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LEAN MANAGEMENT MODEL FOR SUSTAINABLE PROJECT DELIVERY IN EGYPT: IMPLICATIONS FOR OFF-SITE CONSTRUCTION ADOPTION

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Abstract: Off-site construction depends on reliable planning, coordinated information flow, process stability, workforce capability, and digital integration. These requirements closely align with the organisational conditions needed for successful lean implementation. This paper develops and validates a lean management model for Egypt's construction industry with a specific focus on the critical success factors (CSFs) and their enabling conditions. Building on the research theoretical model, five exogenous constructs - top management support, employee training and engagement, process standardisation, collaboration and communication, and technology and innovation - were operationalised through fifteen enablers and tested using responses from 120 construction professionals. Partial least squares structural equation modelling (PLS-SEM) was employed to examine measurement reliability, convergent validity, and the structural effects of each CSF on lean management outcomes. The results confirm that all five paths are positive and statistically significant. Top management support is the strongest predictor of lean outcomes ($\beta = 0.5235$), followed by technology and innovation ($\beta = 0.4591$), employee training and engagement ($\beta = 0.3167$), collaboration and communication ($\beta = 0.2644$), and process standardisation ($\beta = 0.2630$). The model explains 76.5% of the variance in lean management outcomes. The paper contributes an empirically grounded framework that translates the original model into an implementation logic suitable for Egyptian construction firms seeking to improve productivity, coordination, and value delivery. The model is rooted in the broader problem of limited awareness, fragmented delivery practices, weak training, and inconsistent leadership commitment in Egypt, which together prevent lean tools from being institutionalised at the firm level. By translating these contextual challenges into CSFs and enablers, the study moves from general advocacy of lean to a measurable implementation architecture.

Keywords: Lean management; Off-site Construction; Egypt; Critical success factors; Structural equation modelling

1 INTRODUCTION

Off-site construction is gaining attention as the industry seeks more productive, coordinated, and sustainable project delivery systems. However, the effectiveness of off-site approaches depends not only on manufacturing capability and digital technologies, but also on the managerial and organisational conditions that support reliable planning, standardised processes, coordination, and continuous improvement. These requirements closely mirror the core principles of lean management, which have emerged as a key strategy for improving construction performance through waste reduction, workflow stability, and value maximisation at the project level (Ballard and Howell 2003; Koskela 2000; Sacks et al. 2020). In mature lean environments, attention has therefore shifted from the use of isolated tools to the wider organisational conditions that allow lean practices to function consistently. This perspective is especially relevant to the Egyptian construction industry, where increasing demands for faster delivery, tighter cost control, and greater resource efficiency persist alongside fragmentation, rework, coordination gaps, and inconsistent site practices.

Although lean ideas have been discussed in Egypt for several years, implementation remains uneven and often depends on individual champions rather than an integrated management system. The problem is therefore not simply whether firms are aware of lean construction, but whether they possess the enabling conditions required to embed lean in planning, supervision, communication, and digital decision-making. This paper addresses that gap by focusing on the CSFs that support implementation and analysing their measurable enablers using the validated model (Sarhan and Fox 2015; Howell 1999; Abdelhamid 2007).

The extensive research in this study showed that this implementation gap is reinforced by five recurring barrier clusters: cultural resistance, lack of top-management support, inadequate training, limited awareness, and fragmented industry structures. Together, these conditions keep lean tools from moving beyond isolated site practices into an organisation-wide operating model. In the Egyptian context, the consequences are not only technical inefficiency but also reduced predictability in cost, time, and quality, which weakens the sector's ability to align project delivery with national sustainability and productivity objectives (Sarhan and Fox 2015; Howell 1999; Abdelhamid 2007; Salem et al. 2006).

This conceptual emphasis matters directly for off-site construction (OSC), which depends on reliable planning windows, standardised assemblies, supplier and design coordination, workforce capability, and digital information continuity. Each of these requirements maps onto a lean enabler examined here: management commitment secures the governance and resources that OSC pilots require; standardisation underpins the repeatable manufacturing logic of prefabrication and modular elements; collaboration and Last Planner-style routines stabilise the design–factory–site interface; and digital tools such as BIM and integrated platforms provide the information continuity that off-site workflows assume. The contribution of this paper is therefore to position lean enablers as the organisational substrate that operationalises OSC practices, allowing OSC ambitions to scale from isolated pilots to a routine delivery mode in Egypt (Hosseini et al. 2018; Sacks et al. 2020).

