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Social-Network Analytics of Construction Supply Chain

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Article

Social-Network Analytics of Construction Supply Chain

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Highlights

- Supply chain challenges concentrate systematically at specific network positions
- Central brokers face relationship stress, and peripheral actors absorb external shocks
- Central brokers prioritize predictive analytics, while peripheral actors favor traceability
- Network density of 0.591 balances coordination with innovation potential
- Position-based interventions outperform universal supply chain solutions

Abstract

Growing disruptions, uncertainties, and complex risks such as pandemics, extreme weather, and geopolitical conflicts imperil the under-examined construction supply chain, a network that occupies a pivotal nexus in the broader economy. Therefore, it is vital to map its relationships and pinpoint where disruptions concentrate, and recovery can be accelerated. Guided by three research questions on network emergence, positional vulnerability, and how pressures steer technology adoption, this exploratory study maps how construction supply chain networks both create and alleviate operational strain. To address this problem, this study combines empirical, semi-structured interviews with social network analytics. Purposive and snowball sampling yield semi-structured interviews that span all major supply chain roles. Thematic coding translates reported interactions into nodes and edges of a complex network and groups challenges into thematic categories. Furthermore, degree, betweenness, and eigenvector metrics outlined structural vulnerabilities and leverage points. The results show how six main challenge categories (comprising 16 open codes) concentrate systematically at specific network positions. Relationship and contract issues accumulate at high-centrality brokers (degree centrality 0.818) while external pressures affect peripheral suppliers. Technology adoption preferences emerge from structural roles, with central coordinators seeking predictive analytics and peripheral actors prioritizing traceability systems in networks with moderate density (0.591). The research provides a replicable framework for identifying structural vulnerabilities and designing position-based interventions in construction supply chains. The network-theoretic framework opens new research directions for dynamic network analysis, multi-project supply webs, and stakeholder-centered technology integration strategies.

Keywords: construction supply chain; network theory; supply chain coordination; construction procurement; supply chain network

1. Introduction

The construction industry's GDP in the United States contributes \$1.3 trillion in value added in 2024, representing 4.5% of the total GDP [1]. The supply chain plays a key role, accounting for a considerable portion of construction costs. Previous case studies estimate that materials account for approximately 30% of total project costs [2], depending on project type and management practices [3,4]. This reliance on the supply chain makes the industry vulnerable to disruptions. Recent analyses

show that approximately 13.3% of construction projects in the Americas (and 10% globally) face operational and supply chain delays due to extreme weather events [5].

Despite its significance and the absence of a widely adopted standard, the exact definition of the construction supply chain encompasses a broad range of perspectives. Stakeholders may even hold fundamentally different perceptions of responsibilities within the chain [6]. Liao et al. (2023) frames the construction supply chain as an interlinked network where participants are connected through tasks that facilitate the flow of resources and information across project phases [7]. Adopting a more structural perspective, Vrijhoef et al. (2000) defines the construction supply chain through three distinctive elements: a converging system that directs materials to the construction site, a temporary arrangement for producing one-off projects, and a make-to-order process that creates new prototypes with minimal repetition [8]. This structural perspective is complemented by Bankvall et al. (2010), who emphasizes interdependencies and argues that construction supply chains are characterized by their complex web of sequential, pooled, reciprocal, and synchronic relationships [9]. These unique characteristics distinguish construction supply chains from traditional manufacturing supply chains. A shared definition of the construction supply chain could thus be proposed as a project-specific network that partners for value creation, converges at the construction site, and is defined by interdependent flows of materials, information, and finances.

Conceptualization of supply chains as connected nodes grounds network theory as the appropriate theoretical lens [10]. Individual stakeholder behavior is contextual, with each disposition arising from and contributing to the broader relational structure [11]. This means that the broader management challenges plaguing construction supply chains (e.g., fragmentation or resistance to technological adoption) are not merely operational problems but network phenomena that arise from structural properties. Network theory provides the analytical foundation to investigate how stakeholder positions within webs determine their strategic choices or how local interactions aggregate into system-wide performance [12]. As construction supply chains are increasingly recognized as temporary networks that need coordination across multiple organizations with varying relationship histories, network theory becomes essential for understanding how network topology creates brokerage opportunities and coordination bottlenecks [13]. This theoretical foundation bridges the gap between observed coordination failures and their underlying structural origins.

Understanding supply chain inefficiencies in construction requires looking beyond simple sequential relationships between activities. The interdependencies create a complex web of relationships that cannot be well managed through traditional supply chain management approaches borrowed from manufacturing [9]. Given the temporary, project-based nature of the stakeholder networks, decision-making processes and power dynamics often remain impromptu, creating challenges for those unprepared. With a lack of specialized training and education, construction supply chain management is widely perceived as reactive rather than proactive [14]. Therefore, questions remain on how to conceptualize the system and address the potential issues faced.

