

HOW DISTRIBUTED CONSTRUCTION RESHAPES PRODUCTION SYSTEMS: DEFINING A HYBRID DELIVERY MODEL

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ABSTRACT

The construction industry continues to struggle with productivity and coordination despite ongoing advances in methods and technology. While Lean Construction has improved workflow reliability within individual projects, most efforts remain project-specific and do not address how production is organized across projects. This paper focuses on this gap by examining how construction production systems can be structured more effectively. The study develops a conceptual framework for Distributed Construction (DC), defined as a production approach that combines centralized coordination with distributed execution. Drawing on Lean production theory and industry-informed insights, the framework outlines key system components, including production nodes, coordination logic, and material preparation processes. The results suggest that shifting preparation and sequencing activities upstream can improve workflow stability at construction sites, reduce fragmentation, and support learning across multiple projects. Rather than relying on large, centralized factories, DC enables a flexible network of coordinated production environments. The main contribution of this paper is to position DC as a production system design problem, extending Lean Construction thinking beyond its traditional focus on project-level coordination. The paper concludes by highlighting areas for future research, particularly the need for empirical validation and systematic evaluation of performance outcomes.

KEYWORDS

Distributed construction, lean construction, production system design, industrialized construction, construction productivity.

INTRODUCTION

Despite advances in methodology and innovation, the construction industry continues to struggle with coordination and productivity issues. In fact, productivity growth in construction has consistently lagged behind manufacturing and the rest of economy. Construction projects operate under increasing complexity, labor scarcity, and supply-chain volatility, yet production performance remains inconsistent across markets (Ekanayake et al., 2022; McKinsey, 2017). The primary challenge is not the absence of tools, but the persistence of production systems that remain fragmented and structurally unchanged (Bertelsen & Koskela, 2004).

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Lean Construction research has significantly advanced understanding of production control through concepts such as transformation–flow–value, work structuring, the Last Planner System (LPS), and takt-based planning (Koskela, 2000; Seppanen et al., 2010). These contributions demonstrate that stabilizing workflows can improve project-level performance. However, most Lean implementations operate within temporary, project-bounded production environments. Also, previous industry transformation efforts have similarly failed to achieve system-level change, as they often introduce isolated technologies or delivery innovations without redesigning the underlying production architecture (Bertelsen & Koskela, 2004). As a result, improvements achieved within individual projects rarely translate into persistent production capabilities or system-level learning across multiple projects. In a study by Ballard & Howell (2002), the authors describe this condition as managing an “invisible” production system, in which coordination tools compensate for fragmentation without redesigning the underlying production architecture. For example, consider a construction site where duct installations were planned without a precise sequence due to unresolved design coordination. When workers arrive, they discover that previously installed ductwork needs to be reworked, underscoring the system's invisibility and the reactive steps taken to correct such mistakes. Moreover, Antunes & Gonzalez (2015) argue that construction lacks formally defined and dynamically managed production systems, limiting the ability to analyze and redesign construction production systematically (Koskela, 2000).

Research on industrialized construction has demonstrated that relocating work from the jobsite to controlled production environments can improve productivity and quality. Factory-based modular production, engineering-to-order manufacturing, and platform-based building systems reorganize work through standardized assemblies, buffering, and flow-shop layouts (Bataglin et al., 2025; Lessing et al., 2015). In addition, Design for Manufacturing and Assembly (DfMA) and related prefabrication approaches enable standardized production environments where materials and assemblies move through controlled workflows. Nevertheless, centralized factory-based production models commonly struggle to scale across heterogeneous project conditions and decentralized labor markets due to high capital investment, fixed production capacity, and logistical constraints (Dave et al., 2014; Srai et al., 2015; Vrijhoef & Koskela, 2000). These limitations highlight the need for alternative configurations that balance standardization with distributed execution capacity. At the same time, digital technologies such as Building Information Modeling (BIM), Internet of Things (IoT) systems, and the integration of Lean Construction and BIM (Lean–BIM) have improved coordination and information transparency across construction projects (Dave et al., 2014; Sacks et al., 2010). Nevertheless, digitalization alone rarely alters the underlying production logic of construction systems. Digital tools often replicate and enhance existing coordination practices, leaving the production architecture itself largely unchanged (Liu et al., 2023).

