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PRACTICES AND BARRIERS TO THE ADOPTION OF DIGITAL TWIN CONSTRUCTION IN LATIN AMERICA

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ABSTRACT

The Digital Twin Construction paradigm, built on existing concepts of Lean project production systems, Building Information Modelling, Artificial Intelligence, and Automated data acquisition, proposes a new mode of construction management that leverages real-time insights and predictive analytics to optimise production flow and mitigate risks proactively. Its potential adoption in Latin America has yet to be explored. This study examines current practices and barriers to implementing Digital Twin Construction-based production planning and control systems. A survey was developed and validated through the Delphi method, involving an expert panel to ensure reliability and relevance. According to the survey's results and experts' opinions, technological, organisational, cultural, and economic factors have impacted the adoption of Digital Twin Construction, including lack of robust digital infrastructure, gaps in knowledge, and resistance to innovation. The research findings provide practical recommendations to support future research and industry efforts.

KEYWORDS

Lean construction, Digital Twin, Digital Twin Construction, Planning and Control, Automated Data Acquisition, and Building Information Modelling.

INTRODUCTION

The construction industry faces a transformative phase driven by integrating advanced digital technologies. Digital Twin (DT) has arisen as a critical innovation, allowing physical and virtual environments to synchronise (Adebiyi et al., 2024). DT facilitates real-time data exchange, allowing for enhanced decision-making, predictive analytics, and optimisation of construction processes (Rosen et al., 2015). In the construction context, adopting DT has become progressively essential. DT has been implemented in different industries, including

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manufacturing, agriculture, aerospace, and others. Building on the DT foundations, Digital Twin Construction (DTC) paradigm has been developed, offering a new approach to construction production management. DTC paradigm builds upon Lean construction, Building Information Modelling (BIM), Artificial Intelligence (AI), and Automated Data Acquisition (ADA) technologies to create dynamic, data-driven construction management systems. The distinction between DTC and BIM is essential for understanding the study's focus. BIM provides a structured, static digital model for planning, design, and coordination, while DTC enhances this capability by incorporating AI-driven analytics and ADA.

DTC-based systems implementation could vary widely across regions, with Latin America (LATAM) presenting unique challenges and opportunities. The LATAM construction industry has made partial progress in adopting BIM and Lean Construction to enhance efficiency, reduce waste, and improve project outcomes. While Chile, Brazil, Mexico, and Colombia lead in BIM implementation through national standards and government initiatives like Chile's PlanBIM and Brazil's BIM BR Strategy, the region lags behind Europe and North America in technological innovation (Machado et al., 2021). This gap hinders the adoption of AI and ADA systems, making DTC-based production planning and control systems challenging to implement due to the need for seamless integration of advanced technologies.

Despite the relevance of these innovations, existing studies have analysed BIM, Lean, and ADA adoption separately, lacking an integrated approach within a DTC framework for planning and control. Moreover, there is a lack of comprehensive empirical studies evaluating how construction companies in LATAM adopt and integrate BIM, Lean Construction, ADA, and AI for predictive planning and workflow optimisation. This study explores the adoption practices and barriers associated with DTC-based systems in LATAM. The research focuses on 20 construction companies from Chile, Brazil, Mexico, Peru, and Colombia, countries recognised as early adopters with advanced BIM and Lean Construction implementations.

LITERATURE REVIEW

Project planning and control are essential for successful construction project delivery. Planning involves developing a roadmap, defining milestones, and sequencing activities to optimise workflow, often integrating BIM for visualisation and coordination. Lean Construction principles help minimise waste and improve efficiency during this stage. Control focuses on tracking project performance through KPIs like schedule adherence and budget compliance (J. G. Martinez et al., 2023). Emerging technologies like AI and ADA systems enable real-time monitoring, predictive analytics, and data-driven decision-making (Regona et al., 2022).This dynamic feedback loop aligns execution with objectives, enhancing efficiency, adaptability, and innovation and improving project outcomes in complex and evolving construction environments.