The paper develops the argument in three steps. First, it defines the construct codes and enabler codes used in the model. Second, it reports the measurement and structural results of the validated PLS-SEM analysis. Third, it interprets those results as a practical sequencing logic for Egyptian construction firms. In this way, the paper provides a concise conference version of the underlying research while retaining the study's validated empirical core.

2 CONCEPTUAL MODEL AND HYPOTHESES

The model specifies lean management outcomes as the dependent construct (DV) and five exogenous CSFs coded IDV1-IDV5. These constructs capture the strategic, behavioural, procedural, collaborative, and technological conditions that repeatedly appear in lean construction research as prerequisites for reliable implementation (Sacks et al. 2020; Sarhan and Fox 2015; Alarcon et al. 2017; Ballard 2016; Dave et al. 2018; Hair et al. 2016). Each construct is operationalised through three enablers (E1-E15), enabling the framework to represent both high-level managerial commitment and concrete operational practices.

Table 1 defines the construct codes used in the model, while Table 2 defines the fifteen enablers. Together, the two coding layers create a measurement system that links the conceptual logic of the framework to observable implementation practices inside construction firms. The structural logic of the model, as shown in Figure 1, is represented by five direct hypotheses: H1, top management support positively influences lean management outcomes; H2, employee training and engagement positively influence lean management outcomes; H3, process standardisation positively influences lean management outcomes; H4, collaboration and communication positively influence lean management outcomes; and H5, technology and innovation positively influence lean management outcomes.

The selection of these five CSFs is therefore a direct response to the barrier structure identified in the original study. Top management support addresses the absence of strategic sponsorship; employee training and engagement address low awareness and weak capability development; process standardisation addresses variability in repetitive operations; collaboration and communication address fragmented delivery structures; and technology and innovation support transparency, real-time coordination, and decision quality. In combination, the constructs translate lean from a philosophy into a measurable implementation architecture suitable for Egyptian firms operating under resource constraints and multi-actor project environments (Salem et al. 2006; Alarcon et al. 2017; Ballard 2016; Dave et al. 2018; Mossman 2017; Bryde et al. 2013; Hamzeh et al. 2012; Azhar 2011).

The coding structure is analytically important because it allows the latent constructs to be interpreted in operational terms. IDV1 is not treated as a vague leadership category; it is expressed through active leadership, strategic alignment, and resource commitment. The same logic applies to the remaining constructs. As a result, the model can support both statistical testing and managerial diagnosis, since each significant path can be traced back to a concrete set of implementation practices.

Table 1: Construct codes used in the validated lean management model.

Code	Construct
IDV1	Top Management Support
IDV2	Employee Training & Engagement
IDV3	Process Standardisation
IDV4	Collaboration & Communication
IDV5	Technology & Innovation
DV	Lean Management Outcomes

Table 2: Enabler codes and definitions for the five CSFs.

Code	CSF	Enabler definition
E1	IDV1	Active leadership in lean initiatives
E2	IDV1	Strategic alignment with lean goals
E3	IDV1	Resource commitment for lean training and tools
E4	IDV2	Continuous lean training programs
E5	IDV2	Empowerment through Kaizen and daily meetings
E6	IDV2	Performance feedback and employee involvement
E7	IDV3	Standard procedures for repetitive tasks
E8	IDV3	Use of checklists and visual controls
E9	IDV3	Continuous improvement of standardised workflows
E10	IDV4	Early stakeholder involvement
E11	IDV4	Implementation of Last Planner System (LPS)
E12	IDV4	Transparent communication using collaborative platforms
E13	IDV5	Use of Building Information Modelling (BIM)
E14	IDV5	Real-time data analytics for decision-making

Code	CSF	Enabler definition
E15	IDV5	Integration of lean software and digital tools

The code system also clarifies that the CSFs are complementary rather than competing. Employee engagement without process discipline is unlikely to stabilise work. Technology without collaboration will not improve coordination. Standardisation without management commitment will remain temporary. Accordingly, the model frames lean implementation as an integrated configuration of mutually reinforcing enablers rather than a checklist of disconnected actions (Dave et al. 2018; Mossman 2017; Azhar 2011; Jaca et al. 2016).