Taken together, these streams of research indicate that construction is gradually evolving toward more distributed and digitally connected production environments. However, most contributions remain focused on isolated improvements, such as project-level coordination tools, individual technologies, or single production facilities. Distributed production in construction has not been systematically conceptualized as a production-system design problem, leaving a critical gap between technological advancement and the redesign of production architecture. (Turner et al., 2021). This leads to a central research question: how can construction production systems be designed to combine centralized production learning and standardization with distributed, project-based execution? Addressing this question requires shifting the focus of Lean Construction research from optimizing individual projects toward designing scalable production system architectures.

This paper addresses this gap by developing a theory-informed framework for Distributed Construction (DC) as a hybrid production-system architecture. Specifically, DC centralizes

repeatable, knowledge-intensive functions, including design intelligence, production standards, and material preparation, while distributing fabrication and assembly through localized execution environments. The study conceptualizes DC as a configurable production-system architecture that reorganizes the locations of learning, buffering, and coordination within the construction supply chain, without introducing a new delivery method or technological platform. By explicitly modeling these relationships, the study contributes to Lean Construction research on production system design, extending the focus from project-level coordination toward system-level production architecture. In Section 2, the literature on Lean production systems, industrialized construction, and digital enablement is reviewed. Section 3 outlines the research methodology. Section 4 develops the DC framework, and Section 5 discusses implications for Lean theory and future research.

BACKGROUND

Lean Construction research has long framed construction as a production system, emphasizing flow, waste reduction, and collaborative planning as mechanisms to improve performance (Ballard & Howell, 2002; Koskela, 2000). Despite decades of methodological development, constant challenges remain, including fragmentation between design, supply, and site execution, subcontractor-dependent labor, and unstable material flows (Bertelsen, 2004; Vrijhoef & Koskela, 2000). These conditions suggest that many inefficiencies stem from the structure of construction production systems, not from a lack of coordination tools.

Across the IGLC literature, production improvement is most often pursued at the project level. Planning and control methods such as the LPS, takt planning, and location-based management have demonstrated effectiveness in stabilizing workflow and improving reliability within individual projects (Frandsen et al., 2013; Seppanen et al., 2010). Conversely, these approaches typically assume a temporary production system that is reconfigured for each project, limiting the accumulation and reuse of production knowledge across a portfolio. From a production-system perspective, this condition constrains the industry's ability to develop persistent production capabilities comparable to those found in manufacturing sectors (McKinsey, 2017).

More recent research has begun to explicitly address production system design. Antunes & Gonzalez (2015) argue that construction lacks formal models capable of representing dynamic, project-based production systems. Building on this foundation, Bataglin et al. (2025) propose a structured model for production system design in engineer-to-order modular construction, linking operational decisions such as buffering, sequencing, and layout to strategic system configuration. Similarly, Geiger et al. (2023) introduce a modular production toolkit that enables systematic analysis of labor productivity through standardized production models. Together, these studies signal a shift within Lean Construction research from optimizing project coordination routines toward explicitly designing construction production systems.

Industrialized and off-site construction further highlight the importance of system configuration. Centralized modular factories and platform-based housebuilding systems have demonstrated productivity and quality improvements under conditions of stable demand and limited variability (Lessing et al., 2015). However, recent studies show that fixed capacity, capital intensity, and logistical rigidity make it difficult for such centralized production models to scale across diverse markets and decentralized labor environments (Mourtzis & Doukas, 2013). These limitations have renewed interest in hybrid production configurations that combine centralized standardization with localized execution.

From a supply-chain perspective, Lean research emphasizes that upstream material preparation and buffering play a critical role in stabilizing downstream production flows (Vrijhoef & Koskela, 2000). The position of buffers, decoupling points, and material preparation activities within the production system strongly influences workflow stability.

