

FROM TOOLS TO BEHAVIORS: HOW A VDC IMPLEMENTATION INFLUENCES A CONSTRUCTION COMPANY

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ABSTRACT

Although VDC is often promoted to improve project performance, empirical evidence explaining how and when such improvements occur remains limited. This study examines VDC implementation from a behavioral perspective, focusing on observable changes in commitment-making, and learning routines.

Using longitudinal data from a Peruvian construction company implementing VDC across eight residential and mixed-use building projects, the study analyzes behavioral indicators that readers can directly inspect. The findings show that VDC primarily functions as a behavioral catalyst, with the stabilization of social routines preceding technical proficiency. Early routines were socially fragile and required scaffolding through mentoring and visible leadership reinforcement. Staff turnover was identified as a significant moderating variable, creating an 11% gap in behavioral maturity between stable and unstable teams

The study contributes empirical evidence to the Lean Construction literature by demonstrating how VDC functions as a socio-technical and behavioral intervention. It offers methodological guidance for grounding Lean research in observable data and provides practical insights for more sustainable VDC implementation.

KEYWORDS

Virtual Design and Construction, lean construction, behavioral change, socio-technical systems, organizational routines.

INTRODUCTION

Virtual Design and Construction (VDC) has been widely promoted as a means to improve coordination, integration, and performance in construction projects (Fosse et al., 2017). Through a structured framework, VDC aligns client objectives with project goals by integrating people, processes, tools, and information (Fischer et al., 2017). Within the Lean Construction community, several studies have highlighted the conceptual alignment between VDC and Lean principles, particularly through practices such as Integrated Concurrent Engineering (ICE), shared digital models, and visual management (Ballard et al., 2008; Fosse et al., 2017; Schimanski et al., 2021).

Lean Construction conceptualizes projects as socio-technical systems in which outcomes emerge from the interaction between technical processes and human behavior (Koskela, 2000; Ballard & Tommelein, 2021). From this perspective, sustainable improvement depends not

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only on introducing new methods or technologies, but on changing everyday behaviors such as coordination, decision-making, commitment, and learning (Hamzeh et al., 2012; Gordon et al., 2021; Romo et al., 2025). However, while prior research has established that VDC can enable Lean practices, few studies have provided detailed empirical accounts of the behavioral changes triggered by VDC implementations over time, particularly regarding how VDC practices reshape day-to-day interactions within project teams.

This study addresses this gap by examining VDC implementation across several residential and mixed-use building projects, with teams ranging from 8 to 15 professionals per project, within a single construction company in Perú. Rather than assessing tool adoption or organizational structures, the research focuses on how VDC influenced observable daily behaviors of project teams. The objective is to identify which behaviors changed, through which VDC practices these changes occurred, and why these behavioral changes matter from a Lean Construction perspective. The study is guided by the following research question: How does a VDC implementation influence project teams' everyday behaviors in a construction company?

BACKGROUND

LEAN CONSTRUCTION AS A SOCIO-TECHNICAL SYSTEM

Lean Construction theory builds on the view of production as a socio-technical system, where technical processes and human interactions are inseparable (Koskela, 2000). Core Lean objectives—such as improving flow, reducing variability, increasing reliability, and enabling continuous learning—are achieved through the coordination of interdependent actors rather than through isolated task optimization (Ballard & Howell, 1998; Tommelein, 2015).

Within this framework, behavior plays a central role. Planning systems, such as the Last Planner System, explicitly focus on commitment reliability and coordination behavior as mechanisms to improve production performance (Ballard, 2000). Several IGLC studies have highlighted that Lean implementation challenges are often rooted in behavioral and cultural barriers rather than technical limitations (Gordon et al., 2021; Romo et al., 2025). Consequently, understanding behavioral change is essential for explaining why Lean initiatives succeed or fail in practice.

BEHAVIOR, ROUTINES, AND LEARNING IN PROJECT TEAMS

In project based organizations, behavior is manifested through routine-repeated patterns of interaction that shape how work is coordinated and decisions are made (Feldman & Pentland, 2003). Lean Construction research has increasingly focused on these routines as units of analysis, particularly in relation to coordination, commitment, and learning (Hamzeh et al., 2012; Schöttle et al., 2014).

Key behavioral dimensions repeatedly discussed in IGLC literature include:

- Commitment is often operationalized through promise and fulfillment.
- Learning is demonstrated through reflection and the use of feedback for improvement.

