three hypothesized relationships, offering both theoretical and practical implications for the construction industry undergoing digital transition.

First, the findings confirm that digital transformation has a significant and positive effect on project management optimization (H1). This reinforces the notion that DT is not merely a technological upgrade, but a strategic enabler that enhances coordination, efficiency, and control in complex project environments. In the context of construction projects-where uncertainty, multi-stakeholder coordination, and time constraints are prevalent-digital tools such as real-time dashboards [32], Building Information Modeling (BIM), and integrated cloud platforms play a critical role in reducing delays, minimizing cost overruns, and improving decision-making. This highlights the critical role of DT as a foundational capability that enables better execution under pressure, rather than a stand-alone solution. In practice, organizations that strategically integrate digital systems into their core operations are more likely to achieve consistent project delivery outcomes.

Second, the results reveal that organizational agility significantly mediates the relationship between DT and project management optimization (H2). This suggests that the benefits of digital transformation are not automatic but are contingent upon an organization's ability to rapidly sense and respond to change. Digitally enabled organizations with agile structures can better adapt to dynamic project demands, reallocate resources efficiently, and mitigate emergent risks. This aligns with recent literature emphasizing the need for adaptive capabilities in digital project environments [33], particularly in construction, where change orders, regulatory shifts, and unexpected field conditions are common. This finding underlines that agility acts as a performance amplifier—organizations that build agility alongside digital capabilities can better exploit the full value of digital transformation. Rather than viewing DT as a one-time change, this suggests the need for continuous organizational adaptation.

Third, the mediating role of knowledge management capability (KMC) was also found to be significant (H3), highlighting the importance of organizational knowledge processes in translating digital investments into performance outcomes. DT enhances the acquisition, sharing, and application of project knowledge-ranging from technical specifications to experiential insights-thereby enabling project teams to learn faster and execute more effectively [34]. The results underscore that project performance improvements are not driven solely by data availability, but by the organization's ability to transform that data into actionable knowledge.

This suggests that knowledge is not merely a byproduct of digitalization, but a core enabler of performance improvement. In practice, organizations must ensure that digital systems are embedded within effective knowledge-sharing cultures and workflows.

Taken together, these insights show that while digital transformation offers substantial potential, its realized impact on project performance depends on how well organizations cultivate complementary capabilities like agility and knowledge management. These findings move the discussion beyond surface-level technology adoption to emphasize the deeper organizational shifts required to achieve meaningful project outcomes.

More importantly, this study advances previous models of digital transformation in construction by empirically validating a capability-based view, which has often been suggested in theory but rarely tested using an integrated mediation framework. In doing so, it addresses a critical gap in the literature—explaining not just whether DT works, but through what internal processes it becomes effective in project environments.

While the findings offer valuable insights into the relationship between digital transformation, organizational agility, and knowledge management in the construction industry, it is important to consider the contextual nature of the sample. Given that all respondents are based in Taiwan, the results may partly reflect regional industry characteristics, such as local project delivery practices, digital maturity, or organizational culture. These factors may influence the generalizability of the findings beyond this setting and warrant attention in future cross-country studies.

6. Implications

6.1. Theoretical Implications

This study contributes to the theoretical understanding of digital transformation in the construction industry by empirically validating a dual-path mediation model that integrates organizational agility and knowledge management capability. The results highlight that digital transformation influences project performance not merely through technological implementation, but through the development of internal dynamic capabilities. This extends existing digital transformation and project management theories by clarifying the mechanisms through which digital strategies are converted into measurable performance outcomes.

6.2. Managerial Implications

For managers, the findings emphasize that digital transformation should be approached as an organization-wide strategic initiative rather than a set of isolated technological upgrades. Managers are encouraged to build agile organizational structures with decentralized decision-making and flexible workflows to effectively manage change in complex project environments. Leadership support and cross-functional collaboration are essential to fostering the responsiveness needed to fully leverage digital initiatives.

6.3. Practical Implications

The findings of this research highlight key strategies for construction project managers seeking to optimize performance through digital transformation. Digital tools alone are insufficient; organizations must foster agility to respond to the dynamic nature of construction projects. Building an agile organizational structure with decentralized decision-making and flexible workflows enables quicker adjustments to changes in project scope and client demands. Moreover, this study underscores the importance of enhancing knowledge management capabilities. Construction firms should develop systems for efficiently capturing, sharing, and applying knowledge, ensuring that data collected through digital tools is effectively utilized for informed decision-making. Integrating digital technologies with strong knowledge management practices enables project teams to make timely, evidence-based decisions that improve efficiency and reduce risk. Finally, organizations should view digital transformation as a strategic enabler, aligning technological investments with cultural and structural changes to maximize project performance and long-term competitiveness.

7. Conclusions and Limitations

This study sheds light on how digital transformation can be strategically leveraged to optimize project management in the construction industry. Moving beyond a technology-centric perspective, the findings demonstrate that the success of digital initiatives depends not only on adopting advanced tools, but also on cultivating internal capabilities—specifically, organizational agility and knowledge management. Theoretically, this research contributes a dual-path mediation model that reveals the organizational mechanisms through which digital transformation translates into operational performance. By

integrating agility and knowledge capability into the digital transformation-performance link, the study deepens our understanding of how internal dynamics condition the value of technological change. Practically, the study offers timely guidance for construction firms navigating digital transition. It suggests that to fully realize returns on digital investments, managers must build agile structures that respond quickly to change, and develop robust systems for capturing and applying project knowledge. Without these capabilities, the potential of digital tools may remain underutilized. Ultimately, this research emphasizes that digital transformation is not simply a matter of technology adoption, but a holistic organizational shift that requires alignment between strategy, structure, and learning capacity.

This study focused on construction firms in Taiwan, providing context-specific insights into digital transformation practices in this region. Future research could expand the scope to include firms from other countries or regions to explore potential differences across contexts. In addition, longitudinal studies and the inclusion of other influencing factors such as leadership style or innovation orientation may offer a more comprehensive understanding of the proposed relationships.

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