From a production-system perspective, these processes can be further understood through “*factory physics*,” which explains how flow, variability, and buffering interact to determine system performance (Spearman, 2014). In construction, where such structures are often implicit or poorly defined, variability frequently propagates directly to the jobsite. Distributed Construction (DC) can therefore be interpreted as a production-system configuration that repositions buffers and decoupling points upstream to stabilize downstream execution.

Digitalization has been widely promoted as an enabler of integration across construction production systems. Early work on Lean–BIM interaction highlighted the potential of digital models to support planning and coordination (Sacks et al., 2010). More recent studies caution that digital tools frequently digitize existing workflows without fundamentally redesigning production logic (Dave et al., 2014; Schimanski et al., 2021). Consequently, digitalization alone has not resolved the structural fragmentation of construction production systems.

Synthesizing these strands reveals a persistent gap. While Lean methods, industrialized production, and digital tools have improved local performance, few studies examine how construction production systems can be deliberately configured to combine centralized learning with distributed execution across projects. Recent research explicitly notes the lack of conceptual and empirical work on hybrid production architectures capable of bridging this divide (Bataglin et al., 2025). Addressing this gap requires reframing construction not merely as a sequence of projects but as a distributed production system that can be deliberately designed, replicated, and improved over time.

METHODOLOGY

This study adopts a qualitative approach to conceptual framework development, grounded in Lean Construction and production system design theory, to analyze construction as a production system and to formulate a theory-driven framework for Distributed Construction (DC). This approach is particularly suited to emerging production models in which empirical data is limited but structural reconfiguration can be modeled theoretically. Conceptual research methods are appropriate when the objective is to articulate production architectures, theoretical relationships, and explanatory system models, not to test causal relationships empirically (Antunes & Gonzalez, 2015). The research design combines literature synthesis with structured analysis of practice-based production configurations, treating DC as an illustrative production architecture without claiming empirical validation. This approach enables theoretical insights from Lean production system design to be compared with emerging DC practices while avoiding empirical generalization (Figure 1).

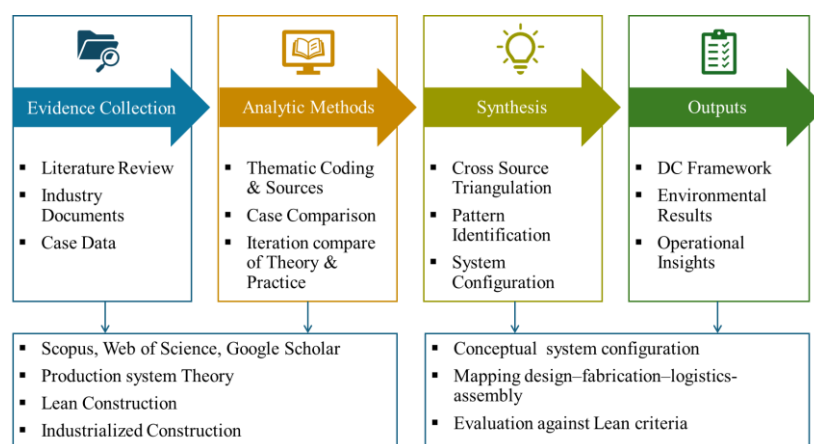


Figure 1: Research methodology flow chart

The research process consisted of four stages: (1) Evidence Collection, (2) Analytic Methods, (3) Synthesis, and (4) Outputs, as illustrated in Figure 1. First, in the Evidence Collection stage, a structured literature review and document analysis were conducted to identify theoretical constructs relevant to construction production systems, including flow stability, buffering, decoupling points, work structuring, and production learning mechanisms. Sources included peer-reviewed literature and industry documentation related to Lean Construction, production system theory, and industrialized construction. These sources were selected based on relevance, recency, and theoretical contribution. Second, in the Analytic Methods stage, thematic coding and cross-case comparison were applied to both literature and practice-based materials. This stage involved iterative comparison between theoretical constructs and observed production configurations to examine how Lean production principles manifest in DC environments. Third, in the Synthesis stage, cross-source triangulation and pattern identification were conducted to integrate insights from theory and practice. This process enabled the identification of recurring production structures and the configuration of key system elements, including production nodes, material preparation strategies, and coordination mechanisms. Finally, in the Outputs stage, the analysis resulted in the development of the DC framework, including a conceptual system configuration, mapping of design–fabrication–logistics–assembly relationships, and evaluation against Lean production criteria. The literature synthesis identifies dominant assumptions, structural limitations, and design requirements for production systems that support flow, learning, and scalability across projects.