With the arrival of new advanced technologies, the construction industry has experimented with digitalising and integrating its processes at all stages. The DT concept has gained significant attraction over the past decade, particularly in manufacturing, production, and operations. A DT is a detailed digital model of assets, processes, or systems within built or natural environments in the construction industry. Tao et al. (2019) identified three core components of a DT: the physical entity, the virtual representation, and the interconnect mechanisms. This foundational understanding has led to the development of the DTC paradigm. DTC introduces an innovative approach to construction production management by leveraging data from advanced ADA technologies and AI to deliver precise real-time status updates. This paradigm enhances production planners' situational awareness and equips them with predictive analytics to inform decision-making processes (Sacks et al., 2020). DTC is built upon the foundations of Lean project production system, BIM, AI and ADA to create a data-centric approach to managing construction processes (Sacks et al., 2020). DTC adopts Lean Construction principles by incorporating the Plan-Do-Check-Act (PDCA) cycle and the Last

Planner® System (LPS), enabling proactive planning, constraint management, and waste reduction. Real-time monitoring and feedback loops enhance situational awareness, ensuring smooth workflows and minimising inefficiencies. Besides, BIM serves as the foundation, providing digital models of physical assets and processes enhanced by integration with real-time monitoring technologies (Hannan Qureshi et al., 2023). ADA ensures accurate, continuous updates of the project's physical and operational states using sensors, IoT devices, and computer vision. AI processes this data through machine learning, predictive analytics, and complex event processing, enabling real-time insights, proactive decision-making, and predictive scenario modelling. Together, these technologies close feedback loops in construction management, aligning planned designs with as-built outcomes.

Various studies have examined technological advancements and management techniques in the LATAM construction sector. Osorio-Gómez et al. (2024) analysed the relationship between digital transformation and organisational structure in Colombia's construction industry, highlighting its impact on productivity. Huaman-Orosco et al. (2022) identified barriers to Lean Construction adoption in medium-sized enterprises (SMEs) in Peru and across multiple LATAM countries, categorising them by company size and project type. Martinez et al. (2019) explored Lean Construction's role in LATAM for improving affordable housing quality and scalability. Finally, Safour et al. (2021) assessed global BIM adoption, finding North America leading while LATAM remains at varying maturity levels. These studies provide insights into regional adoption challenges.

METHODOLOGY

The study examines the practices and barriers toward adopting DTC-based production planning and control systems in LATAM. Specifically, it seeks to: (1) Identify the current practices implemented in the LATAM construction industry to adopt production and control systems aligned with the DTC paradigm and (2) analyse the main barriers to adopting DTC in LATAM.

The study follows a four-phase process: (1) identification of best practices through an extensive literature review, (2) development of a structured survey instrument to measure adoption levels, (3) empirical validation through expert feedback to refine the instrument, and (4) Survey implementation.

GOOD PRACTICES IDENTIFICATION

An extensive literature review identified and documented 28 best practices aligned with the DTC paradigm. The analysis of these practices aimed to evaluate the technological and managerial maturity of construction companies in selected countries from LATAM, comparing their progress with optimal benchmarks based on the DTC framework. This in-depth review established a theoretical basis for assessing how extensively leading regional firms have adopted advanced technologies and management methodologies. Table 1 shows a detailed list of 28 practices identified during this study.

Table 1: Best practices identified - LC: Lean construction; AI: Artificial Intelligence; AD: ADA; B: BIM

N	References	Category	Code	Practice
1	(Ballard & Tommelein, 2021)	Lean	LC1	Use Pull Planning and LPS to visualise and optimise task dependencies, resource allocation, and potential bottlenecks.
2	(Evans & Farrell, 2022)	Lean	LC2	Establish a formal and prioritised program for variation reduction actions, ensuring consistent application and tracking long-term improvement trends in selected processes to minimise