The dependent construct is equally important for interpretation. In substantive terms, lean management outcomes refer to gains in waste reduction, time efficiency, workflow reliability, quality enhancement, and cost savings. This makes the DV block meaningful to practitioners because improvements in the model are directly linked to project-level performance dimensions rather than to abstract organisational attitudes (Ballard and Howell 2003; Koskela 2000; Sacks et al. 2020; Abdelhamid 2007; Salem et al. 2006).

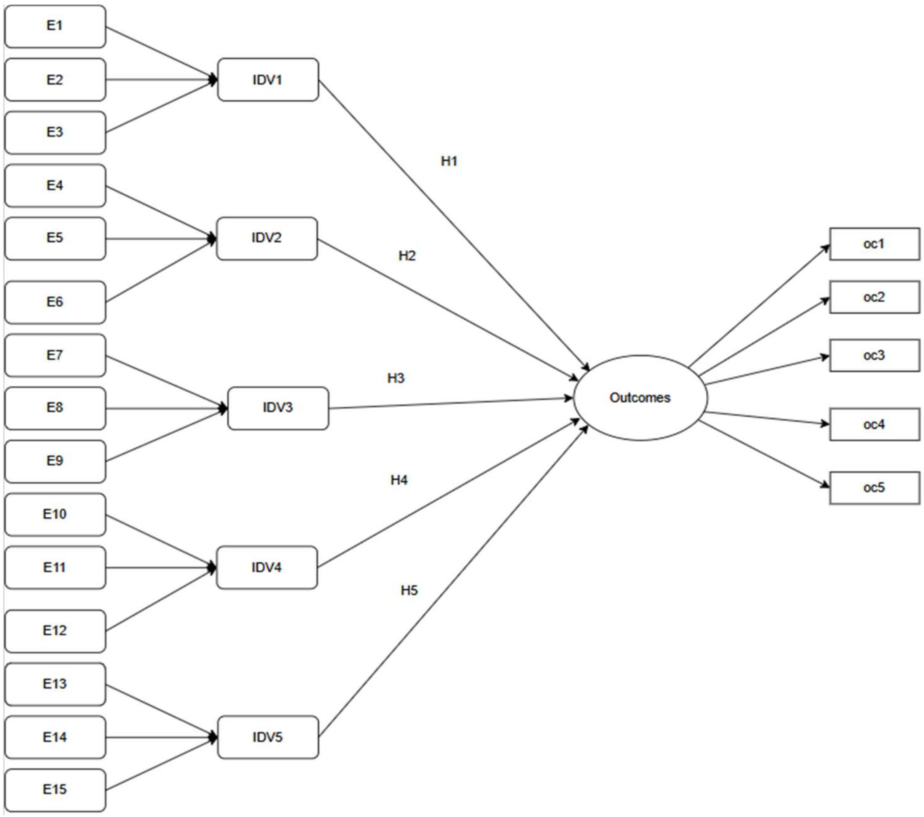

Figure 1: Original theoretical framework linking the five CSFs (IDV1-IDV5) to lean management outcomes (DV).

Defining the construct in this way strengthens the practical value of the framework. When a contractor improves the enabling conditions associated with a significant path, the anticipated gains should be reflected in everyday project metrics, such as smoother workflows, fewer errors, lower material waste, faster task completion, and more efficient use of labour and equipment.

3 RESEARCH METHODOLOGY

The study followed a mixed-method design. The conceptual framework was first developed from the lean construction literature and then translated into a structured questionnaire for empirical validation in the Egyptian construction context. The questionnaire captured the extent to which each enabler is present in current practice and the degree to which each construct supports lean implementation. The final dataset comprised 120 valid responses from construction professionals with relevant project experience.

PLS-SEM was selected because the study aimed to test a predictive model with several latent variables, multiple indicator blocks, and an emphasis on explained variance rather than covariance fit alone (Hair et al. 2016). The reflective measurement model was assessed through indicator outer loadings, Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE). The structural model was then evaluated through bootstrapping, path coefficients, t-statistics, p-values, variance inflation factors (VIF), and the coefficient of determination (R^2).

