INGENIERÍA E INVESTIGACIÓN VOL. 45 No. 3, December (e120958)
DOI: https://doi.org/10.15446/ing.investig.120958

Research Article/Systems and Computer Engineering

Extending the TOE Framework for Digital Twin Adoption in Latin American Project Management

Ampliación del marco TOE para la adopción de gemelos digitales en la gestión de proyectos en América Latina

Gabriel Silva Atencio[1] and Roberto Bonelli Alzamora[2]

ABSTRACT

This study uses an explanatory mixed-methods design to develop and validate a DT–PM (digital twins-project management) maturity framework. To this effect, it combines a cross-sectional survey of 200 professionals working in PM, six in-depth case studies, and, as part of a design science research (DSR) cycle, a representative sample of individuals working in PM. The results extend the technology-organization-environment (TOE) framework by incorporating time-based project factors such as stakeholder movement and workflow plasticity. Taken together, these factors account for 71% of the difference in implementation success. The analysis reveals significant sociotechnical contradictions with direct effects on PM practice, namely an authority paradox and a 15% threshold phenomenon for initial project viability, which provides managers with a clear way to assess whether benefits are being realized. The maturity framework validated in this study is an organized diagnostic tool that ensures that DT capabilities are aligned with project lifecycle stages and PM knowledge areas. This study concludes that successful DT adoption in the cases examined entails not only upgrading technology but also addressing sociotechnical alignment. This involves moving from a technology-centered implementation towards adaptive project governance and organizational learning in environments with limited resources.

Keywords: digital twin, emerging economies, project management, sociotechnical systems, technology adoption, TOE framework

RESUMEN

Este estudio utiliza un diseño explicativo de métodos mixtos para crear y confirmar un marco de madurez DT-PM (gemelos digitales-administración de proyectos). Para ello, combina una encuesta transversal a 200 personas que trabajan en la gestión de proyectos, seis estudios de caso en profundidad y, como parte de un ciclo de investigación en ciencias del diseño (DSR), una muestra representativa de personas que trabajan en la gestión de proyectos. Los resultados se suman al marco tecnología-organización-entorno (TOE) al incluir factores temporales del proyecto, como el movimiento de las partes interesadas y la plasticidad del flujo de trabajo. Estos factores juntos representan el 71 % de la diferencia en el éxito de las implementaciones. Se observan contradicciones sociotécnicas significativas en el análisis que tienen efectos directos en la práctica de la gestión de proyectos, *i.e.*, una paradoja de autoridad y un fenómeno de umbral del 15 % para la viabilidad inicial del proyecto, lo que ofrece a los gestores una forma clara de medir si se está obteniendo un beneficio. El marco de madurez que se valida en este trabajo es una herramienta de diagnóstico organizada que garantiza que las habilidades de DT estén en consonancia con las etapas del ciclo de vida de un proyecto y las áreas de conocimiento de la gestión de proyectos. Este estudio concluye que la adopción exitosa de DT en los casos estudiados significa no solo actualizar la tecnología, sino también abordar la alineación sociotécnica. Esto implica pasar de una implementación centrada en la tecnología a una gobernanza de proyectos adaptable y a un aprendizaje organizacional en entornos con recursos limitados.

Palabras clave: gemelo digital, economías emergentes, gestión de proyectos, sistemas sociotécnicos, adopción de tecnología, marco TOE

Received: June 14th, 2025
Accepted: December 12th, 2025

[1] System Engineer, Universidad Nacional Experimental Politécnica “Antonio José de Sucre” (UNEXPO), PhD in Business Management, Instituto Tecnológico de Costa Rica, Costa Rica, Affiliation: Researcher Professor, Universidad Latinoamericana de Ciencia y Tecnología (ULACIT), Costa Rica. Email: gsilvaa468@ulacit.ed.cr

[2] Business Administration professional, INCAE Business School, Master's in Advanced Business Administration Research, Universidad Politécnica de Catalunya, Spain, Affiliation: Researcher Professor, Universidad Peruana de Ciencias Aplicadas (UPC), Perú. Email: perbonel@upc.edu.pe

DOI: https://doi.org/10.15446/ing.investig.120958

Introduction

As cyber-physical merging changes the way businesses work, digital twin (DT) technology has become an important part of the fourth industrial revolution. A DT is an active, data-driven virtual picture of a real-world thing or system that allows running simulations, performing monitoring tasks, and using predictive analytics in real time [1, 2]. In project-based fields, this technology could greatly change core project management (PM) tasks like prediction scheduling, resource optimization, risk reduction, and stakeholder communication through data display [3].

However, there is still a wide gap between this possibility and its execution, especially in small and medium-sized enterprises (SMEs) in growing sectors. Infrastructure issues and complicated social and technical hurdles that make it hard for people to use technology can delay its acceptance in Latin America and compromise its operation [4]. This work aids in filling three significant gaps in the current academic discussion.