N	References	Category	Code	Practice
				defects, reduce rework, and optimise inspections effectively.
3	(Lehtovaara et al., 2022)	Lean	LC3	Plan and control at different levels of resolution and time horizon (e.g., monthly, weekly, daily), which corresponds to Master, Look Ahead Planning, and Weekly Planning in LPS.
4	(Olawale & Sun. 2015)	Lean	LC4	Employ multiple scheduling methods to analyse the project timeline from different perspectives (Gantt charts, Critical path method (CPM), location-based scheduling (LBMS), LPS).
5	(Hannan Qureshi et al., 2023)	Lean	LC5	Employ a lean-based management system that controls the project based on flows and constraints (e.g., LPS, LBMS, Advanced Work Packaging (AWP), Takt).
6	(Dinis-Carvalho, 2021)	Lean	LC6	Implement training and education programs focused on Lean principles for employees, ensuring they develop the necessary skills to apply Lean practices effectively in projects.
7	(Chen et al., 2021)	Lean	LC7	Report the project's current status regularly by utilising a combination of advanced communication technologies (digital dashboards, Augmented Reality (AR)/Virtual Reality (VR)) to ensure all project personnel stay informed and aligned.
8	(Omrany et al., 2023)	Lean	LC8	Store key data in a centralised, accessible, and secure manner, including productivity rates per crew, machinery failure rate, probability of quality defects/incompleteness, and problems during task execution for use in future construction projects, ensuring continuous improvement and more informed decision-making.
9	(Yang et al., 2010)	Lean	LC9	Evaluate construction project performance across multiple levels of detail to achieve thorough monitoring and analysis, facilitating informed, data-driven decision-making.
10	(Haponava & Al-Jibouri, 2009)	Lean	LC10	Establish and use a clear set of Key Performance Indicators (KPIs) to monitor and control project development, ensuring alignment with project objectives, timelines, and quality standards.
11	(Jaskula et al., 2023)	BIM	B1	Store the as-designed BIM models in a common data environment (CDE) to enable seamless sharing and synchronisation of model data across multiple teams and locations.
12	(Alankarage et al., 2023)	BIM	B2	Adopt cloud-based platforms and direct APIs connections to enable real-time collaboration
13	(Zhang et al., 2022)	BIM	B3	Implement BIM models with a Level of development of 350 (model elements include precise geometry and connections to adjacent components for support coordination, clash detection, and constructability) or higher to ensure precise design coordination, construction documentation, and reliable project execution. This will enhance accuracy, clash detection, and seamless collaboration across disciplines.
14	(Wan Abdul Basir et al., 2023)	BIM	B4	Integrate n-Dimensional BIM models (nD BIM), using different dimensions such as time (4D), cost (5D), sustainability (6D), and facility management (7D) into project management to

N	References	Category	Code	Practice
				enhance scheduling, control costs, and monitor environmental impact and workplace safety.
15	(Rashidian et al., 2022)	BIM	B5	Leverage the as-designed BIM model to perform a comprehensive range of technical and management analyses to ensure a holistic and efficient approach to project planning and execution.
16	(Tran et al., 2024)	BIM	B6	Leverage the as-built model to enhance project progress tracking, safety, cost management, and estimation processes.
17	(Preidel et al., 2016)	BIM	B7	Embrace BIM model transparency and accessibility by centralising data and enabling role-based access while promoting interdisciplinary collaboration through standardised workflows and real-time communication tools.
18	(Lin et al., 2018)	BIM	B8	Update the as-built BIM model frequently during the construction stage to ensure it accurately reflects real-world conditions and project changes.
19	(Hannan Qureshi et al., 2023)	ADA	AD1	Leverage a combination of data collection technologies to provide accurate, real-time insights into the current status of the construction site, ensuring comprehensive and accurate situational awareness.
20	(Omrany et al., 2023)	ADA	AD2	Establish a routine and protocols for collecting relevant data on a weekly or monthly basis, depending on the activity, to monitor the status, progress, materials, and equipment usage on the construction site.
21	(Růžička et al., 2022)	ADA	AD3	Use an automated or semi-automatic tool to merge data from multiple workflows and integrate them for comprehensive analysis.
22	(Agrawal et al., 2022)	ADA	ADA4	Use of central repositories such as cloud storage or graph databases for storing the project's current status information
23	(Rezgui et al., 2011)	ADA	AD5	Implement clear standards and protocols for creating, storing, and sharing data and information across different domains or specialities to ensure consistency, reliability, and collaboration throughout the project’s lifecycle.
24	(Lalmi et al., 2021)	ADA	AD6	Collect current status information regularly to ensure that project activities are routinely monitored, risks are managed, and project performance is optimised.
25	(Rane, 2023)	AI	AI1	Use AI during construction to support project planning, risk management analysis, and enhance quality control.
26	(Wen, 2024)	AI	AI2	Use forecast algorithms to evaluate the outcome of changes in the production system configuration, plan, and schedule.
27	(Pan & Zhang., 2023)	AI	AI3	Utilise AI to analyse real-time sensor data from the physical asset to predict equipment failures or structural issues, enabling proactive maintenance.
28	(Wen, 2024)	AI	AI4	Implement standards and protocols for accurate, consistent, and clean data collected from the site.