The analytical design is appropriate to the research problem because it combines theoretical specification with empirical validation. It also allows the study to move from a descriptive discussion of lean enabling conditions to a quantified explanation of which conditions matter most and how strongly they influence lean management outcomes in Egypt (Hair et al. 2016).

Although this research reports the validated PLS-SEM core of the study, the underlying research employed a broader analytical approach to strengthen construct development. The exploratory phase synthesised lean principles, international applications, Egyptian barriers, and expected outcomes; the quantitative phase then translated these themes into construct blocks and indicator items for empirical testing. This sequencing improved content validity because the survey instrument was not assembled as an abstract statistical model but rather as a structured representation of the implementation problems faced by Egyptian practitioners.

Barrier items were also screened in this research through relative importance analysis and Gini-based comparison before the explanatory model was interpreted. That broader procedure is valuable because it connects statistical significance to managerial urgency: high-ranking barriers explain where implementation pressure is strongest, while the CSF model explains where intervention leverage is highest. The conference paper, therefore, presents the confirmatory core of a larger research design rather than a stand-alone questionnaire exercise.

For transparency, sampling followed a purposive approach supplemented by snowball recruitment to broaden coverage across firm sizes and project types. The questionnaire was distributed in 2024–2025 through professional networks, LinkedIn industry groups, and direct outreach to contractors, consultants, and clients operating in Egypt; the 120 valid responses, screened for completeness and engagement-with-lean experience, span engineers, project managers, and senior executives, with the majority reporting more than five years of experience across building, infrastructure, and mixed-use projects. The qualitative phase of the wider study—literature synthesis, expert review of indicator wording, and analytical comparison of Egyptian barrier reports—was used to refine construct definitions, sharpen item wording, and ensure that the survey instrument reflected operational realities rather than an abstract statistical scaffold. This qualitative-to-quantitative sequence provides the content validity layer behind the confirmatory PLS-SEM model reported here.

4 RESULTS AND DISCUSSION

4.1 Measurement Model Assessment

The measurement model demonstrates strong reliability and convergent validity across all constructs, as shown in Table 3. All retained indicators load above the recommended 0.70 threshold, indicating that the observed items are good measures of their intended constructs. Cronbach's alpha values range from 0.746 to 0.969, composite reliability values from 0.845 to 0.977, and AVE values from 0.646 to 0.916. These results confirm that the construct blocks are internally consistent and that the model's coded structure corresponds to coherent empirical dimensions rather than loosely connected survey items (Hair et al. 2016).

The strongest indicators within each construct are strategically informative. Strategic alignment with lean goals (E2) is the leading indicator of top management support; empowerment through Kaizen and daily meetings (E5) leads employee training and engagement; standard procedures for repetitive tasks (E7) dominate process standardisation; early stakeholder involvement (E10) is the strongest indicator of collaboration and communication; and BIM use (E13) is the strongest manifestation of technology and innovation. This pattern indicates that lean implementation in Egypt depends on both strategic direction and disciplined operational routines.

Table 3: Measurement model summary by construct.

Construct	Indicators	Highest loading	Alpha	CR / AVE
IDV1	E1-E3	E2 = 0.874	0.824	0.895 / 0.739
IDV2	E4-E6	E5 = 0.887	0.821	0.893 / 0.735
IDV3	E7-E9	E7 = 0.879	0.746	0.845 / 0.646
IDV4	E10-E12	E10 = 0.905	0.845	0.906 / 0.764
IDV5	E13-E15	E13 = 0.898	0.820	0.893 / 0.737
DV	O1-O4	O3 = 0.964	0.969	0.977 / 0.916

4.2 Discriminant Validity and Model Quality

Discriminant validity was also supported, as shown in Table 4. The square roots of AVE for the six constructs range from 0.804 to 0.957, and the diagonal values exceed the corresponding inter-construct correlations. This confirms that the constructs are empirically distinct and that the model is not merely redistributing the same underlying phenomenon under different labels. Methodologically, the CSFs capture related but separable dimensions of lean implementation (Hair et al., 2016).