Firstly, there is a deficit regarding the PM context in the existing literature, which mostly focuses on the design of DT technology. This contrasts with the organizational and human factors that affect the way in which people accept DTs in brief project settings that are focused on outcomes. When managing a project, there are certain dates that cannot be changed, teams that only work together for short periods of time, and a clear idea of what the project will include. These factors affect how technology is used in projects, often including ways that are not considered when modeling the use of technology by people within organizations.

Secondly, there is a high level of theoretical misapplication, as studies often use conceptual models involving information systems or manufacturing in project settings without sufficiently adapting them. This creates a difference between tech-centered learning and project-based work, neglecting the way in which project managers use tech in relation to aspects like integration, scope, and communication management [5].

Thirdly, it is clear that many people do not know much about environmental issues. Most adoption models are based on Western nations that are rich and stable. People do not often consider how unstable businesses and society can be in places like Latin America. Here, acceptance often relies on unique social and science factors that have not been thoroughly studied [6, 7]. An example of this is called the *threshold phenomenon* and corresponds to the smallest amount of early success required in order for a project to be considered successful. Moreover, there is the *authority paradox*: when the boss wants things to be done quickly and workers are not open to communication.

This study analyzes the strong link between the new DT technologies that can be developed and the sociotechnical fabric of project-based SMEs in Latin America. Its main contribution is very important: a good DT integration is not only about how advanced a technology is, but also about how well it works with society. Our work examined the influence of aspects such as technological skill, organizational readiness, project timelines, and environmental factors.

The research question that guides this study is as follows: *How do time-based project dynamics and sociotechnical factors affect the drivers, barriers, and outcomes of digital twin adoption in Latin American project management?* To answer this question, we hope to make three contributions: (i) adding time-based project dimensions to the technology-organization-environment (TOE) framework; (ii) finding and describing important sociotechnical contradictions in DT-driven project governance; and (iii) creating and validating a diagnostic DT-PM maturity framework to help practitioners.

Methodology

Using a practical approach aimed at finding solutions to issues in the real world [9, 10], this study used an explanatory sequential mixed-methods design along with a design science research (DSR) cycle. Via DSR, a quantitative poll and qualitative case studies within a three-stage method ensured that the research was thorough, open, and reproducible. This also helped in acquiring a complete picture of what is causing DT demand.

Sequence planning began with a numeric stand aimed at identifying overall trends. Afterwards, a qualitative strand was used to study environmental processes, in parallel with a DSR strand, with the purpose of obtaining actionable findings.

Quantitative strand 1

We conducted a survey including 200 project managers from Latin American SMEs. People who worked in construction, healthcare, and information technology (IT) were purposely selected since these sectors have particular ways to use technology and undertake both simple and complex projects [11]. To qualify, the participants had to have been in charge of projects for at least one year. The survey was a 35-question form based on a broad TOE framework, albeit with an additional construct for time-related factors such as stakeholder movement and workflow plasticity. A 5-point Likert scale was used for all categories. Face validity was tested with 30 pros, and internal consistency was proven (Cronbach's *alpha* > 0.78 for all major categories). Table 1 characterizes the participants.

Table 1. Demographic and professional profile of the survey respondents (N=200)

Characteristic	Category	Frequency (n)	Percentage (%)	Practical DT experience	years in current role	Typical project budget range (USD)	Main PM methodology
Primary role	Project manager	98	49.0	Varied (see below)	5.2 (avg)	$250 K - $5 M	Hybrid (65%)
	Engineer/technical lead	67	33.5	Intermediate (73%)	4.1 (avg)	$100 K - $1 M	Predictive/waterfall (58%)
	Senior executive (CEO/CTO)	35	17.5	Novice (60%)	8,5 (avg)	>$5 M	Agile (42%)
PM experience	<5 years	45	22.5	Novice (89%)	2.3 (avg)	<$500 K	Agile (71%)
	5-10 years	102	51.0	Intermediate (68%)	4.8 (avg)	$500 K - $2 M	Hybrid (70%)
	>10 years	53	26.5	Advanced (40%)	7.5 (avg)	>$2 M	Predictive/waterfall (55%)
DT Familiarity (theoretical)	Novice	72	36.0	Novice: no hands-on use	3.9 (avg)	$300 K - $3 M	Varied