Primary sources were selected for relevance to three domains: Lean Construction production system theory, industrialized and modular construction production models, and distributed and digitally coordinated production environments. Peer-reviewed journal articles and conference papers were prioritized, with particular emphasis on research published within the IGLC community and related production-system design literature. We used practice-based materials from MiTek, a construction technology company that combines software, services, engineered products, and automation, and focuses on off-site construction, to help us define DC as a system-level configuration (MiTek, 2023). MiTek was selected as an analytically useful industry reference because it publicly articulates a “*Distributed Construction*” initiative that explicitly links design, manufacturing, and delivery decisions across modular construction projects through BIM/VDC (Virtual Design and Construction), advanced manufacturing, and logistics/supply chain decision support. Accordingly, MiTek materials are used to support conceptual reconstruction of production-architecture logic, not as empirical evidence for generalized performance claims.

The analytical procedure follows an abductive reasoning process, iterating between theory and practice to refine the framework. Initial categories were derived from Lean production system concepts, including flow stability, buffering strategies, standardization, and system-level learning. Practice-based configurations were examined to identify how principles appear in DC production environments. Through iterative comparison between theory and practice, the study developed a conceptual framework describing the configuration of production nodes and the material and information flows within a DC production system. Analytical rigor is ensured through explicit traceability between theoretical constructs and framework elements. Each component of the proposed DC framework is linked to established concepts from Lean production theory or documented production practices, ensuring that the framework remains grounded in existing theory while exploring new production configurations.

The study is scoped to system-level production design, excluding governance, contractual arrangements, and market adoption dynamics. These aspects are acknowledged but remain outside the study's analytical boundary. The framework, therefore, provides a conceptual foundation for future empirical research, including comparative evaluation of distributed

production configurations and quantitative modeling of variability propagation within construction production systems.

FRAMEWORK DEVELOPMENT AND RESULT

DISTRIBUTED CONSTRUCTION AS A HYBRID PRODUCTION SYSTEM

DC can be understood as a hybrid production-system architecture that redistributes production intelligence, material preparation, and fabrication activities across a coordinated network of production nodes. The DC system separates coordination, material preparation, and assembly functions across the construction supply chain, avoiding their concentration at the jobsite.

In conventional project-based construction, the jobsite frequently serves as the primary integration point where design resolution, material preparation, and execution occur simultaneously. This configuration exposes site operations to design variability, incomplete material deliveries, and sequencing conflicts. As a result, variability generated upstream propagates directly into installation activities, destabilizing workflow and reducing labor productivity (Vrijhoef & Koskela, 2000).

The DC framework addresses this condition by relocating preparation, sequencing, and coordination activities upstream. Production intelligence is centralized, materials are prepared in dedicated preparation nodes, and fabrication capacity is distributed geographically. The construction site, therefore, operates primarily as an assembly environment, with limited involvement in material preparation and problem-solving. This architectural separation reflects Lean production principles that emphasize flow stability, buffering strategies, and the strategic placement of decoupling points within production systems.

CORE PRODUCTION NODES AND EXECUTION LOGIC

The production architecture of DC is illustrated in Figure 2, which shows the system's primary nodes and flows. The proposed framework conceptualizes DC as a network of coordinated production nodes that redistribute work across the construction supply chain. Three primary nodes define the production architecture, including (1) a Kitting Center (central coordination node); (2) multiple Rapid Plants (regional fabrication nodes); and (3) Construction Sites (local assembly environments). Together, these nodes form a hybrid production structure that combines centralized coordination with distributed execution across a defined geographic region.