Critical gaps remain despite the growing body of literature on construction supply chains [15]. As the construction strives toward industrialization, exploratory and empirically grounded studies are needed to capture its evolving landscape [16]. Current research lacks systematic collection of perspectives across different supply chain tiers, which is essential for developing a holistic understanding of coordination mechanisms [17]. While theoretical knowledge of construction supply chains has advanced, empirical investigation of how stakeholder relationships shape operational dynamics remains limited. Moreover, existing research frequently suggests technological solutions without validating their applicability against real-world operational constraints and stakeholder perspectives [18].

Thus, the aim of this research is to conduct an exploratory study to understand how operational dynamics and technology integration emerge from and reshape construction supply chain network structures. Through semi-structured interviews with stakeholders across different tiers and echelons of the supply chain, this research examines current practices, challenges, and perspectives on

technological adoption. The study examines the structure of construction supply chains and how power dynamics influence decision-making. The comprehensive analysis maps the relationship between construction typology, supply chain practices, and stakeholder perspectives to identify patterns that can inform more effective management strategies.

The overall aim will be achieved through answering the following research questions:

1. How do construction supply chains emerge as networked systems of stakeholder relationships?
2. How does structural positioning within supply chain networks determine stakeholder challenge exposure?
3. How do stakeholder needs in construction supply chains impact technology adoption?

2. Literature Review

The competitive pressures facing companies, along with the potential for gaining a competitive edge, make the construction supply chain an area ripe for improvement. Operational changes in construction over the past decades, such as the increasing move from site-based to off-site construction, demand logistical adaptation [19]. It is widely believed that construction supply chain management concepts originated in the manufacturing industry. However, the unique production system of construction projects and its impact on the supply chain are not thoroughly studied. Given that construction supply chains consist of multiple interconnected parties, analyzing them as networks rather than linear buyer-supplier dyads offers a more accurate analytical framework [20]. Network perspective reveals that performance dynamics can stem from structural properties rather than merely operational inefficiencies [21]. Network constructs in supply chain analysis and their implications for technology integration are reviewed below.

2.1. Supply Chain Structures in Construction

The built environment represents a collection of assembled components. Supply chains in construction can follow various procurement paths: engineer-to-order (custom design and build), modify-to-order (adaptation of existing designs), configure-to-order (combination of standard modules), and select variant (choosing from predefined options). Make-to-stock is an example of a delivery method in manufacturing that is not applicable to construction [22]. Therefore, while general supply chain management standards like SCOR model and ISO 28000 series exist, they are not fully aligned with the unique characteristics of construction [23,24]. Currently, construction supply chain management principles appear mainly as subsets of broader frameworks, such as material sourcing criteria in sustainability standards like LEED and BREEAM [24,25]. Construction-specific supply chain standards are not yet widely established. This situation affects their resilience management, as standardized processes for organizational structures remain underdeveloped in both theoretical foundation and practical implementation [7].

Construction supply chains exhibit inherent network properties that traditional frameworks fail to capture. Specifically, structural holes — gaps in network structures where actors lack direct connections — enable intermediaries to control information flow, with Burt's constraint score quantifying this brokerage potential [26]. Empirical evidence shows that managers positioned near these gaps achieve superior performance outcomes due to their access to diverse, non-redundant information sources [26]. In tandem, brokerage positions emerge when actors span these structural holes, bridging otherwise disconnected parties [27]. Construction supply chains exhibit systematic structural holes, including those between the construction and operation phases, between end-of-life stages and forward supply chains, and where reverse logistics interfaces with forward logistics. These disconnections prevent information flow across project lifecycle stages [28]. Contractors systematically occupy brokerage positions, bridging owners and suppliers in triadic structures. These brokers can function as mediators, tertius gaudens, or oppressors, with their power depending on dependency relationships and switching costs [27].

2.2. Stakeholder Dynamics and Management Challenges

Construction supply chain is characterized by significant customer influence, a large number and variety of stakeholders, complex relationships, resistance to change, an often make-to-order supply model, and cyclical demand patterns [29]. Typically, a diverse array of stakeholders, including architects, engineers, main contractors, specialty subcontractors, and material suppliers are involved in the construction project's supply chain. The construction supply chain has been categorized into vertical (often attributed to the private sector) and horizontal sectors. The actors involved often collaborate on a one-time basis for a specific project, creating multiple temporary organizational structures [30].