DOI: https://doi.org/10.15446/ing.investig.120958

	Intermediate	105	52.5	Intermediate: used in ≥1 project	5.1 (avg)	$500 K - $4 M	Varied
	Advanced	23	11.5	Advanced: led implementation	6.3 (avg)	$1 M - $10 M+	Varied
Company size (employees)	50-250	128	64.0	Intermediate (55%)	4.5 (avg)	$200 K - $2.5 M	Hybrid (61%)
	251–500	72	36.0	Intermediate (63%)	5.5 (avg)	$750 K - $5 M	Predictive (52%)
Primary sector	Construction	85	42.5	Intermediate (65%)	5.8 (avg)	$1 M - $10 M+	Predictive/waterfall (82%)
	Healthcare	60	30.0	Novice (70%)	4.2 (avg)	$500 K - $3 M	Hybrid (78%)
	IT	55	27.5	Intermediate (75%)	4.0 (avg)	$200 K - $1.5 M	Agile (85%)

Source: Authors

Strand 2 (qualitative)

As shown in Table II, six instrumental case studies were selected using maximum variation sampling in order to analyze a range of DT adoption results. Each case involved a SME that had been actively implementing this technology for more than six months.

As part of the data collection, 45 semi-structured conversations with important stakeholders were conducted, as well as system observations and analyses of project documents. The interviews were transcribed and studied using NVivo 14 [12].

Table II. Descriptive profile of qualitative case studies

Case ID	Sector	Project scope & value	Primary PM challenge addressed	DT implementation – focus & tools	Project phase with DT deployment	Key PM tools integrated	Observation period	Key interviewees (positions)
C-A	Construction	45-story commercial tower ($120 M)	Chronic schedule delays due to uncoordinated trades and delayed material delivery	Predictive scheduling and logistics: IoT sensor data (crane, deliveries) fed into a 4D building information modeling (BIM) model for progress tracking and clash detection	Execution	Primavera P6, BIM 360	14 months	Project director, site engineer, DT specialist, supply chain manager
C-B	Healthcare	Regional hospital network digitization ($35 M)	Patient flow bottlenecks causing resource idleness (operating rooms, ORs; imaging) and extended wait times	Patient flow and resource allocation modeling: simulated patient pathways using historical electronic health RECORD (EHR) data to optimize staff and facility scheduling	Planning	MS Project, hospital information system	11 months	Chief medical officer, it project manager, operations manager, head nurse
C-C	Manufacturing	Automated automotive assembly line retrofit ($28 M)	High defect escape rate and unpredictable machine downtime impacting production quotas	Real-time quality control and predictive maintenance: computer vision-based inspection integrated with programmable logic controller (PLC) data for anomaly detection and failure forecasting.	Execution	SAP PM, manufacturing execution system (MES), Andon system	9 months	Plant manager, process engineer, maintenance lead, data analyst
C-D	IT	Enterprise software development platform ($15 M)	Inefficient DevOps pipeline leading to slow-release cycles and post-deployment bug resolution	DevOps pipeline monitoring and bug prediction: containerized DT mirrored the continuous integration (CI)/continuous deployment (CD) pipeline to simulate commits and identify integration risks	Planning/execution	Jira, GitLab, Kubernetes Dashboard	12 months	Chief technology officer (CTO), scrum master, lead developer, DevOps engineer
C-E	Construction	Major river bridge construction and monitoring ($85 M)	Risk of structural defects and long-term maintenance cost overruns	Structural health monitoring (SHM): network of strain gauges and accelerators created a live DT for stress analysis and maintenance forecasting	Execution and closure	AutoCAD Civil 3D, asset management database	18 months	Lead civil engineer, asset manager, data scientist, safety officer
C-F	Healthcare	Multi-site phase III clinical trial management ($22 M)	Risk of protocol deviations and patient dropout, jeopardizing trial validity and timelines	Protocol adherence and risk simulation: DT modeled patient recruitment, treatment adherence, and site performance against the trial master protocol	Planning/execution	Clinical trial management system (CTMS), electronic data capture (EDC)	10 months	Clinical research manager, data manager, bioinformatics

Source: Authors

DOI: https://doi.org/10.15446/ing.investig.120958

Strand 3 (DSR)

Following the guidelines of problem relevance, design as a product, and thorough evaluation [13], our DT-PM maturity framework was created and validated through a three-cycle DSR method (Fig. 1).

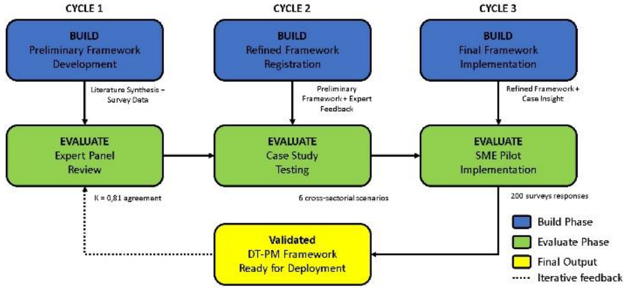

Figure 1. Iterative DSR evaluation cycles for validating the DT-PM maturity framework
Source : Aparicio *et al.* [34].