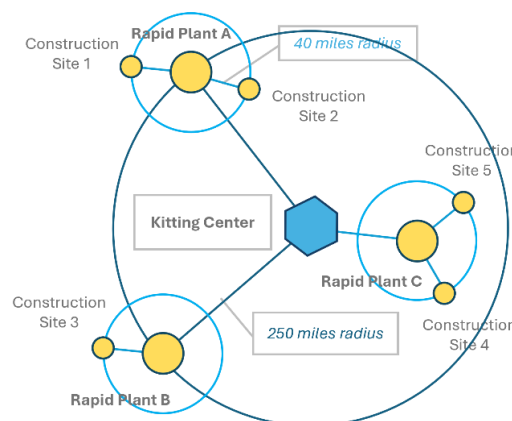


Figure 2: DC system architecture diagram, adapted from MiTek (2023)

Kitting Center: Central Coordination and Buffering Node

The Kitting Center functions as the central coordination hub of the DC system. It operationalizes production intelligence by integrating digital design models, production rules,

and sequencing logic into executable material and workflow instructions. BIM and related digital tools support this process by enabling component standardization, constructability analysis, and task-based sequencing prior to execution. In addition to coordination, the Kitting Center serves as the system's primary buffering and decoupling node. Materials are curated for direct consumption, eliminating the need for workers to search, sort, or interpret inputs during execution. Materials and components are received, sorted, and assembled into task-specific kits aligned with installation sequences. These kits are then distributed to Rapid Plants or directly to Construction Sites. From a Lean production perspective, the Kitting Center repositions buffering upstream, reducing the need for on-site material handling and shielding downstream operations from supply variability. By centralizing preparation activities, this approach ensures that installation crews receive complete, correctly sequenced materials, thereby improving workflow reliability across multiple projects simultaneously.

Rapid Plants: Regional Fabrication Nodes

Rapid Plants serve as regional production nodes, providing localized fabrication and pre-assembly capacity. Located within a defined service radius (e.g., 40 miles), each Rapid Plant supports multiple Construction Sites within its area while connected to the central Kitting Center (MiTek, 2023). Unlike centralized modular factories, Rapid Plants are smaller-scale, flexible production environments configured based on project demand and regional conditions. They receive prepared materials and production instructions from the Kitting Center and perform fabrication or pre-assembly activities in alignment with standardized production rules. This distributed fabrication structure enables the system to balance standardization and flexibility. Production logic remains centralized, while execution capacity is distributed, allowing the system to adapt to local labor availability, transportation constraints, and project variability. These environments enable parallel, multi-trade assembly rather than sequential trade progression typical of conventional construction.

Construction Sites: Local Assembly Environments

Construction Sites serve as the final assembly nodes within the DC system. In contrast to traditional construction, where sites function as primary coordination and preparation environments, DC sites operate primarily as installation-focused environments. At a larger scale, multiple Rapid Plants operate within an extended regional network (e.g., approx. 250 miles), enabling deployment across geographically dispersed projects (MiTek, 2023). Within this structure, site activities are streamlined: minimal sorting, staging, or ad hoc problem-solving is required. Sequencing decisions are resolved prior to delivery, reducing exposure to upstream variability. The site transitions from a problem-solving environment to a controlled execution environment. As a result, site crews can concentrate on execution, achieving more consistent and efficient assembly operations. Within the DC framework, two types of preparation nodes support distributed production: kitting centers and rapid plants. Although both operate upstream of the jobsite, their roles differ in the production system.