Table 4: Diagonal square-root AVE values used for discriminant validity assessment.

Construct	Square root of AVE
IDV1	0.860
IDV2	0.858
IDV3	0.804
IDV4	0.874
IDV5	0.858
DV	0.957

Beyond validity, the model also demonstrates strong explanatory and predictive performance, as shown in Table 5. The coefficient of determination shows that the five CSFs explain a substantial share of the variance in lean management outcomes. The adjusted R^2 indicates that this explanatory power is not inflated by unnecessary complexity, while the Q2 value confirms predictive relevance beyond simple in-sample explanation. In practical terms, the framework can therefore serve as a decision-support structure rather than merely a descriptive map (Hair et al. 2016).

These quality indicators are practically significant because they indicate that the model has sufficient explanatory power to support prioritisation decisions. Rather than launching many lean initiatives simultaneously, firms can use the relative size of the structural effects to phase implementation: leadership commitment and digital enablement first, workforce engagement second, and institutionalisation through standardised routines and collaborative planning thereafter. This prioritisation logic reflects the underlying research argument that successful lean adoption in Egypt must be cumulative and staged rather than symbolic and one-off (Ballard 2016; Dave et al. 2018; Mossman 2017).

Table 5: Overall model quality criteria.

R^2	Adjusted R^2	RMSE	Q^2
0.765	0.757	0.515	0.741

4.3 Structural Model Results

Figure 2 presents the original PLS-SEM structural model obtained from the validated dataset. The standardised paths confirm that all five CSFs contribute positively and significantly to lean management outcomes. The model explains 76.5% of the variance in the dependent construct, which indicates substantial explanatory power for a behavioural and organisational model in the construction domain.

Among the five paths, top management support has the largest standardised effect, confirming that lean implementation in Egypt is fundamentally a governance and leadership issue. Technology and innovation have the second-largest effect, indicating that digital capability amplifies lean coordination, visibility, and response speed. The remaining constructs - employee training and engagement, collaboration and communication, and process standardisation - also make statistically significant contributions, demonstrating that lean performance emerges from a coordinated system rather than from any single intervention (Bryde et al. 2013; Azhar 2011).

The path ordering also clarifies why awareness campaigns alone are insufficient. Even when employees recognise the value of lean, improvement remains fragile if resource commitment, decision authority, and inter-organisational coordination are not embedded at the management level. Conversely, top-down mandates without workforce engagement and routine stabilisation may increase compliance activity but not real process learning. The Egyptian industry, therefore, needs an implementation balance in which leadership, training, standard work, and collaborative control reinforce one another over time rather than being introduced as separate initiatives (Sarhan and Fox 2015; Howell 1999; Abdelhamid 2007; Jaca et al. 2016).

One useful way to read these results is through dependency logic. Management support and technology have the largest direct effects because they create the infrastructure within which other practices can function. Without leadership approval, training budgets, time for coordination, and willingness to standardise work remain limited. Without digital visibility, planning commitments and information flow stay fragmented. The comparatively smaller, yet still significant, effects of process standardisation and collaboration should therefore not be read as secondary; rather, they act as mechanisms through which the stronger strategic drivers are translated into repeatable project behaviour. This interpretation is consistent with the original research emphasis on staged lean maturity rather than isolated tool deployment.

Within the Egyptian context, this dependency pattern is consistent with prior local and regional evidence, in which weak top-management sponsorship and limited digital integration repeatedly emerge as the binding constraints on lean adoption, while training and standardisation are reported as enabling but rarely sufficient on their own (Sarhan and Fox 2015; Salem et al. 2006). The present results refine that hierarchy quantitatively by showing that technology and innovation now exert an effect comparable in magnitude to leadership commitment, reflecting the expanding role of BIM and integrated platforms in Egyptian project delivery over the past decade.