- In the first step of the first cycle, we identified a problem and elaborated the first design, using information from the literature and the first themes of a poll in order to create a framework prototype.
- In the second step (expert refinement), a group of eight separate professionals from both academia and industry used a Delphi-like method to assess and improve the prototype, resulting in a high inter-rater agreement (Cohen's $\kappa = 0.81$) [12].
- In the third stage (artifact testing and finalization), the six case studies were tested with the improved framework, which proved to be a useful tool for determining why usage is slow and for planning future steps. Fig. 2 shows the final framework structure.

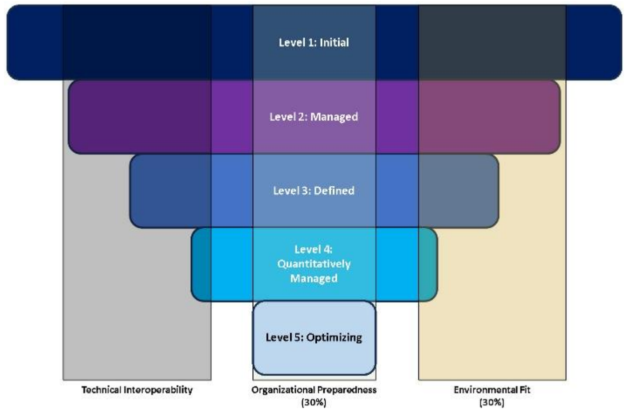

Figure 2. The DT-PM maturity framework structure
Source: Authors

Each strand was examined using a specific method. Analysis of Variance (ANOVA) and hierarchical regression were used to evaluate quantitative data and identify the most important factors for adoption. Structural equation modeling (SEM) was then used to check the fit of the extended TOE model. Qualitative data were analyzed in NVivo 14 using a mixed inductive-deductive theme method. Inter-coder reliability checks showed an 80% agreement [14].

Methodological triangulation brought together the results of all three lines at points that had been previously defined. As an example, the questioning methods for the case studies were based on poll data (*e.g.*, regarding aspects such as help from middle management). On the other hand, qualitative theories like the authority paradox helped to make sense of the numeric relationships seen in the poll data. The main synthesis method in the DSR process turned practical, firsthand information into an organized, useful object called the *DT-PM maturity framework*. By striking a balance between general applicability and a deep understanding of the case, this combined approach increased the percentage of truth, as it merged evidence from different sources.

Results

An analysis of performance data showed that DT acceptance alters major project parameters across all domains. To summarize, Table III shows the major changes in performance, the major issues identified, and how they impacted some parts of PM.

Table III. DT Impact on project performance by sector and linked PM knowledge area

Sector	Key performance Δ (Mean)	Primary barrier and linked PM knowledge area	Implication for core PM processes
Construction	-28.3% project duration (standard deviation=5.1) -30-45% planning errors	Union resistance (65%) PM area: resource and stakeholder management	Enables predictive scheduling but necessitates enhanced communication planning and stakeholder engagement strategies to align all parties with data-driven workflows.
Healthcare	-18.7% process duration (SD=6.9) +22% resource utilization	Clinician buy-in (58%) PM area: integration and stakeholder management	Highlights the critical nature of change management and stakeholder analysis in clinical projects. DT tools require integration protocols that respect professional autonomy and clinical pathways.
IT	60-80% faster debugging cycles +45% cost overrun (avg)	Vendor lock-in (45%) PM area: procurement and cost management	Makes it clear that looking into the seller and deal choices is very important when buying plans. The total cost of purchase needs to be weighed against the risk of depending on technology.
Manufacturing	-40% machine downtime -25% defect escape rate	Workforce upskilling gap (82%) PM area: resource and quality management	Directly impacts quality control and knowledge transfer. Successful adoption is contingent on integrating targeted training and data literacy into the project's resource management plan.

Source: Authors

DOI: https://doi.org/10.15446/ing.investig.120958

Predictive clash detection aided in keeping the schedule, but the fact that unions often fought against it constituted a major stakeholder management problem: people saw openness as a danger [15]. In healthcare, growth was slowed by issues with handling change in professional teams. This shows that today's world needs to make sure that merger methods support professional freedoms. In IT, faster tests showed that DT was a good way to keep projects on track and high-quality. On the other hand, having to pay more because of vendor lock-in showed that project buying management was not working properly [16].

A hierarchical regression model (R^2=0.71) showed that using a broader TOE approach that adds time-based project factors is useful for identifying the issues at play. The main signs were:

- The technical dimension of interoperability (β=0.32, p=0.002).
- The organizational dimension, *i.e.*, support from middle management (β=0.28, p=0.008).
- The project's time-related aspects: ΔR^2=0.11 for stakeholder movement and β=0.29, p=0.003 for process flexibility.