The effectiveness of temporary organizational structures depends on how stakeholders are embedded within broader networks of relationships. Network embeddedness refers to how deeply a stakeholder is positioned within a network of relationships, affecting their access to informational and reputational benefits [31]. Dense networks create tightly connected stakeholders with many common contacts, which leads to intense communication but often results in the sharing of redundant information from multiple sources [32]. In contrast, sparse networks provide diverse and non-redundant information and weaker coordination mechanisms, which can create space for innovation. Understanding stakeholder network positions becomes critical for predicting relational behaviors and collaborative potential [33].

Behera et al. (2015) investigate the inherent complications of the construction supply chain management [29]. Both simple and complex construction projects share common challenges in the supply chain, such as the number of stakeholders, conflicting functional objectives, and the need for improved information flow and balanced objectives. Unlike process-based supply chains with recurring demands, construction is project-based, pull-driven, and characterized by high levels of uncertainty [34]. The inherent uncertainties in construction supply chains lead to inefficiencies in network interactions and stakeholder relationships. Process uncertainties constitute the largest share of these inefficiencies, with timely and accurate information flow being one of the most critical factors [35]. One of the defining features of the construction supply chain is its fragmentation and the prevalence of short-term, adversarial relationships. For example, one common supply chain method is competitive bidding, which, although seemingly cost-effective, often leads to limited information sharing and long-term improvement. Therefore, identifying the key stakeholders and understanding their viewpoints on the issues they face in the construction supply chain is essential.

2.3. Technological Advancements and Adoption

Despite its slow progression, the construction industry is gradually evolving as technological advancements create new opportunities. Many firms are beginning to recognize the need for a more efficient supply chain, drawing lessons from sectors such as manufacturing. As the industry progresses, there is a growing emphasis on improving knowledge transfer, information exchange, and facilitated decision-making within construction networks. The shift toward more collaborative practices may help address the longstanding issues of fragmentation and inefficiency that have characterized the construction supply chain. However, technology adoption is not always uniform across stakeholders. The network perspective demonstrates that stakeholder position within supply chain networks significantly influences innovation capacity [36]. Stakeholders in core network positions face different innovation pressures and technology needs compared to those in peripheral positions, resulting in variations in adoption preferences [37]. This suggests that technology preferences emerge from the innovation pressures created by stakeholder network positioning rather than mere universal industry requirements. Understanding how network embeddedness shapes technology adoption willingness becomes essential for explaining variation in stakeholder technology preferences and developing effective implementation strategies.

Recent review papers report an increasing effort in proposing technology-based applications for construction supply chain [18]. Digitalization of construction, through the use of Building Information Modeling (BIM) and digital twins, has the potential to significantly impact supply chains

by acting as an innovation-enabling information hub [38]. Secure tracking and data preservation can be achieved through the implementation of Internet of Things (IoT) and blockchain. Predictive and analytic capabilities provided by Artificial Intelligence (AI) can enhance supply chain decision-making [39]. Nevertheless, a common limitation shared by the previous studies is the lack of real-world implementation and industry-insight-driven studies specific to this area.

2.4. Research Gap

While construction supply chain management has gained research attention, gaps persist in understanding supply chain practices and dynamics. Research has developed in a fragmented manner, focusing on isolated operational issues rather than examining supply chains as interconnected networks of stakeholder relationships. While theoretical frameworks are proposed, empirical studies that map actual stakeholder networks and analyze how structural positioning affects operational practices remain limited. Additionally, although recent literature emphasizes technological solutions, these propositions rarely investigate stakeholder expectations or consider how their roles influence technology adoption preferences. The relationship between network structure, operational challenges, and technology adoption patterns remains poorly understood.

Therefore, this study addresses these gaps by applying network theory to analyze construction supply chain practices, challenges, and technology adoption. Through interviews with different construction supply chain actors, this research investigates how various stakeholders interact and operate within the network. The findings will contribute to developing a better understanding of the relationship between supply chain challenges and potential technological solutions.

3. Research Method

This study employs a qualitative research design utilizing semi-structured interviews and thematic analysis to investigate construction supply chain practices, challenges, and technological adoption. As shown in Figure 1, the research methodology follows a systematic workflow starting by data collection through screening and interviewing experts, data processing with a grounded theory approach, and data analysis through pattern identification. The proposed approach allows for a deep exploration of stakeholder perspectives while maintaining methodological rigor through structured coding procedures and reliability testing. The methodology was specifically chosen to capture the complex interactions and varied viewpoints within construction supply chains, addressing the identified research gap in empirically validated stakeholder perspectives.