Importantly, these behaviors are observable in practice and can be documented through systematic field observation rather than relying solely on self-reported perceptions.

VDC AS AN ENABLER OF LEAN PRACTICES

VDC integrates organizational practices, processes, and digital representations to support project delivery (Fischer et al., 2017). Research has shown that VDC practices such as ICE sessions, shared digital models, and common data environments enhance transparency, integration, and cross-disciplinary collaboration (Fosse et al., 2017; Schimanski et al., 2021).

From a Lean perspective, VDC can be understood as a socio-technical intervention that structures interactions rather than merely introducing technology. By shaping when teams meet, what information is made visible, and how problems are discussed, VDC practices influence coordination and decision routines in ways that are consistent with Lean principles (Ballard et al., 2008; Mandujano et al., 2021).

However, while several studies have demonstrated the compatibility between VDC and Lean, fewer have explicitly examined the behavioral mechanisms through which VDC contributes to Lean outcomes. This study builds on this body of work by focusing explicitly on behavioral change as the primary unit of analysis.

PROPOSED FRAMEWORK

The VDC implementation process described in this study is conceptualized as a socio-technical intervention where behavioral change serves as a precursor to technical maturity. The implementation actions are categorized into three primary dimensions: Executive Governance, Adaptive Mentoring, and Routine Discipline.

- **Executive Governance:** Executive Governance refers to the set of leadership, structural, and organizational mechanisms that frame and sustain VDC adoption beyond project level routines.
- **Adaptive Mentoring:** focuses on knowledge transfer through customized, on-site support that evolves to meet the specific needs of each project. This dimension is characterized by a differentiated service modality that provides intensive, staged training for novice teams and targeted coaching for experienced teams.
- **Reinforcement Mechanisms:** This dimension focuses on sustaining VDC adoption through the ongoing reinforcement of key behaviors at both project and organizational levels. At the project level, it emphasizes the establishment of reliable work habits and disciplined commitment, aligned with the logic of the Last Planner® System, where reliability is a prerequisite for coordination and control (Ballard, 2000). At the organizational level, reinforcement mechanisms help create visibility and continuity across projects, supporting the stabilization of new routines before additional technical complexity is introduced.

A critical but often overlooked factor in stabilizing routines is staff project turnover. Since routines are embedded in the repeated interactions of specific actors, the departure of key team members may lead to 'behavioral reset,' where the team loses its accumulated social capital and must restart the learning curve of new practices.

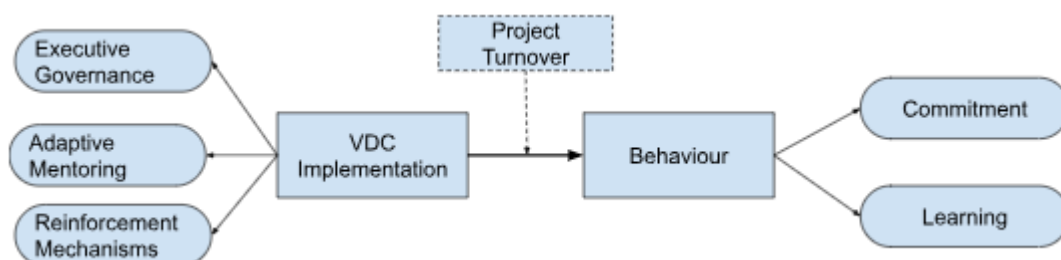


Figure 1: Conceptual model

RESEARCH METHOD

RESEARCH DESIGN

The study adopts a longitudinal, structured qualitative case study. This approach is well suited to exploring behavioral change over time within its real organizational context, as

recommended in prior IGLC research addressing complex socio-technical phenomena (Yin, 2018; Gordon et al., 2021). Within this framework, documentary analysis was employed as the primary method for data collection and triangulation, allowing the research to capture the transition from individual proficiency to collective behavioral maturity.

The research design utilized three distinct layers of documentary evidence to track the implementation's evolution:

- **Corporate Policy Analysis:** The Corporate VDC Implementation Protocol was analyzed to establish the strategic baseline and the "prescribed" sequence of the intervention.
- **Evaluative Content Analysis:** The study analyzed the VDC Compliance Assessment Rubric populated by external mentors. By examining structured qualitative scores and descriptors over seven months, the research compiled expert observations into a longitudinal dataset for statistical analysis.
- **Process Documentation Analysis:** Monthly VDC Implementation Reports were reviewed to cross-reference performance metrics with contextual factors, including staff turnover and leadership involvement.