These results change the adoption debate. They show that success depends on the organization's capabilities as well as on how well the technology fits the temporary needs of the project and the everchanging group of people that are interested in it.

Our mixed-methods study showed two major sociotechnical issues that complicate PM.

First, there is the authority paradox: 68% of middle managers admitted that DT analytics could speed up project decisions by 52% on average, but, at the same time, they were not willing to adopt the process openness required to reap the benefits of this technology. Case data (C-A, C-B) showed that stakeholders saw openness as a loss of informal power and a rise in responsibility, constituting a clear stakeholder management problem.

Second, the survival analysis found a 15% threshold phenomenon ($\chi^2(1)$=6.33, p=0.012). There was an 80% chance that projects would be terminated if they failed to report at least a 15% improvement in key performance measures (such as adherence to the plan) within nine months. This allowed project benefit management to perform early performance checks.

Fig. 3 uses a DT adoption paradox matrix to illustrate these tensions. It shows how technology might affect PM based on the level of pushback in the company. It is hard to deal with changes in cases in the high-resistance/high-potential region (C-B), but it is easier to combine cases that are in the low-resistance/high-potential area (C-D).

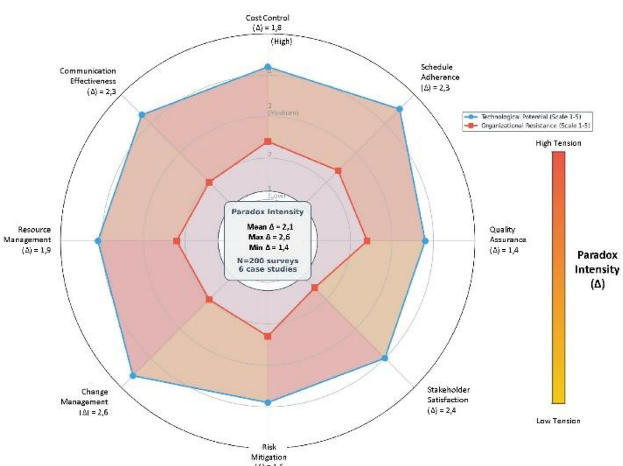

Figure 3. The DT adoption paradox matrix: technology potential *vs.* organizational resistance
Source: Authors

Our study got a better sense of what the problems were after looking at the six cases evaluated with the accepted DT-PM maturity framework. For example, in cases C-B, a gap was identified in level 4 (advanced) growth and level 2 organizational readiness. Doctors found it difficult to use the new technology because of a lack of synchronization. As a result, management decided to focus on organized attempts to change the situation rather than on technological growth. This was also an indicator of clinical acceptance issues.

The results were greatly influenced by the situation in Latin America. Relational management proved to be very important; the group's average performance success rate was only 41%, much lower than the world's 72% standard. It took, on average, 32% more time than the world average (p=0.012) to obtain a return on investment. This was mostly due to problems with infrastructure. However, in 54% of the cases, mixed-cloud methods helped to reduce delays, demonstrating their potential in managing risks when few resources are available.

There are both numbers and words in the mix, which shows that sociotechnical unity—not just technical skill—is the key to good acceptance. This link in short-term organizational systems can be explained by the wider TOE theory with time-based project dynamics.

Discussion

This study looks at the use of decision theory in PM as an important sociotechnical alignment problem that goes beyond issues involving technology. Our findings are relevant for three main areas: they add to theories of adoption, they identify problems that are particular to the project, and they yield a useful model for identifying failures in an application.

When partner movement and workflow freedom are incorporated as time-based factors, the TOE framework can explain 71% of the difference in project performance (p<0.001, ΔR^2 = 0,22). This theoretical addition forms a very important connection between unchanging models of adoption and project-based work, which usually features a changing structure [5]. This premise is based on systems theory and shows that technology can be used in certain places where conditions change over time [17].

The differences found in this study offer new ideas to understand how digital change works in businesses that are only temporary. 68% of managers want quick choices but are not open to the transparency needed to realize them (*i.e.*, the authority paradox), suggesting a structure clash between directive and facilitative roles that directly affects change and stakeholder management processes [18]. Furthermore, the 15% threshold phenomenon ($\chi^2(1)$=6.33, p=0.012) indicates when a project should be continued using standards based on cognitive load, which is a way for benefit realization management to perform accurate measurements from the outset [8].

Criticism related to fragmentation is addressed through our sequential explanatory mixed-methods design that uses deep triangulation and combines overall trends, setting-based mechanisms, and design rules [5, 19]. During the parallel DSR cycle, the DT-PM maturity framework was both created and validated (κ=0.81). This is a product that turns theory into an organized and usable diagnostic tool [13, 20]. Fig. 4 shows that this framework adds weighted factors that are unique to DT

DOI: https://doi.org/10.15446/ing.investig.120958

integration in project settings [21, 22], going beyond basic development models.