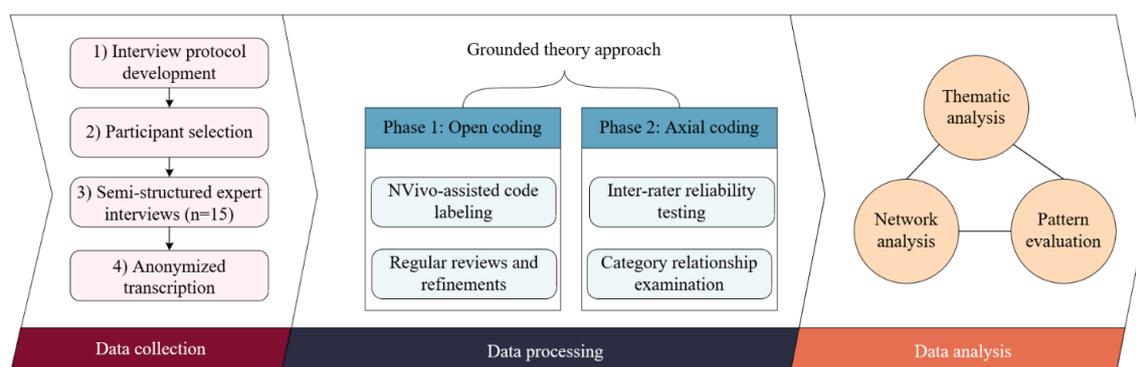


Figure 1. General research flow.

3.1. Data Collection

This study employs semi-structured interviews as the primary data collection method. Semi-structured interviews are chosen for their ability to balance systematic data collection with the flexibility needed to explore complex supply chain dynamics [40]. Semi-structured interviews provide methodological alignment with the complex nature of construction supply chain research.

The interconnected network of stakeholders in construction supply chains demands an interview format that adapts to varying organizational perspectives while maintaining consistent data collection protocols [40]. The dual approach of targeted closed-ended questions and exploratory open-ended inquiries facilitates examination of both operational and strategic dimensions of supply chain management [41]. The semi-structured interview is a particularly suitable approach to this topic, as supply chain management has complexities that necessitate open-ended questions as follow-up queries [42].

Participant selection employs purposive and snowball sampling to ensure comprehensive coverage of supply chain roles. Through professional networks in the construction industry, participants were recruited based on their experience and position within the supply chain. The selection criteria required a minimum of three years of experience in construction supply chain operations, targeting roles such as supply chain managers, project managers, and suppliers. While each participant is primarily attributed to one role, they may have transitioned between roles or worked closely with other stakeholder functions. Table 1 provides an overview of participant demographics. The interview protocol is designed to address the outlined research questions on supply chain practices, challenges, and technology adoption. The questions were formulated to facilitate the discussion while maintaining alignment with the research objectives. Each interview session was conducted via online platforms and lasted approximately 60-90 minutes to ensure coverage of the research scope.

Table 1. Participant profiles by role, experience, and education level.

Role	Experience		Degree		
	6 to 10 years	> 10 years	Associate	Bachelor's	Master's
Owner/ Developer	1	3	0	2	2
Consultant/Designer	0	1	0	0	1
Contractor	0	4	1	3	0
Subcontractor	1	2	1	2	0
Supplier	0	3	0	2	1
Total	2	13	2	9	4
	15				

In determining the appropriate sample size for this qualitative research, this study adopts a balanced approach that draws on both Francis et al.'s (2010) structured guidance and Braun and Clarke's (2020) emphasis on interpretative depth [43,44]. While Francis et al. suggest an initial analysis of 10 interviews followed by three additional interviews to confirm saturation, Braun and Clarke argue against rigid numerical criteria, emphasizing instead the importance of rich data interpretation and thematic depth. For this study, while initial thematic patterns emerged after eight interviews, the study proceeded to 12 interviews to ensure adequate coverage of key supply chain roles and achieve interpretative depth as emphasized by Braun and Clarke (2020). Following Francis et al.'s (2010) guidance, three additional interviews were conducted to confirm saturation, bringing the total sample to 15.

3.2. Data Processing

Grounded theory is particularly suitable for exploratory studies where the aim is to understand phenomena from participants' perspectives without imposing preexisting theoretical frameworks. Taking a grounded theory approach, the data processing and data collection followed a cyclic iterative process. Following the anonymization of interview transcripts, data processing occurred in

two main phases. The first phase involved open coding using NVivo software, where transcripts were examined to identify and label concepts within the data. The coding process included regular reviews and refinements to ensure consistency and reliability.

The second phase involved axial coding to examine relationships between the identified categories. Traditional collaborative analysis sessions were conducted using affinity diagramming techniques, where researchers examined and mapped category interconnections. Consequently, codes were grouped and reorganized to identify patterns and relationships between categories. While traditional grounded theory concludes with selective coding to develop a unified theory, this step is omitted as theory development is not objective.