This longitudinal case study design, grounded in systematic documentary analysis, ensures that the findings reflect observable everyday practices rather than self-reported perceptions, providing a high degree of transparency and auditability for the research.

CASE DESCRIPTION

The case organization is based on V&V Bravo, a Peruvian construction company executing multiple building projects concurrently. The eight projects included in this study are all mid-to-large scale residential and mixed-use building projects, ranging from 8 to 25 floors, with project team sizes between 6 and 12 key participants per project (including resident engineers, BIM coordinators, and site supervisors). The company initiated a structured VDC implementation across eight projects, combining formal training, on site application, and continuous support. The implementation was supported by Idear Consultores, an external consulting firm composed of two experienced professionals who acted as VDC mentors. Their role was to provide coaching, observe project practices, and support teams during implementation. Importantly, they also documented progress, challenges, and observed behaviors monthly across projects.

VDC implementation process

The implementation of Virtual Design and Construction (VDC) was intentionally designed as a structured organizational change process rather than a purely technical rollout. The strategy emphasized the transition from individual tool proficiency to collective behavioral maturity, following this path:

Executive Governance: Executive leadership framed VDC as a strategic priority with top management participating in formal VDC certification to lead the transformation. To reduce adoption barriers, the company updated HR roles, resource allocation, and construction policies. Monthly, executive reviews ensured visibility, reinforcing a culture of discipline and learning over short-term results, thus providing the legitimacy needed to institutionalize new behavioral routines

Adaptive Mentoring and Staged Approach: Following the initial training, the implementation followed a differentiated support modality based on team maturity.

- **Training and Initial Application:** Monthly on-site sessions combining theoretical instruction with immediate application to real project tasks.
- **Strategy Definition and Metric Analysis:** Teams were required to align VDC objectives with client goals, developing strategic trees and systematic metric registration.

- **Live Session Feedback:** Consultants acted as observers during live ICE sessions, providing structured feedback on coordination quality and information use.

Reinforcement Mechanisms: A key component of the process was the Monthly VDC Review Meeting. These sessions were attended by the General Manager and executive leadership, and functioned, by design, as a forum for collective reflection rather than a performance audit. Project teams presented their progress, lessons learned, and behavioral metrics with deliberate emphasis on adoption and learning rather than project results.

DATA SOURCES

Multiple data sources were used to enable triangulation, as recommended in Lean Construction case study research (Gordon et al., 2021):

- **Monthly VDC implementation reports** produced by the external mentors, documenting observed behaviors related to coordination, commitment fulfillment, learning, and leadership involvement across projects. These reports were generated consistently over time, providing a longitudinal record of behavioral evolution.
- **Corporate VDC Implementation Protocol:** This document serves as the strategic and tactical map for the organization's VDC journey. It defines a VDC implementation framework that prioritizes the stabilization of project routines and adaptive mentoring over purely technical milestones.
- **VDC Compliance Assessment Rubric:** This instrument represents the evaluative framework used by mentors to translate qualitative behavioral shifts into quantitative data. The rubric categorizes performance into three levels of maturity: Beginner (0-50%), Competent (51-80%), and Highly Competent (81-100%).

DATA ANALYSIS

To quantify the progress of the implementation and its impact on team behavior, a set of specific metrics was established for each of the three dimensions. These metrics allowed for a systematic evaluation of how teams transitioned from theoretical knowledge to application.

Learning Metrics

- **Project and Client Objectives:** Measures the degree of alignment between VDC activities and the desired business outcomes.
- **Strategic Tree:** Evaluates the logical connection between production objectives, controllable factors, and experimental metrics.
- **Theoretical knowledge of ICE, VIA, PPM:** Quantitative assessment of the team's understanding of Integrated Concurrent Engineering and Visual Information Analysis principles and Project Production Management.
- **Metrics:** Evaluates the team's ability to define valid KPIs.

Commitment Metrics

- **Percent of Commitment Fulfilment:** Inspired by the Last Planner® System, this tracks the reliability of the team in executing VDC related tasks assigned in previous sessions.
- **Session Attendance Rate:** Measures the physical and virtual presence of key roles in VDC sessions. High attendance is viewed as a prerequisite for effective multidisciplinary collaboration.