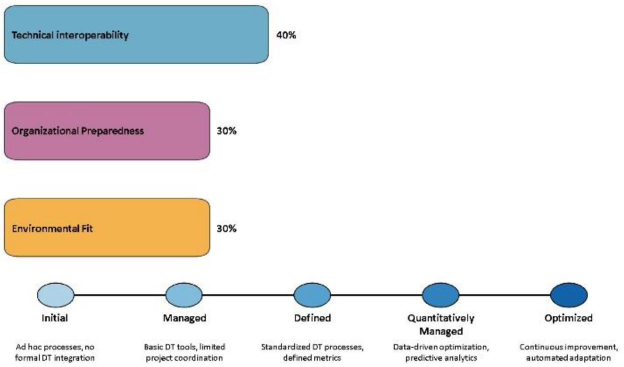

Figure 4. Structure of the DT-PM maturity framework
Source: Authors, informed by maturity model principles [23, 24] and the TOE framework [25]

The paradox matrix (Fig. 3) included in this article is a useful tool that helps practitioners identify and mitigate adoption risks before they materialize in important areas of PM knowledge, like managing communication (Δ=2.3) and controlling costs (Δ=1.8).

In light of the above, Latin America needs to elaborate plans that are unique to each area. Here, it takes 32% longer to obtain a return on investment (ROI) than the global average (p=0.012), and relationship success rates are lower (41 *vs.* 72% in general). This proves that social capital and physical readiness are quite significant [4]. Still, using both public and private cloud services reduced delays in 54% of cases, suggesting that technology can help when businesses are short on time or cash. This makes it easier for digital change to fit the ideas of long-term growth [26].

In this study, we only covered the first two years of implementation, showcasing the initial use of the technology but not how it gradually becomes a part of society and people's lives. Our results might not work as well in companies that are based on art or services because the study was mostly (52%) about industrial and building activities. Longitudinal tests in the future should aim to find out how the authority paradox changes as DT technology grows older. The 15% threshold must be proven to be true in both megaprojects and in places where nothing is happening economically. Modern society can learn more about environmental factors by studying the pros and cons for both developing and developed nations. Moreover, using the paradox matrix on other project management tools like artificial intelligence-driven analytics could help to determine the strength of our sociotechnical framework.

Conclusions

This study shows that using DT in PM creates a sociotechnical coordination problem, and that the way in which technological, organizational, and time-based project factors interact decides how well it is put into action. For small Latin American businesses, merely improving the technical infrastructure is not enough; they need to be able to learn as a company and change their workflows based on lessons from data [4, 27].

The main theoretical contribution of this work lies in its expansion of the TOE framework to include time-based aspects that have been shown to be significant and valid. Stakeholder movement (ΔR^2=0.11) and workflow flexibility (β=0.29, p=0.003) explain 71% of the difference regarding the way in which implementations are carried out. This finding helps to connect static adoption models with the dynamic reality of project-based work [5, 28].

Our observational study shows two important sociotechnical issues. The authority paradox creates a structuration conflict where the wish of managers to speed up decision-making appears to oppose process clarity and openness [29]. The 15% threshold phenomenon ($\chi^2(1)$=6.33, p=0.012) sets a cognitive-load-based milestone for whether or not a project can work, providing project managers with a clear way to measure progress towards benefits from the outset [8].

Methodologically, this study improves mixed-methods research in sociotechnical areas by combining different techniques with a strong approach. The explanatory sequence design, which included a 200-person poll, six case studies, and a DSR cycle, was useful for finding common ground in many different areas, such as general patterns, context-based causes, and useful design rules [10, 13, 20].

The DT-PM maturity framework, which was proven to be valid, with a high inter-rater agreement score of 0.81 after three test and revision rounds, provides important help in practice. This assessment tool offers organizations an organized technique to navigate five levels of development. Each level is based on the following aspects, with their corresponding percentages: technical interoperability (40%), organizational readiness (30%), and environmental fit (30%) [21, 22]. Project managers can use the paradox matrix (Fig. 3) to effectively find and lower acceptance risks in certain areas of PM knowledge.

The regional results show the need for contextualized tactics. ROI takes a lot longer in Latin America (*i.e.*, 32% longer, p=0.012), with a lower relationship success rate (41 *vs.* 72% worldwide). This is a sign of the value of social capital and infrastructure [4]. Adaptive solutions can work in places with few resources available [26]; the fact that delays were shortened in 54% of the cases by using both public and private cloud methods is proof of this.