3.3. Data Analysis

The analysis part examines the patterns and relationships within the coded interview data. The analysis employs both thematic analysis for stakeholder perspectives and network analysis for structural patterns. Thematic analysis involves reviewing and interpreting coded segments to identify recurring patterns and relationships. During pattern identification, the analysis considers responses that both align with and diverge from emerging themes, with specific focus on relationships between supply chain challenges and technological solutions while maintaining attention to contextual factors. Network analysis systematically maps stakeholder relationships and coordination patterns reported in interviews. Stakeholder connections are identified through evidence of recurring information exchange or coordination directly impacting material procurement. These relationships are quantified using frequency counts across interviews and visualized using network metrics including degree centrality, betweenness, closeness, eigenvector centrality, and clustering coefficients. Network visualization employs multidimensional scaling to position stakeholders based on relationship strength.

The analysis evaluates emerging patterns based on their frequency across interviews, strength of support, contradictions, and relevance to research objectives. Frequency assessment tracks consistency across organizational roles. Challenge intensity mapping overlays thematic findings onto network positions to identify how structural positioning influences stakeholder experiences. Therefore, the relational analysis helps develop a more holistic view of the construction supply chain system.

4. Results

Analysis of the data reveals construction supply chains as complex networks where operational practices, challenges, and technology adoption preferences emerge from stakeholder positioning and relational dynamics. The results demonstrate that construction supply chains function as interdependent networks where individual experiences and strategic choices are intertwined by relationship patterns within the broader system.

4.1. How Does Construction Supply Chain Work?

Supply chain operations in construction are shaped by role, scale, and project type but generally follow a staged, role-differentiated structure. Across different tiers, supply chain management typically involves early identification of material needs during preconstruction phases, followed by systematic procurement processes that balance cost considerations with delivery reliability. Among contractors and subcontractors, supply chains are structured with internal teams coordinating across procurement, field operations, and preconstruction. Procurement typically begins early, especially for long-lead items, and involves detailed scope definition, vendor vetting, and coordination on submittals and delivery timelines. General contractors operate decentralized procurement where individual offices or project teams manage buying decisions while following consistent corporate frameworks. In contrast, specialty contractors maintain more centralized control with dedicated purchasing specialists managing day-to-day operations under strategic oversight. Material suppliers

employ hybrid approaches, combining automated reorder alerts with manual review processes where purchasing managers factor in market trends and product-specific demand patterns.

The supply chain structures demonstrate significant variation in vertical versus horizontal integration strategies. Some organizations develop warehouse storage, trailer fleets, and prefabrication capabilities to support vertical integration, while others maintain leaner footprints and rely more heavily on external vendor performance. Communication loops, e.g., weekly coordination calls or multi-stakeholder meetings, are essential for maintaining alignment between office-based planning and on-site execution. Several interviewees emphasized a service-oriented mindset within supply chain teams that essentially treats internal field crews as primary customers. Others prioritized early-stage alignment, using scope clarity and long-lead item tracking as risk mitigation tools. Notably, stakeholders consistently prioritize relationship-based decision-making over purely cost-driven procurement. In many cases, relationships and trust outweighed cost as the dominant factor in vendor selection. Some adopted flexible payment terms for trusted partners, while others introduced competitive pressures through periodic vendor reviews. Coordination practices also varied. Some teams built procurement directly into the design phase, using product specifications to steer future choices. Others managed procurement separately, relying on early warehousing or advanced purchasing agreements to ensure readiness. Across the board, supply chains were described as dynamic systems requiring adaptability, foresight, and constant communication. As one participant framed it, "The field has to have the green light at all times", underscoring a shared principle that supply chains must enable execution, not delay it.

Given the network theory lens adopted in this study, stakeholders and relationships found in the interviews are systematically mapped to provide a holistically standardized view of the construction supply chains underlying network (Figure 3). Network representation provides a systematic framework for interpreting the structural properties that influence coordination patterns and dynamics within the system. To establish the network, first a list of 12 nodes is found, then the 39 edges connecting the nodes are formed by evidence of recurring information exchange or coordination directly impacting material procurement. The triangular matrix in Figure 2 displays the frequency of reported connections between stakeholder types, where each cell value represents the number of interviews that described a working relationship between the corresponding node pairs. The network visualization was created using Multidimensional Scaling to position nodes based on relationship strength, where stakeholders with stronger working relationships appear closer together in the network layout.

Analysis of the network reveals notable structural patterns that correspond to the operational dynamics described earlier. Table 4 presents network metrics for each stakeholder type. General contractors and manufacturers emerge as the most central actors, with degree centrality scores of 0.818, which shows their extensive direct connections across the network. Although roles such as third-party logistics (3PL) providers and owner's representatives appear in the network, their presence does not imply participation in every project. Rather, they exist within the studied supply chain space as specialized functions utilized selectively. Thus, since these roles are employed less frequently across projects, they exhibit lower centrality scores and appear as more peripheral network positions. Conversely, general contractors consistently demonstrate high centrality, reflecting their position as essential coordinating actors across virtually all construction projects. The metrics presented in Table 2 provide the foundation for identifying structural holes and brokerage opportunities within the network.