FINDINGS

The longitudinal analysis of the VDC implementation across eight projects shows a positive behavioral evolution, characterized by a steady increase in both Learning and Commitment

dimensions. While both indices showed an upward trend, their trajectories reveal distinct patterns of adoption and stabilization.

Table 1: Behavior evolution by dimensions and metrics

Dimensions of Behavior	Metrics	Month 01	Month 02	Month 03	Month 04	Month 05	Month 06	Month 07
Learning	Objectives	88.8%	93.1%	95.0%	99.4%	100.0%	100.0%	100.0%
	Strategic Tree	76.3%	81.3%	87.5%	98.1%	98.6%	99.3%	100.0%
	ICE Theory	80.0%	70.0%	87.5%	88.8%	88.8%	95.0%	100.0%
	VIA Theory		72.5%	77.0%	84.0%	90.0%	91.0%	97.9%
	Process Mapping		55.0%	73.8%	77.5%	83.1%	84.6%	90.0%
	Metrics		68.1%	72.5%	74.9%	77.5%	83.6%	83.6%
Learning average		81.7%	73.3%	82.2%	87.1%	89.7%	92.2%	95.2%
Commitment	Fulfilment	84.4%	74.4%	81.5%	92.6%	87.9%	92.4%	83.9%
	Attendance at ICE	85.6%	91.5%	88.0%	92.1%	92.9%	94.3%	91.7%
Commitment average		85.0%	82.9%	84.8%	92.4%	90.4%	93.3%	87.8%
Behavior average		83.3%	78.1%	83.5%	89.7%	90.0%	92.8%	91.5%

The chart "Behavior evolution by dimension" in Figure 2 illustrates a critical relationship for VDC implementation. During the first three months, the Commitment (green line) consistently outperformed the Learning (orange line). This indicates that the initial phase of the transformation relied on disciplined participation and appears to be a precursor to deep comprehension. By Month 04, a crossover occurred: once a threshold of social reliability was established (Commitment > 90%), the Learning index accelerated, eventually overtaking Commitment to reach its highest peak on month 07. This pattern supports the study's hypothesis that Reinforcement mechanisms (Dimension 3) of VDC implementation provide the necessary social support for effective Learning to take root.

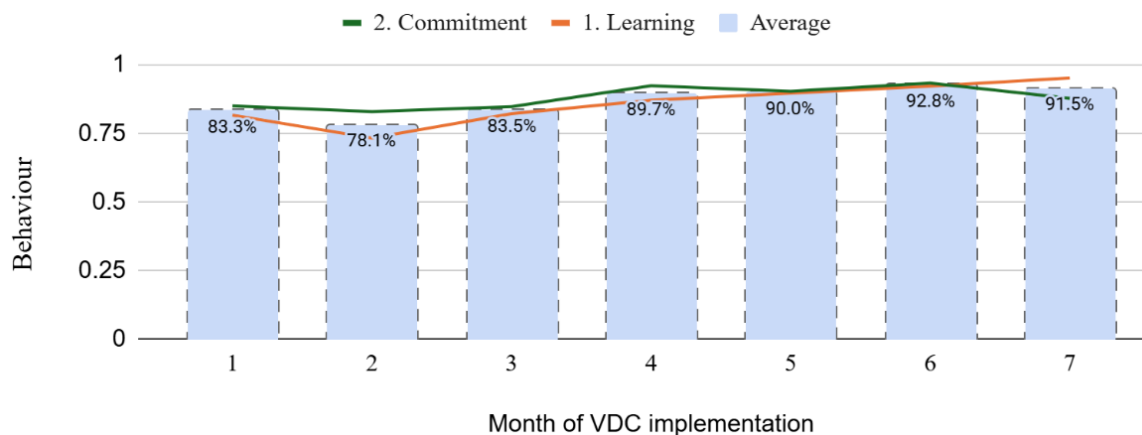


Figure 2: Behavior evolution by dimension

EVOLUTION OF THE LEARNING DIMENSION

As shown in the "Learning average" row in Table 1 and the "Learning Evolution by Project" box plots in Figure 3, this dimension exhibited a non linear progression. The initial average of 81.7% in Month 01 experienced a noticeable dip to 73.3% in Month 02. Following this dip, the Learning evolution showed sustained growth, reaching 95.2% by Month 07.