The 24-month study period, as well as the fact that over half of the studied industries are building and manufacturing companies (52%) indicate the need for further research. As the growth of DT increases, future studies should examine how sociotechnical conflicts evolve. The 15% threshold should be validated in both megaprojects and other types of projects that do not involve businesses. Modern society can learn more about foreign factors by looking at what makes rich and developing countries different. Using the paradox matrix on other new project management tools, like artificial intelligence-driven data analysis or blockchain for contract management, could show whether the framework is generally useful and if it is strong enough to yield trustworthy results [7, 18].

Lastly, this research shifts the focus from technology determinism to business learning and adaptable governance. When it comes to project-based work in emerging countries, which are always changing, making sure that professional skills are in line with people and structure during digital change constitutes a successful combination. This work provides a detailed and useful view of how to move forward with digital innovation.

CRediT author statement

Gabriel Silva-Atencio: conceptualization, methodology, validation, data curation, writing (original draft, review, and editing)

Roberto Bonelli-Alzamora: writing (review and editing), visualization, project administration.

DOI: https://doi.org/10.15446/ing.investig.120958

Conflicts of interest

The authors declare no conflict of interest.

Data availability

All the research data is provided in the article.

Statement on artificial intelligence (AI)

The authors did not employ AI technologies to prepare the manuscript, analyze data, or create images.

References

[1] Y. Pan and L. Zhang, "A BIM-data mining integrated digital twin framework for advanced project management," *Autom. Constr.,* vol. 124, art. 103564, 2021. https://doi.org/10.1016/j.autcon.2021.103564

[2] J.-F. Yao, Y. Yang, X.-C. Wang, and X.-P. Zhang, "Systematic review of digital twin technology and applications," *Vis. Comput. Ind. Biomed. Art,* vol. 6, no. 1, art. 10, 2023. https://doi.org/10.1186/s42492-023-00137-4

[3] M. Attaran and B. G. Celik, "Digital Twin: Benefits, use cases, challenges, and opportunities," *Decis. Anal. J.,* vol. 6, art. 100165, 2023. https://doi.org/10.1016/j.dajour.2023.100165

[4] J. P. Tamvada, S. Narula, D. Audretsch, H. Puppala, and A. Kumar, "Adopting new technology is a distant dream? The risks of implementing Industry 4.0 in emerging economy SMEs," *Technol. Forecast. Soc. Change,* vol. 185, art. 122088, 2022. https://doi.org/10.1016/j.techfore.2022.122088

[5] S. R. Newrzella, D. W. Franklin, and S. Haider, "5-dimension cross-industry digital twin applications model and analysis of digital twin classification terms and models," *IEEE Access,* vol. 9, pp. 131306–131321, 2021. https://doi/org/10.1109/ACCESS.2021.3115055

[6] D. Wu *et al.*, "Digital twin technology in transportation infrastructure: A comprehensive survey of current applications, challenges, and future directions," *Appl. Sci.,* vol. 15, no. 4, art. 1911, 2025. https://doi.org/10.3390/app15041911

[7] H. Zribi, B. A. T., E. A., Y. Hani, B. Bechir Graba, and A. Elmhamedi, "Industry 4.0: Digital twins characteristics, applications, and challenges in-built environments," *Prod. Manuf. Res.,* vol. 13, no. 1, art. 2456277, 2025. https://doi.org/10.1080/21693277.2025.2456277

[8] J. Sweller, S. Roussel, and A. Tricot, "Cognitive load theory and instructional design for language learning," *in The Cambridge Handbook of Working Memory and Language,* J. W. Schwieter and Z. Wen, Eds. Cambridge, UK: Cambridge University Press, 2022, pp. 859–880. https://doi.org/10.1017/9781108955638.045

[9] E. Miehling *et al.*, "Agentic ai needs a systems theory," arXiv preprint arXiv:2503.00237, 2025. https://doi.org/10.48550/arXiv.2503.00237

[10] M. W. Grieves, "Digital twins: Past, present, and future," *in The Digital Twin,* N. Crespi, A. T. Drobot, and R. Minerva, Eds. Cham, Germany: Srpinger, 2023, pp. 97–121. https://doi.org/10.1007/978-3-031-21343-4_4

[11] E. VanDerHorn and S. Mahadevan, "Digital twin: Generalization, characterization and implementation," *Decis. Support Syst.,* vol. 145, art. 113524, 2021. https://doi.org/10.1016/j.dss.2021.113524

[12] M. Singh, E. Fuenmayor, E. P. Hinchy, Y. Qiao, N. Murray, and D. Devine, "Digital twin: Origin to future," *Appl. Syst. Innov.,* vol. 4, no. 2, art. 36, 2021. https://doi.org/10.3390/asi4020036

[13] T. D. Nguyen and S. Adhikari, "The role of BIM in integrating digital twin in building construction: A literature review," *Sustainability,* vol. 15, no. 13, art. 10462, 2023. https://doi.org/10.3390/su151310462