Table 1: Comparison of roles of kitting center vs rapid plant in distributed construction

Attribute	Kitting Center	Rapid Plant
Role in the DC system	Material intelligence and preparation node	Temporary, project-specific assembly environment
Primary purpose	Translate centralized standards into task-ready material flows	Enable parallel, multi-trade assembly near the jobsite
Relationship to execution	Protects execution by absorbing supply variability	Extends the jobsite into a controlled environment
Ownership/operation	Centrally managed within the DC platform	Leased and operated by the project's general contractor
Labor model	No trade labor; preparation and verification only	Local trade labor; continuity with onsite work
Production logic	Task-based kitting and sequencing	Task-based, parallel assembly (non-linear)
Degree of standardization	High (assemblies, kits, identifiers)	Configuration to project demand
Primary value creation	Execution predictability and flow stability	Productivity gains through organization and sequencing
Technology role	Supports preparation, verification, and release logic	Supports task guidance, sequencing, and quality checks

Note: These nodes function as interdependent elements within a single distributed production system and are not standalone facilities or interchangeable alternatives.

Kitting centers organize materials into task-specific installation kits, ensuring that installation crews receive complete and correctly sequenced material sets. Rapid plants perform fabrication operations, producing standardized components that can be delivered to multiple projects. Together, these nodes distribute preparation and fabrication activities across the production network while maintaining standardized production logic.

MATERIAL AND TASK SYNCHRONIZATION

A key mechanism enabling distributed production is the synchronization of material preparation with installation tasks. In conventional construction, materials often arrive without clear alignment with installation sequences, forcing crews to perform sorting, staging, and coordination on-site. In the DC system, task-based installation sequences are translated into material-preparation instructions at the kitting center (Figure 3).

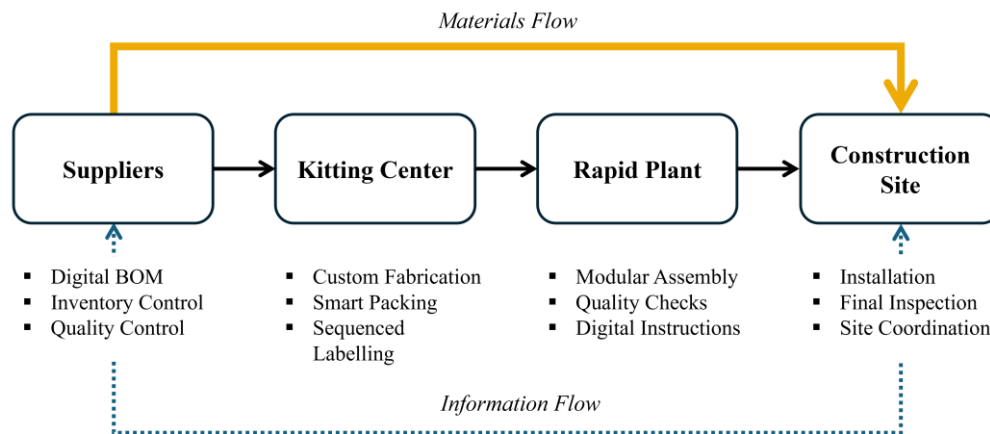


Figure 3: Material and Task Information synchronization supporting execution stability in DC

Materials are packaged into installation-specific kits and delivered according to planned work sequences. This synchronization ensures that complete material sets are available when installation begins and allows crews to focus on assembly activities. From a Lean production perspective, this mechanism operates as a buffering and decoupling strategy, reducing the propagation of upstream variability into site operations.

LOCAL SUPPORT AT SCALE

DC also enables localized production support and scalable, multi-nodal production networks across geographically dispersed projects. Instead of relying on a single centralized factory, the system deploys multiple smaller-scale production nodes that support project clusters within a geographic region (Figure 4). Each cluster consists of a Rapid Plant that serves multiple Sites within a defined local radius (e.g., 40 miles) while remaining connected to a Kitting Center operating at a larger regional scale (e.g., 250 miles).

This configuration replaces sequential trade-based workflows with parallel production fields operating across multiple sites. Materials and components are prepared upstream, allowing construction crews to install without delays caused by on-site preparation. Unlike linear production systems, where trades follow sequentially through the building, distributed production environments allow multiple work fronts to proceed simultaneously. This structure supports scalable, distributed production, in which additional clusters can be deployed as demand increases. As a result, DC enables local responsiveness while maintaining system-level coordination and standardized production processes.