Detailed metrics, specifically % Understanding of Objectives and % Understanding Strategic Tree reached 100% as shown in Table 1, indicating a full conceptual alignment with the VDC framework. Furthermore, the box plots in Figure 4 highlight a significant reduction in variability; as the implementation progressed, the "spread" between projects narrowed, suggesting that the organization was successful in standardizing VDC knowledge across different teams.

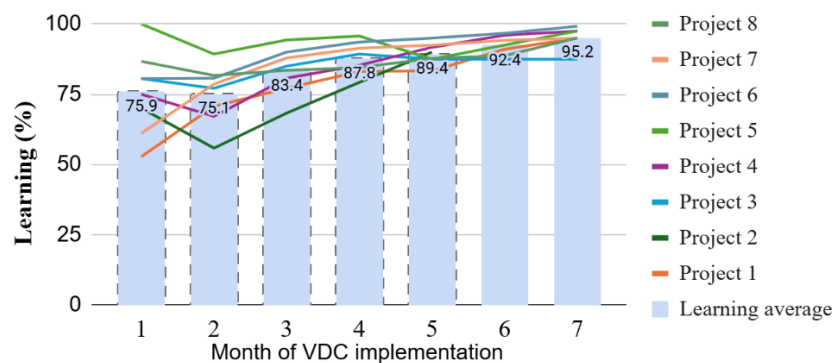


Figure 3: Learning evolution by project

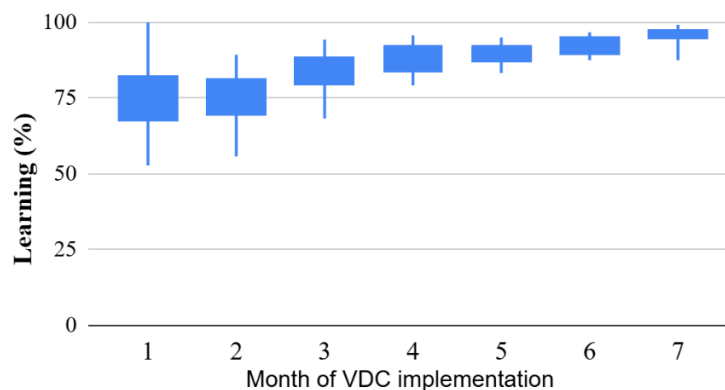


Figure 4: Variability of Learning evolution

EVOLUTION OF THE COMMITMENT DIMENSION

The Commitment dimension, which tracks % Commitment fulfillment and % Attendance at ICE Sessions, began with a high baseline of 85.0%. Unlike the Learning dimension, Commitment remained relatively stable during the first quarter but displayed higher operational volatility. The Figure 5 "Commitment Evolution by Project" shows significant fluctuations between projects compared to the more uniform Learning curves. While the average commitment peaked at 93.3% in Month 06, it experienced a slight decline to 87.8% in Month 07. This suggests that while cognitive learning is cumulative and stable, social commitments remain sensitive to project issues, such as deadlines or staff turnover. However, the box plots in Figure 6 confirm that the value for commitment rose significantly compared to the first two months, indicating an overall improvement.