[14] J. Whyte *et al.*, "Using digital twins for managing change in complex projects," *in Proc. Int. Conf. Sustain. Dev. Smart Built Environ.,* 2024, pp. 1575–1582. https://doi.org/10.48550/arXiv.2402.00325

[15] S. Infante, J. Robles, C. Martín, B. Rubio, and M. Díaz, "Distributed digital twins on the open-source OpenTwins framework," *Adv. Eng. Inform.,* vol. 64, art. 102970, 2025. https://doi.org/10.1016/j.aei.2024.102970

[16] C. Lin and P. Critchley, "Quantum Computing and Digital Twins," *in Hybrid Healthcare*, M. Al-Razouki and S. Smith, Eds. Cham, Germany: Springer, 2022, pp. 199–214. https://doi.org/10.1007/978-3-031-04836-4_14

[17] K. Lyytinen, B. Weber, M. C. Becker, and B. T. Pentland, "Digital twins of organization: implications for organization design," *J. Organ. Des.,* vol. 13, no. 3, pp. 77–93, 2024. https://doi.org/10.1007/s41469-023-00151-z

[18] J. Zhou, S. Zhang, and M. Gu, "Revisiting digital twins: Origins, fundamentals, and practices," *Front. Eng. Manag.,* vol. 9, no. 4, pp. 668–676, 2022. https://doi.org/10.1007/s42524-022-0216-2

[19] H. H. Hosamo, H. K. Nielsen, A. N. Alnmr, P. R. Svennevig, and K. Svidt, "A review of the Digital Twin technology for fault detection in buildings," *Front. Built Environ.,* vol. 8, art. 1013196, 2022. https://doi.org/10.3389/fbuil.2022.1013196

[20] M. A. Guinea-Cabrera and J. A. Holgado-Terriza, "Digital twins in software engineering—A systematic literature review and vision," *Appl. Sci.,* vol. 14, no. 3, art. 977, 2024. https://doi.org/10.3390/app14030977

[21] M. Grieves, "Digital twins and their role in reengineering engineering education," *in Digital Twin: Fundamentals and Applications,* S. Sabri, K. Alexandridis, and N. Lee, Eds. Cham, Germany: Springer, 2024, pp. 237–261. https://doi.org/10.1007/978-3-031-67778-6_11

[22] C. Su, Y. R. Han, X. Tang, Q. Jiang, T. Wang, and Q. He, "Knowledge-based digital twin system: Using a knowlege-driven approach for manufacturing process modeling," *Comput. Ind.,* vol. 159-160, art. 104101, 2024. https://doi.org/10.1016/j.compind.2024.104101

[23] H. Ünlü, O. Demirörs, and V. Garousi, "Readiness and maturity models for Industry 4.0: A systematic literature review," *J. Softw. Evol. Process,* vol. 36, no. 7, art. e2641, 2024. https://doi.org/10.1002/smr.2641

[24] E. J. Omol, L. W. Mburu, and P. A. Abuonji, "Digital maturity assessment model (DMAM): Assimilation of design science research (DSR) and capability maturity model integration (CMMI)," *Digit. Transform. Soc.,* vol. 4, no. 2, pp. 128–152, 2024. https://doi.org/10.1108/DTS-04-2024-0049

[25] A. w. AL-Khatib, A. Shuhaiber, I. Mashal, and M. Al-Okaily, "Antecedents of Industry 4.0 capabilities and technological innovation: a dynamic capabilities perspective," *Eur. Bus. Rev.,* vol. 36, no. 4, pp. 566–587, 2023. https://doi.org/10.1108/EBR-05-2023-0158

[26] D. de Kerckhove, "The personal digital twin, ethical considerations," *Philos. Trans. Roy. Soc. A,* vol. 379, no. 2207, art. 20200367, 2021. https://doi.org/10.1098/rsta.2020.0367

[27] J. Barata and I. Kayser, "How will the digital twin shape the future of industry 5.0?," *Technovation,* vol. 134, art. 103025, 2024. https://doi.org/10.1016/j.technovation.2024.103025

[28] C. Kober, F. Gomez Medina, M. Benfer, J. P. Wulfsberg, V. Martinez, and G. Lanza, "Digital twin stakeholder

DOI: https://doi.org/10.15446/ing.investig.120958

communication: Characteristics, challenges, and best practices," *Comput. Ind.,* vol. 161, art. 104135, 2024. https://doi.org/10.1016/j.compind.2024.104135

[29] H. Zhu, B.-G. Hwang, Y. Z. Tan, and F. Wei, "Building on digital twin: Overcoming barriers and unlocking success in the construction industry," *J. Constr. Eng. Manag.,* vol. 150, no. 10, art. 04024142, 2024. https://doi.org/10.36680/j.itcon.2024.008