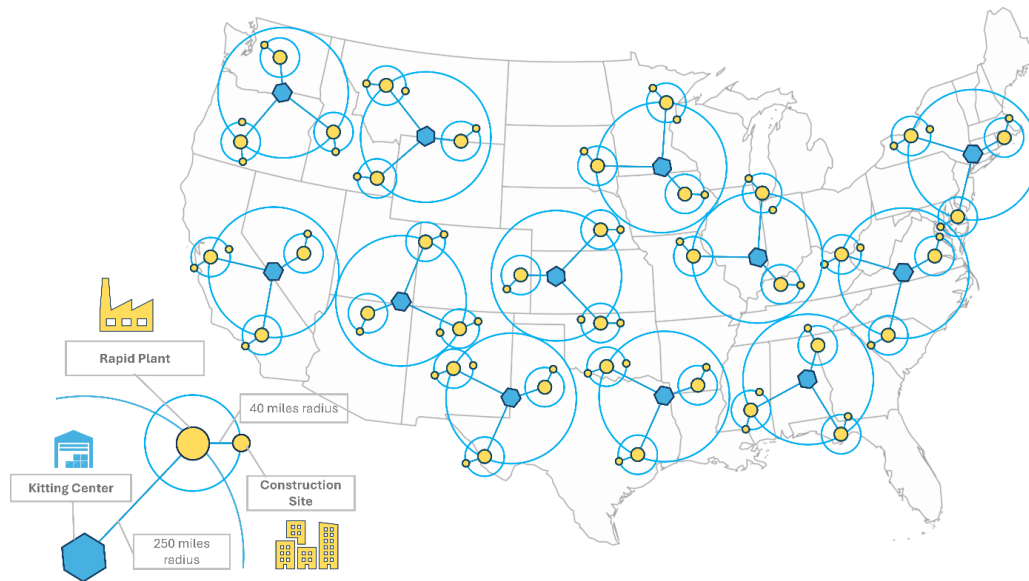


Figure 4: Local support at scale diagram, adapted from MiTek (2023), illustrating a task-based assembly environment configured for parallel execution instead of linear production.

SYSTEM-LEVEL IMPLICATIONS

Taken together, the framework presents DC as a system-level reconfiguration of construction production, not an incremental improvement to existing practices, by centralizing learning, standards, and material intelligence while decentralizing execution through coordinated production nodes. DC directly addresses fragmentation, labor inefficiency, and coordination failure identified in prior research on Lean and industrialization (Schimanski et al., 2021). Significantly, this reconfiguration does not require replacing existing contractors, trades, or supply networks; instead, it reorganizes how work is prepared, sequenced, and executed within the current industry structure. Importantly, this non-disruptive transition ensures that subcontractors continue to play a vital role, easing their integration into the DC model. By aligning with existing roles and responsibilities, DC reduces perceived risk, fosters broader industry acceptance, and paves the way for the adoption of innovation (Alnajjar et al., 2025).

At the system level, DC achieves scalability not by linearly expanding site-based operations or by relying on centralized factories, but by replicating standardized execution nodes across regions. This structure resembles distributed logistics networks, where production nodes operate as interconnected hubs within a larger system. Figure 4 illustrates how Rapid Plants and Kitting Centers are deployed within defined geographic catchments to support multiple construction sites in parallel, enabling local execution while maintaining centralized production intelligence. This spatial configuration demonstrates how DC balances centralization and decentralization at scale. By aligning temporary production capacity with regional demand, the system absorbs variability upstream, preserves continuity for local trades, and supports parallel execution across multiple projects. Scalability is therefore achieved through network replication instead of intensifying site-level control or expanding fixed factory capacity.

From a production-theory perspective, DC shifts construction away from reactive, site-driven control toward rate-controlled, flow-stabilized execution, supporting parallel work and consistent learning across projects. These system-level characteristics differentiate DC from both traditional project delivery and centralized modular manufacturing, forming a foundation for data-driven evaluation of productivity, labor utilization, and execution reliability, which are examined in the following sections. These systems also enable continuous learning through data capture across nodes, supporting iterative improvement across projects.