SURVEY DESIGN

A structured survey of 47 questions was designed to explore current practices in identified knowledge domains. The survey design began with an extensive literature review to identify critical focus areas, ensuring comprehensive coverage of the DTC-based knowledge domains. The survey was divided into four sections, each targeting a specific domain. The first section focused on BIM, addressing questions related to its current usage, levels of adoption, and perceived benefits in the construction and engineering industries. The second section emphasised Lean principles, exploring the application of Lean-based methods, training programs, and planning techniques. The third section examined ADA, including IoT devices, reality capture devices, sensors, and other technologies for real-time data collection on construction sites. The final section centred on AI, delving into implementing AI-driven tools for predictive analytics, decision-making, and project optimisation related to BIM.

SURVEY VALIDATION

The survey underwent a two-round validation process using the Delphi method to ensure consistency and validity. In the first round, three academic researchers and DT technology experts reviewed the initial version, providing feedback on technical precision, logical flow, and interoperability challenges. The second round involved construction company representatives, who suggested simplifying language, incorporating scenario-based questions, and balancing survey length for engagement. Their input further adjusted question phrasing, section organisation, and content clarity to enhance usability and relevance.

SURVEY IMPLEMENTATION

Twenty construction companies across five LATAM countries, including Colombia, Chile, Brazil, Peru, and Mexico, served as case studies for this research. These companies were selected based on their advanced BIM and Lean Construction implementation. All surveyed companies rank among the top 20 construction firms within their respective countries, ensuring a robust representation of technological and managerial trends in the region. Table 2 provides an overview of the participating companies, detailing the average budget per project, the number of employees and the type of projects. Most of the surveyed companies can be categorised as large businesses (71%), based on their number of employees. The average project budget these companies manage exceeds $10 million per construction project. Regarding industry sectors, most companies focus on residential buildings (71%) and industrial facilities (47%).

Table 2: Companies' characterisation

Total Employees in the Company		Average Budget per-Project			Company Sector			
50 to 249 employees	More than 250 employees	USD 1 Million - USD 10 Million	USD 10 Million - USD 50 Million	> USD 50 Million	Residential buildings	Civil infrastructure	Commercial buildings	Industrial facilities
29.4%	70.6%	7.4%	75.0%	17.7%	70.6%	35.3%	35.3%	47.1%

FINDINGS

The survey was distributed to 25 construction companies across five LATAM, with a response rate of 80% (20 companies). According to the survey results, 40% of respondents were BIM

Managers and 18% held Chief Operating Officer (COO) positions. Senior Engineers accounted for 9%, while 5% were Chief Executive Officers (CEOs). The remaining 28% represented other management roles.

SURVEY ANALYSIS

Lean construction implementation: The study's findings indicate that Lean Construction represents the most extensively implemented methodology. 84% of companies have integrated Lean practices for project planning and control. However, Lean implementation remains primarily restrained to upper management levels, as evidenced by 60% of companies providing Lean training exclusively for senior executives. This gap in training at the operational level hinders the widespread adoption and practical execution of Lean methodologies across the project team. Additionally, 42% of companies reported having a formal and prioritised approach to variation reduction, enabling continuous improvement and process optimisation.

Regarding planning and control processes, companies employ varied time intervals for project scheduling. Notably, over 80% of firms utilise Look-Ahead planning (LAP) and weekly scheduling to track project progress. Besides, 63% of companies have primarily adopted LPS to optimise project planning, coordination, and execution. However, the level of detail in planning remains insufficient, as many schedules fail to incorporate key production flow variables, including cycle times, throughput, and differentiation between value-added and non-value-added activities. The omission of these variables can lead to inefficiencies and disruptions, ultimately affecting project performance and predictability. All surveyed companies utilise KPIs to assess project performance based on cost, time, and quality. However, incorporating metrics to measure environmental impact remains null, with no companies currently using such indicators to evaluate sustainability performance. 70% of companies systematically store historical information to support future project planning and decision-making. 90% of firms utilise cloud-based storage solutions to enhance data accessibility and collaboration. Nevertheless, a significant gap persists in using the as-built BIM model to store project information. Notably, over 79% of companies report project status using digital dashboards, facilitating data-driven decision-making and improved project transparency.