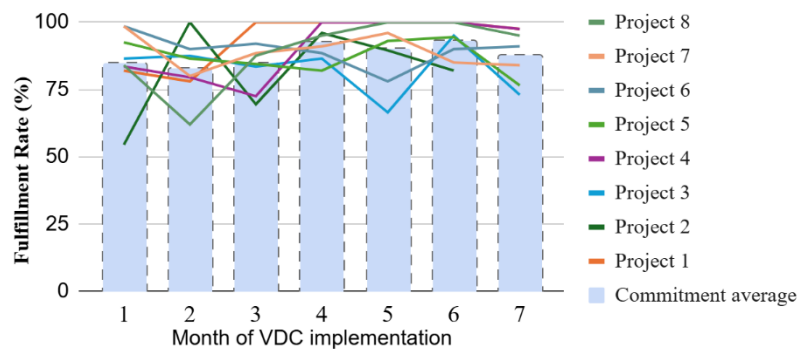


Figure 5: Commitment Evolution by Project

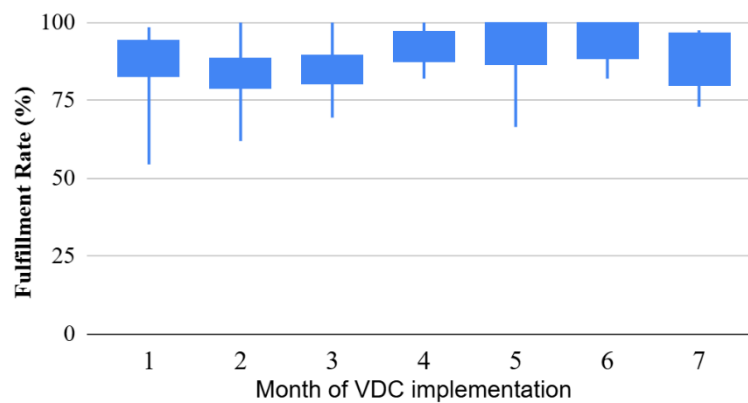


Figure 6: Variability of Commitment Evolution

TURNOVER AS A MODERATING VARIABLE

To analyze the impact of personnel instability on VDC adoption, projects were categorized into two groups based on their cumulative turnover frequency: (1) Low Rotation Group, comprising projects with less than 1 event of rotation (e.g., Project 4, Project 8), and (2) High Rotation Group, comprising projects with 2 or more events of rotation or personnel instability (e.g., Project 3 with 5 events). The following Table provides the longitudinal record.

Table 2: Turnover by project

Project	Month 01	Month 02	Month 03	Month 04	Month 05	Month 06	Month 07	Turn.	Rotation
Project 1	0%	0%	29%	0%	0%	0%	0%	1.0	Low
Project 2	0%	0%	0%	14%	14%	0%	0%	2.0	High
Project 3	17%	14%	0%	14%	0%	14%	14%	5.0	High
Project 4	0%	0%	0%	0%	0%	0%	0%	0.0	Low
Project 5	0%	0%	14%	0%	14%	14%	0%	3.0	High
Project 6	0%	0%	14%	0%	0%	0%	0%	1.0	Low
Project 7	0%	0%	17%	0%	0%	0%	17%	2.0	High
Project 8	0%	0%	0%	0%	0%	0%	0%	0.0	Low

The quantitative analysis of behavioral maturity reveals a significant divergence between both groups. As shown in Table 3 and illustrated in Figure 7, both groups started with near identical

baselines (approx. 80.4%). However, by Month 07, a maturity gap of 11.27% emerged. The Low Rotation Group exhibited a sustained and linear growth, achieving a final maturity score of 95.96%. Conversely, the High Rotation Group struggled to consolidate routines, experiencing a growth of only 4.23% over the seven-month period and ending at 84.69%.

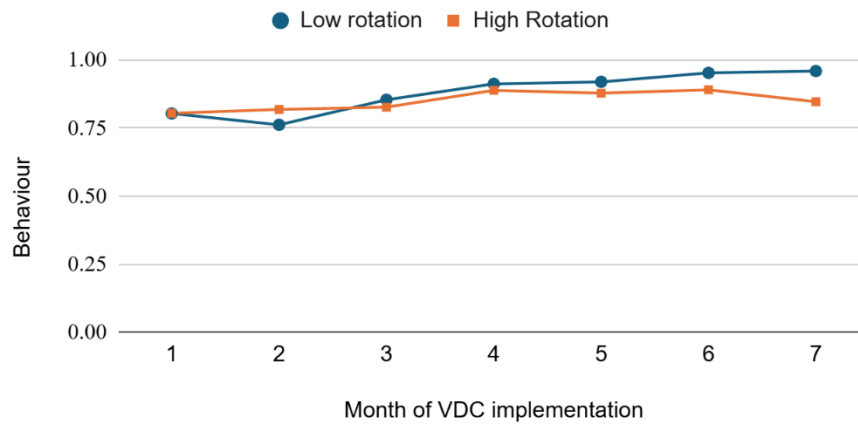


Figure 7: Behavior evolution group by turnover

Table 3: Evolution of behavior group by project turnover

Level of turnover	Month 01	Month 02	Month 03	Month 04	Month 05	Month 06	Month 07	Total Growth
Low	80.4%	76.2%	85.4%	91.3%	92.0%	95.3%	96.0%	15.6%
High	80.5%	81.9%	82.7%	88.9%	87.8%	89.1%	84.7%	4.2%

DISCUSSION

The findings of this longitudinal study provide empirical support for conceptualizing VDC as a behavioral intervention. The results suggest that early progress in VDC implementation is not merely a technical achievement, but is associated with the stabilization of a socio-technical system in which commitment precedes learning.