DISCUSSION

The proposed Distributed Construction (DC) framework highlights the importance of reconsidering construction not only as a sequence of temporary projects but also as a configurable production system spanning multiple projects. Rather than focusing solely on improving coordination within individual projects, the framework shifts attention toward the design of the production system itself. This perspective aligns with Lean Construction research that frames construction as a production system whose performance depends on flow stability, buffering strategies, and coordination across supply-chain actors (Bertelsen & Koskela, 2004; Vrijhoef & Koskela, 2000). From this perspective, DC can be interpreted as a production architecture that intentionally separates production intelligence, buffering, and execution across different nodes within the construction supply chain. This separation contrasts with conventional project-based construction, where design resolution, material preparation, and assembly frequently occur simultaneously on-site.

DC differs from current Lean planning methods, which improve workflow reliability within individual projects. In contrast, DC operates at the production-system level by relocating preparation, buffering, and sequencing upstream (e.g., through kitting centers), thereby reducing variability before it reaches the jobsite. This shifts the focus from project-level readiness to system-level production architecture design.

When these functions are concentrated at the jobsite, variability generated upstream often propagates directly into site operations, destabilizing production flows. By relocating preparation and sequencing activities upstream, DC systems aim to shield installation work from upstream variability and stabilize downstream production flows. This interpretation is consistent with Lean production principles, emphasizing the strategic positioning of buffers and decoupling points within production systems. In addition, the framework suggests that DC may enable new forms of production learning across projects. Traditional construction projects operate as temporary production systems that dissolve after completion, limiting the ability to accumulate operational knowledge.

Consequently, production knowledge is often fragmented across projects and organizations. By centralizing production intelligence functions, DC systems can accumulate knowledge regarding sequencing strategies, component standardization, and material preparation practices across multiple projects. Such learning mechanisms resemble production learning processes observed in manufacturing environments, where production knowledge evolves through repeated cycles of execution and feedback (Lhachemi et al., 2019). Nevertheless, it is important to emphasize that the proposed framework remains conceptual and has not yet been empirically validated. The framework describes a potential production architecture, while the operational feasibility and performance implications of DC systems remain to be empirically evaluated.

CONCLUSIONS AND FUTURE RESEARCH

This study examines construction through the lens of production system design, proposing Distributed Construction (DC) as a networked and distributed production-system architecture that reorganizes the distribution of knowledge-intensive functions, material preparation, and physical assembly across the construction supply chain. Instead of framing DC as a specific technology, factory model, or delivery method, the study conceptualizes it as a configurable production architecture that redistributes production intelligence, buffering, and execution across multiple coordinated nodes.

This research contributes to the body of knowledge by reframing construction as a networked production system, shifting focus from project optimization to system-level production design. While Lean methods such as LPS and takt planning improve workflow reliability within individual projects, the proposed framework highlights importance of

configuring production systems that enable learning and stability across projects. In this sense, improving construction productivity may depend not only on better project coordination but also on deliberate redesign of the broader production system that supports delivery.

The DC framework illustrates how centralized design intelligence, upstream material preparation, and distributed fabrication environments can collectively reduce the concentration of variability at the construction site. By redistributing these production roles, the framework proposes a system configuration that can stabilize downstream installation activities while enabling cross-project learning. However, the framework remains conceptual and exploratory, and its performance implications require empirical validation, including simulation-based evaluation of how variability propagates and node configuration strategies. Future research should investigate how different configurations of distributed production nodes affect workflow stability, labor productivity, and supply chain coordination in real-world project environments.

Particularly, empirical studies and simulation-based modeling could evaluate how buffering strategies, kitting operations, and distributed fabrication nodes affect the propagation of variability within construction production systems. Such studies would advance our knowledge of how distributed production architectures can support more scalable, learning-oriented construction production systems and complement Lean Construction principles.

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