BIM adoption: The implementation of BIM has seen significant advancements, particularly in the centralisation of data and interoperability among different disciplines. A key practice observed in leading firms is using CDE systems, with 80% of companies adopting such platforms to store the BIM model. Additionally, BIM was increasingly applied for functional analysis, clash detection, cost estimation, and scheduling. However, its use in these areas remains limited, with only 30% of companies integrating these capabilities into their workflows. A critical factor in BIM effectiveness is interoperability, primarily driven by open formats like IFC and cloud-based solutions like BIM360. Around 80% of companies have prioritised open standards to facilitate cross-disciplinary collaboration, ensuring multiple teams can share and utilise models without compatibility issues. However, despite the increasing reliance on digital workflows, the adoption of advanced nD BIM models, including 4D (time-based) and 5D (cost-based) BIM, remains low, at only 15%. This suggests that while BIM is widely recognised as a powerful tool, many companies still rely on traditional scheduling and cost estimation techniques instead of fully leveraging integrated digital modelling for better project planning and execution.

Another key aspect of BIM implementation is updating as-built models, which ensures proper planning and production control. The study found that 42% of companies update as-built models, yet in most cases, these updates occur only at project completion rather than continuously throughout the construction process. This delayed approach restricts the effective use of as-built models for enhancing project tracking, safety management, cost control, and schedule optimisation. Furthermore, the LOD of BIM models varies significantly. 74% of companies achieved a LOD of 350 or higher, primarily in architectural and structural elements.

Nevertheless, many companies are still not incorporating (17%) high-detail models for mechanical, electrical, and plumbing (MEP) systems, which are crucial for improving constructability and reducing on-site errors.

ADA implementation: ADA in construction enhances project monitoring, decision-making, and efficiency. One of the best practices observed was using centralised repositories for project information storage, with 82% of companies employing such systems. CDEs are widely adopted, with 80% of firms integrating them into their workflows, while cloud-based solutions show an even greater adoption rate of 74%. Ensuring project data is stored and accessible in a centralised system enhances stakeholder collaboration, minimises data loss, and improves project control. Additionally, 64% of companies use standardised data creation and storage protocols, ensuring consistency and interoperability across different teams and platforms.

The frequency of data collection is another critical aspect of ADA implementation. The study reveals that 26% of companies collect data daily, while 42% do so weekly. This highlights a gap where many firms may not leverage real-time data acquisition, potentially limiting their ability to respond quickly to project deviations. Regular and systematic data collection improves project tracking and predictive analytics, enabling proactive decision-making. Furthermore, the integration of advanced technologies for data collection is steadily increasing. Physical technologies such as drones (68%), fixed cameras (58%), 360-degree cameras (40%), and Light Detection and Ranging (LiDAR) are being adopted. Additionally, the use of digital technologies is also expanding, with Augmented Reality/Virtual Reality (AR/VR) (33%) and Internet of Things (IoT) (32%). Nevertheless, only 42% of companies utilise semi-automated or automated processes to integrate data from multiple technologies and workflows, limiting efficiency and interoperability. Finally, 84% of companies have embraced standardised data collection procedures for sharing data and collaborating with other specialities.

AI utilisation: A fundamental good practice in this area is using standardised data collection protocols, which 64% of companies implement to ensure the integrity, consistency, and reliability of the data used for AI-driven analysis. Establishing data collection standards allows AI systems to operate with structured and high-quality datasets, reducing errors and improving predictive capabilities. Proper data structuring facilitates interoperability between AI tools and existing project management platforms, ensuring seamless workflow integration.