The centrality metrics reported in Table 2 quantify different dimensions of stakeholder positioning within the supply chain. Degree indicates the number of direct connections; Betweenness reflects a stakeholder's role in bridging others; Closeness measures accessibility to the rest of the network; Eigenvector identifies influence through ties to other central actors; and Clustering coefficient shows how densely connected a stakeholder's neighbors are. In addition, overall network density is 0.591, which indicates a moderate overall connectivity.

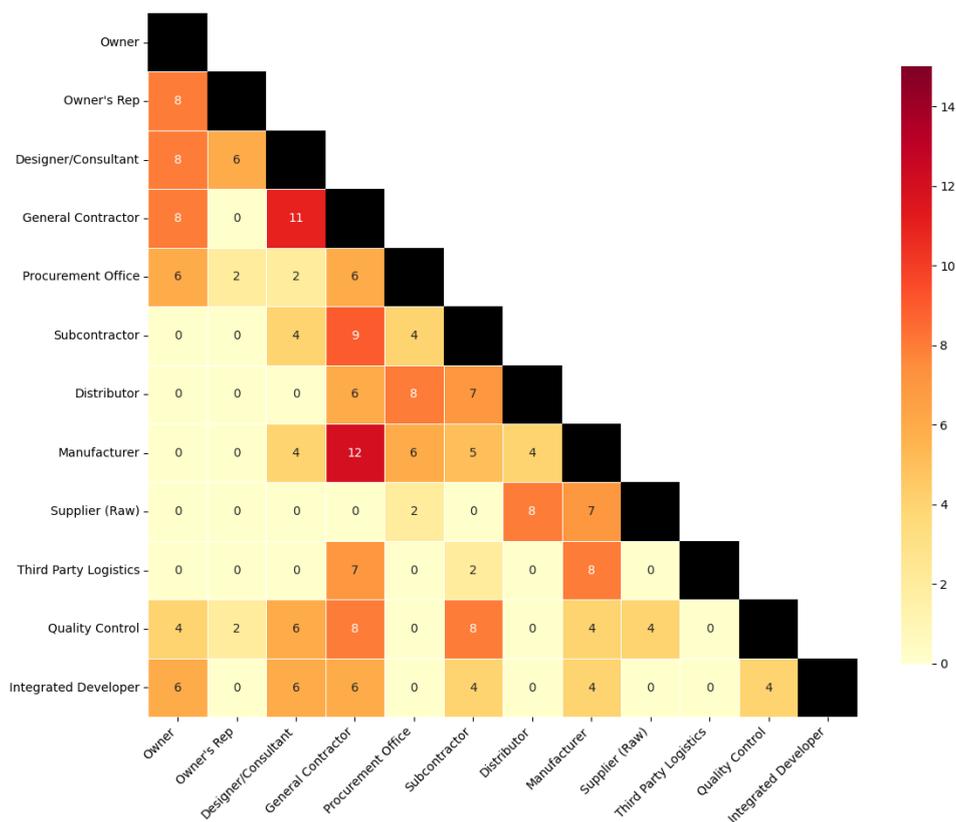


Figure 2. Weighted adjacency matrix of supply chain network .



Figure 3. Construction supply chain multidimensionally scaled network.

Table 2. Structural network metrics for construction supply chain stakeholders.

Node	Degree	Betweenness	Closeness	Eigenvector	Clustering
General Contractor	0.818	0.094	0.846	0.372	0.611
Manufacturer	0.818	0.1	0.846	0.361	0.583
Procurement Office	0.727	0.095	0.786	0.32	0.536
Designer/Consultant	0.727	0.042	0.786	0.347	0.714
Subcontractor	0.727	0.057	0.786	0.339	0.643
Quality Control	0.727	0.078	0.786	0.329	0.571
Integrated Developer	0.545	0.007	0.688	0.285	0.867
Owner	0.545	0.019	0.688	0.26	0.733
Distributor	0.455	0.009	0.647	0.223	0.8
Owner's Rep	0.364	0.003	0.579	0.179	0.833
Supplier (Raw)	0.364	0.007	0.611	0.175	0.667
Third-Party Logistics	0.273	0	0.55	0.152	1

4.2. What Goes Wrong and Where?

Data analysis uncovered a range of challenges faced across the construction supply chain. Through open coding, 16 initial challenge codes were identified, which were then refined through interrater reliability testing and grouped into six main categories through axial coding. A set of interconnected challenge domains that span from external market forces to internal organizational dynamics was revealed (Figure 4).