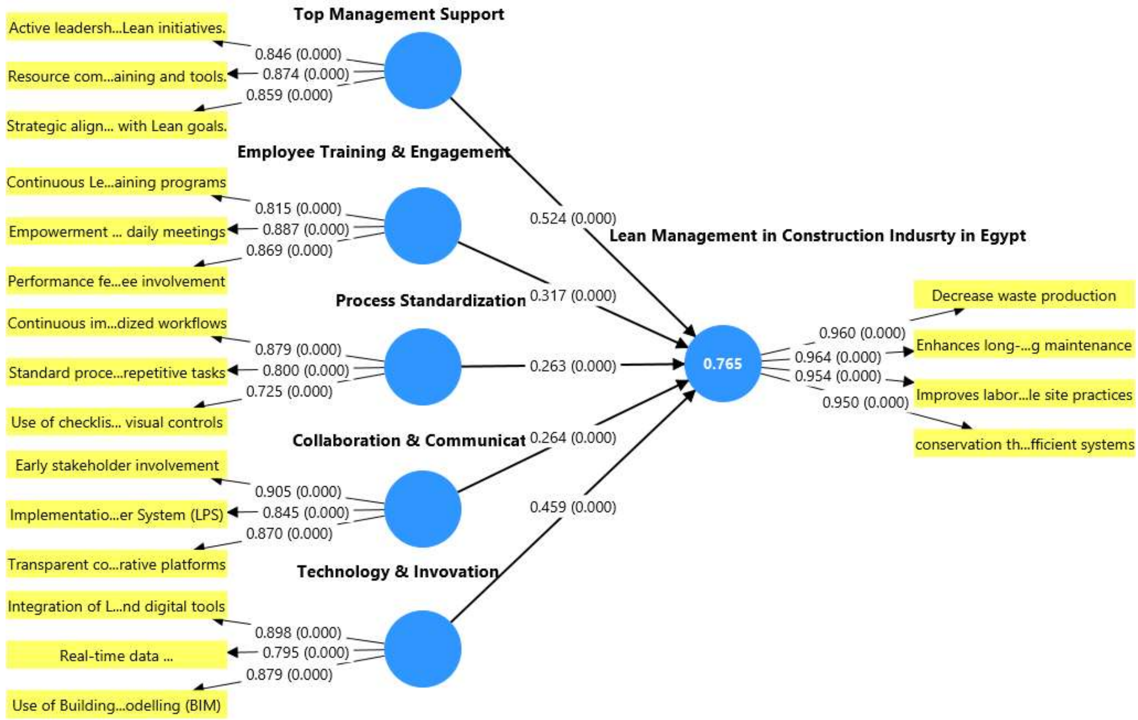

Figure 2: Original PLS-SEM structural model with indicator loadings, path coefficients, and explained variance ($R^2 = 0.765$).

Table 6. Bootstrapped structural results for the five CSF-to-outcome paths.

Hypothesis	Path	β	t	p	VIF
H1	IDV1 -> DV	0.5235	11.3838	0.0000	1.0056
H2	IDV2 -> DV	0.3167	8.1307	0.0000	1.0214
H3	IDV3 -> DV	0.2630	5.4894	0.0000	1.0163
H4	IDV4 -> DV	0.2644	6.5208	0.0000	1.0227
H5	IDV5 -> DV	0.4591	11.4373	0.0000	1.0045

5 MANAGERIAL IMPLICATIONS

The empirical pattern suggests a practical implementation sequence for Egyptian construction organisations. Lean should begin with leadership commitment because IDV1 exerts the strongest structural influence and because its leading enablers - E2, E3, and E1 - create the governance conditions required for every downstream practice. Where strategic alignment is weak, lean initiatives are likely to remain fragmented, under-resourced, and overly dependent on short-term enthusiasm (Sarhan and Fox 2015; Howell 1999; Abdelhamid 2007).

The second priority is to strengthen digital capability and workforce engagement in parallel. The strong performance of E13 and E14 shows that BIM, analytics, and integrated digital tools improve the visibility and responsiveness that lean systems require. At the same time, E5 and E6 demonstrate that training, empowerment, and employee participation are necessary to convert strategic intent into daily site behaviour. Technology without engagement produces compliance rather than improvement; engagement without technology limits coordination and learning (Bryde et al. 2013; Azhar 2011; Jaca et al. 2016).