One of the key findings of this study is the crossover observed in Month 04, where the Learning accelerated only after the Commitment had stabilized above 90% (Figure 2). Additionally, staff turnover acted as a negative moderator. It creates an 11.27% gap in behavioral maturity. While learning is cumulative, commitment is sensitive to personnel changes, disrupting established routines. This reinforces the Lean principle that reliability depends on stable social systems and is a prerequisite for improvement over time (Ballard, 2000). Notably, staff turnover is an under-studied moderating variable in both Lean Construction and digital Lean research. Most existing studies control for or ignore team stability, yet the 11.27% maturity gap documented here suggests that turnover may represent one of the most impactful barriers to sustained behavioral improvement in VDC implementations. This finding calls for dedicated future research into how organizations can design onboarding and knowledge transfer mechanisms that mitigate the behavioral reset effect caused by personnel changes. In the early stages, teams focused on the "routine discipline" of attending ICE sessions and completing basic VDC tasks.

From a socio-technical perspective (Koskela, 2000), the data suggests that VDC tools (such as BIM models and strategic trees) are socially fragile in the beginning. Without consistent attendance and commitment, the technical components of VDC struggle to gain traction.

The noticeable dip in the Learning average during Month 02 (Table 1) reflects the inherent challenges of transitioning from theoretical knowledge to operational practice. This is often a phase where Lean initiatives struggle due to a lack of immediate results or increased perceived workload. However, the subsequent recovery and sustained growth indicates that the Adaptive Mentoring and Executive Governance dimensions played a crucial role by having top management reinforce VDC as a strategic priority rather than an optional tool. This finding aligns with Hamzeh et al. (2012), who emphasize that Lean leadership is essential for sustaining behavioral change during periods of technical uncertainty.

Lean Construction seeks to reduce variability to improve flow and predictability. The box plots in Figures 4 and 6 demonstrate that the implementation contributed not only to improvements in average scores but also to narrowing the performance gap between projects. Initially, there was significant variability in how different teams adopted VDC, influenced by project factors and team composition. Over the seven-month period, the variability of the boxes decreased, indicating a convergence toward a standardized organizational routine. This suggests that the structured implementation process combining reviews with project level mentoring appears to have contributed to the homogenization of the VDC culture within the company, making the organization's overall project delivery more predictable and reliable.

LIMITATIONS AND FUTURE RESEARCH

This study has several limitations. It is based on a single organization with a specific VDC approach, and the behavioral indicators, while applied consistently across projects with calibrated assessments between mentors, are not externally validated instruments. Additionally, the seven-month timeframe captures only early and intermediate adoption stages; project performance outcomes were intentionally excluded. Despite these constraints, the findings offer a meaningful contribution to understanding behavioral change in VDC implementations.

Future research could explore the relationship between leadership style and team behaviors, as well as the use of behavioral design methodologies and motivational incentives to improve adoption outcomes.

CONCLUSION

This study examined how a VDC implementation influences project teams' behaviors over time. The findings support understanding VDC primarily as a socio-technical and behavioral intervention in which behavioral stabilization precedes technical learning.

The results indicate that sustained commitment making and disciplined participation are foundational conditions enabling learning behaviors to emerge and stabilize. While learning routines tended to accumulate, commitment routines remained sensitive to contextual pressures such as workload and staff rotation, requiring continuous reinforcement. Additionally, the analysis of staff turnover as a moderating variable showed a significant 11.27% gap in behavioral maturity between stable and unstable teams.

Beyond project-specific contexts, the authors' interpretation is that organization-wide reinforcement played a critical role in sustaining commitment across heterogeneous environments. Although this interpretation extends beyond what can be conclusively demonstrated by the data alone, it reflects a reasoned synthesis of observed patterns and direct involvement in the implementation.

This study contributes longitudinal, behavior-focused evidence to Lean Construction literature, demonstrating that behavioral stabilization precedes technical learning in VDC implementations. For practitioners: (1) treat early VDC adoption as a behavioral change program, prioritizing governance before technical complexity; (2) monitor team stability as an implementation risk indicator to minimize turnover-driven "behavioral reset". For researchers, promising directions include developing a socio-technical framework for VDC behavioral

assessment, examining the relationship between behavioral maturity and project performance, and studying staff turnover as a moderating variable in digital Lean contexts.

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