- A frequently cited challenge category centered around *relationships & trust*. Stakeholders described a range of interpersonal dynamics that undermine collaboration. Specifically, supply-client variability, lack of long-term relationships, lack of transparency, not understanding construction workflow, and lack of procurement planning create fragmented coordination patterns. A common sentiment is the difficulty in forming enduring relationships in project-specific environments. Without established relationship histories, stakeholders operate with incomplete visibility into others' true capabilities, resource constraints, and strategic priorities. Moreover, the lack of transparency creates asymmetric information dynamics that perpetuate coordination failures. This information asymmetry generates self-reinforcing cycles where limited transparency reduces collaborative potential, which further incentivizes defensive positioning across the network.
- *Contract & payment* issues were another dominant theme. This category includes inter-organizational communication barriers, contractual trust deficits, misaligned incentives, and cash flow constraints. Inter-organizational communication breakdowns often contribute to contractual ambiguities or disputes, with participants recounting examples of scope changes, delayed approvals, or unmet expectations that lead to friction between parties. Contractual trust deficits were cited when stakeholders expressed skepticism about others' reliability in contract execution, ranging from concerns about quality delivery standards to fears of scope creep. Misaligned incentives, such as one party prioritizing cost savings while another focuses on

schedule or quality, can further complicate collaboration. Cash flow constraints, especially when combined with delayed payments or account holds, introduced operational stress that cascaded downstream and affected procurement, staffing, and scheduling decisions.

- *Project-based* and *Quality* challenges are complexities that arise from the unique production characteristics and material management requirements of construction. They include inventory management issues, project-originated risks, quality control problems, and inefficient material tracking systems. Throughout interviews, participants highlighted that each project introduces new conditions — with its own set of design specifications, site conditions, and schedules — which limit the potential for standardized workflows. Inventory management problems often make it difficult to align material deliveries with field readiness. Project-originated risks ranged from unexpected site constraints and permitting delays to last-minute scope changes. These risks not only disrupt procurement planning but also decrease the reliability of upstream coordination. Quality control issues arise when specifications are ambiguous, approvals are rushed, or accountability among stakeholders is unclear. Several interviewees pointed to situations where miscommunication or condensed review windows led to installation errors and rework. Inefficient material tracking systems, which often depend on manual updates or are scattered across platforms, reduce visibility into material location, condition, or compliance. Without dependable tracking, field teams work with limited information, and delays caused by this ripple throughout the project.
- *Transportation* challenges were commonly raised, particularly by those overseeing field operations and material flow. Delays in freight arrivals and limited control over third-party logistics were common concerns. Several participants explained bottlenecks caused by missed or partial deliveries, often due to carrier constraints or coordination breakdowns between distributors and job sites. Such issues were especially pronounced when dealing with long-lead or specialty items. Participants observed that even when internal planning was proactive, the inability to track or reroute shipments in real time led to friction, often forcing site teams to adjust schedules again.
- *External/ Global* challenges capture pressures beyond the immediate control of project stakeholders. For example, port congestion, volatile commodity prices, shifting international trade policies, and tariffs. The difficulty of securing critical inputs in a globally disrupted market was emphasized, especially during and following the COVID-19 pandemic. In several cases, participants described how delayed shipments, customs backlogs, and unfavorable exchange rate fluctuations forced procurement teams to renegotiate contracts, switch vendors midstream, or increase inventory buffers, often undermining lean construction strategies. Tariff-driven price volatility in materials such as steel, aluminum, and electrical components compounded these effects. Although these challenges originate outside the immediate project network, their consequences penetrate inward.

A role-based challenge intensity heatmap was developed for each of the main challenge categories (Figure 5-7). Participants rated the intensity of challenges on their operations. These network visualizations display the frequency and intensity with which different stakeholder types reported experiencing each type of challenge, with node color intensity representing the perceived severity (ranging from light yellow for minimal impact to dark red for severe impact). The resulting patterns reveal distinct concentrations of challenge exposure that correspond to stakeholders' positions within the network.

- The *relationship & trust* challenges (Figure 5, left) appear to be greatest for general contractors, procurement offices, and distributors, who are the nodes with the highest degree centrality. This concentration is not coincidental. Central actors must maintain relationships across the broadest range of network connections and mediate between upstream suppliers and downstream field operations. When relationship breakdowns occur, they disproportionately affect these highly connected nodes because their operational effectiveness depends on successfully managing multiple stakeholder demands simultaneously.