The third priority is institutionalisation through routines and collaboration. E7-E9 show that process standardisation matters because it stabilises repetitive activities and creates a platform for continuous improvement. E10-E12 show that stakeholder involvement, Last Planner System practices, and transparent communication remain essential for reliable handoffs across the project network. In effect, the validated model indicates that lean maturity in Egypt depends on the interaction of leadership, people, process discipline, and collaborative infrastructure (Ballard 2016; Dave et al. 2018; Mossman 2017; Hamzeh et al. 2012).

For practice, the code structure provides a usable roadmap. Firms can employ the model diagnostically by asking whether E2 is visible in strategy deployment, whether E5 is embedded in team meetings and improvement routines, whether E7 governs repetitive field operations, whether E10 shapes early coordination, and whether E13 is integrated into project planning. These five high-loading enablers form a pragmatic entry point for companies seeking measurable lean progress without treating lean as an abstract management slogan.

For off-site construction adoption specifically, the model offers a direct operational reading. Top management support is the precondition for investing in modular pilots, supplier development, and the contractual frameworks that design-for-manufacture-and-assembly (DfMA) delivery requires; standardised procedures (E7–E9) align with the repeatability that prefabrication and volumetric assembly assume; collaborative routines and Last Planner practices (E10–E12) stabilise the design–factory–site interfaces on which OSC depends; and BIM, analytics, and integrated digital tools (E13–E15) supply the information continuity without which off-site components cannot be reliably coordinated with on-site work. Lean enablers therefore act as the implementation substrate through which OSC ambitions can be realised in Egyptian project environments. Owners, public agencies, and academic institutions can accelerate this transition by embedding earlier coordination, collaborative planning, and digital workflow literacy into procurement requirements and construction management curricula, thereby addressing awareness and training deficits in parallel (Hosseini et al. 2018; Dave et al. 2018; Bryde et al. 2013; Azhar 2011).

At the firm level, lean programs should be managed as change portfolios rather than as single workshops or short site campaigns: a practical sequence starts with one pilot project, defines a small number of priority enablers, establishes routine measurement, and then transfers the lessons to adjacent projects and business units, distinguishing early quick wins (visual controls, structured meetings) from deeper organisational shifts (integrated planning, supplier coordination, digital standardisation). At the sector level, the same logic supports a roadmap that begins with awareness-building and executive sponsorship and moves toward standardising recurring site processes, collaborative planning routines, and digital integration, normalised through education, pilot demonstrations, and locally documented success cases so that lean becomes intelligible and credible within the Egyptian project environment (Sarhan and Fox 2015; Mossman 2017; Azhar 2011).

6 CONCLUSION

This paper validated a five-factor model of lean management optimisation for Egypt's construction industry and demonstrated that successful implementation depends on a coherent set of enabling conditions rather than on isolated lean tools alone. All five critical success factors exert significant positive effects on lean outcomes, with top management support and technology and innovation providing the greatest leverage. The model therefore explains lean performance as a structured organisational capability rather than as a narrow operational technique.

The principal conclusion is that lean improvement in the Egyptian context must be led strategically, enabled digitally, reinforced behaviourally, and stabilised procedurally. Strategic alignment, workforce empowerment, standardised workflows, early stakeholder involvement, and BIM-enabled visibility emerge as the most influential entry points for implementation. When these enablers are combined, the model predicts substantial gains in lean management outcomes and provides a credible basis for scaling lean from isolated project practices to firm-level management logic.

Accordingly, the paper offers both an empirical and a practical contribution. Empirically, it confirms the explanatory strength of the CSF-enabler structure through PLS-SEM. Practically, it translates the validated constructs into a compact decision framework that owners, contractors, and project managers can use to prioritise interventions, allocate resources, and sequence implementation in a disciplined manner across Egyptian construction projects. The conference paper, therefore, positions lean management not as a generic improvement label, but as a measurable implementation architecture that can be systematically advanced in Egypt's construction sector.

Two limitations frame future work. First, the 120-response dataset exceeds the indicator-based minimum for PLS-SEM (Hair et al. 2016), yet a larger, industry-wide sample drawn across more firms and regions would strengthen sector-level generalisation. Second, the framework's contribution to off-site construction is theoretical and analytical at this stage—lean enablers are positioned as the organisational conditions that operationalise OSC practices—and future work should test the model on projects already deploying modular, panelised, or volumetric systems to confirm OSC-specific enabler effects in the Egyptian market.

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