26% of companies have claimed that AI is used for construction management activities, including resource optimisation, support the LAP process, safety management, and quality checks. Nevertheless, AI application is null. Another critical aspect of AI implementation is the adoption of forecasting algorithms for predictive analytics, with none of the companies leveraging AI for forecasting in planning and control. However, the null adoption rate suggests that many companies still rely on traditional deterministic scheduling methods rather than leveraging advanced AI capabilities for dynamic and adaptive planning. A significant limitation in AI implementation was the lack of integration with ADA systems, significantly reducing its usefulness in predicting deviations and optimising production plans.

IMPLEMENTATION BARRIERS

As identified by the expert panel and the survey results, adopting advanced technologies and management practices for planning and control in the LATAM construction industry faces multiple barriers. These barriers can be categorised into technological, organisational, cultural, and economic factors that limit the integration of advanced digital solutions toward adopting DTC. A lack of robust data infrastructure and insufficient workforce training were identified as key obstacles to digital transformation. Companies require structured and well-organized data management frameworks alongside continuous training programs for employees at all levels. Without proper knowledge dissemination and digital literacy, organisations struggle to leverage technology effectively, reducing their competitiveness in the long run. Organisational resistance and lack of coordination between departments also hinder implementation. Many

construction firms face drawbacks in aligning different stakeholders, leading to fragmented adoption efforts. Successful integration requires pilot programs that provide minimum technological capabilities to involved teams and ensure ongoing updates and engagement across all business units.

Culturally, the LATAM construction industry remains risk-averse, often viewing technological investment as a financial risk rather than a long-term necessity. Experts argue that digital transformation is essential for competitiveness despite initial costs, requiring strong change management strategies and enablers like BIM, Lean methodologies, and industrialisation. However, economic challenges, including recessions and limited financial resources, hinder technology adoption, while poor internet connectivity restricts access to cloud-based tools. Additionally, ethical and sociocultural factors influence organisational behaviour, emphasising the need for corporate responsibility and social commitment. Without strong leadership and government-private sector support, the industry will struggle to embrace digital innovation.

DISCUSSION

The construction industry in LATAM is progressing in DTC adoption, but challenges remain in fully integrating its components. While Lean Construction, BIM, AI, and ADA are implemented at varying levels, their lack of interoperability has hindered the development of comprehensive, data-driven construction management systems. This fragmentation limits the ability to optimise project performance, reduce inefficiencies, and advance sustainable construction practices. A key gap is the underutilisation of AI and predictive analytics, with only 26% of companies actively using AI-driven tools. Many firms still rely on manual data collection and analysis, highlighting the need to integrate AI with ADA and leverage real-time data systems. The broader adoption of IoT sensors, drones, LiDAR, and automated data repositories can enhance seamless data pipelines, enabling continuous analysis and automated recommendations.

Despite 80% of companies adopting CDEs and cloud-based platforms, the full potential of AI-driven predictive construction management remains largely untapped. While recent advancements in digital planning, nD BIM, and real-time analytics show promise, only 30% of companies use BIM for advanced functional analysis, clash detection, or predictive cost management. Additionally, although 84% of firms implement Lean Construction to reduce waste and enhance value, many struggle to incorporate detailed production flow modelling. Organisational and cultural resistance and financial constraints further hinder full DTC adoption. Overcoming these barriers requires the seamless integration of Lean principles, AI, and ADA into a unified digital ecosystem. Future research should prioritise data standardisation, AI-driven decision-making, workforce upskilling, and economic incentives to accelerate the digital transformation of LATAM's construction sector.

CONCLUSIONS

This study explores DTC-based production planning and control adoption in LATAM, identifying best practices and key barriers. While companies increasingly integrate Lean Construction, BIM, AI, and ADA technologies, their fragmented implementation limits predictive planning and real-time decision-making. Key barriers include insufficient data infrastructure, a lack of skilled professionals, organisational resistance, and economic constraints. Despite investments in cloud-based platforms and CDE, the limited integration of AI, IoT and real-time monitoring technologies for data fusion hinders the seamless adoption of DTC-based systems. Cultural resistance and financial limitations further hinder progress. Despite these challenges, this study provides insights into existing gaps and opportunities but is limited by its focus on leading digital construction firms. Future research should expand to a

broader range of companies, analyse successful digital transformation strategies, and compare LATAM's progress with regions like Europe and North America.

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