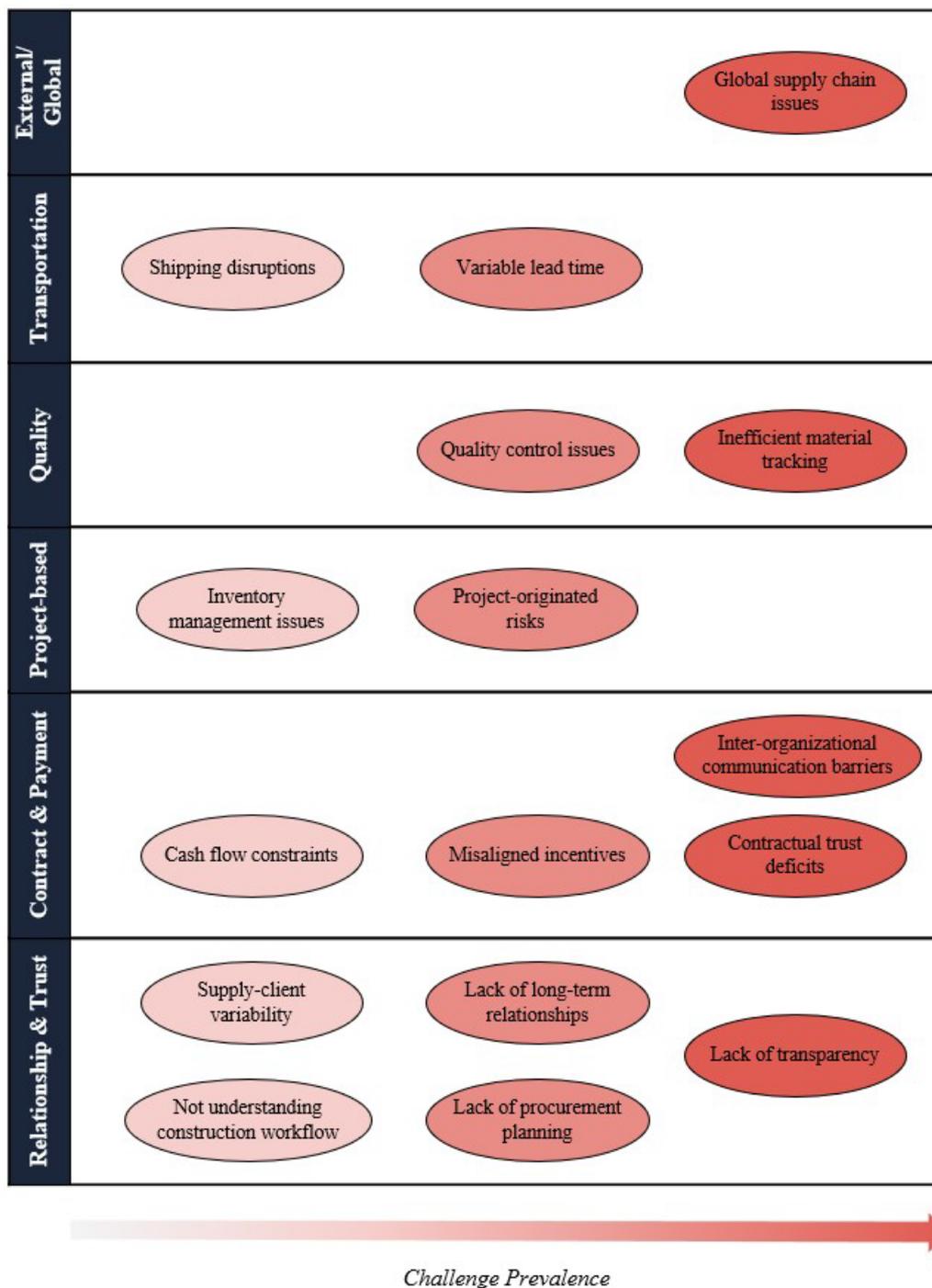


Figure 4. Construction supply chain challenges by category and prevalence.

- *Contract & payment* issues (Figure 5, right) reveal a network pattern where challenge intensity concentrates at nodes occupying brokerage positions between the supply and demand sides of the network. General contractors and manufacturers exhibit the highest intensity, reflecting their roles as financial intermediaries who must coordinate payment cascades across multiple network tiers. The low intensity at subcontractors, in contrast to owners, suggests a form of embedded insulation, where their close relationships with contractors protect them from broader payment system complexities. This distribution illustrates how contractual and payment stress can concentrate at structural brokerage positions that span supply-demand divides rather than being evenly distributed among all financially connected actors.
- *Transportation* challenges (Figure 6, left) show intensity at distributors and third-party logistics providers, which is consistent with their operational role as intermediaries navigating logistics.

General contractors experience the impact as primary recipients of deliveries. The notable intensity at integrated developers suggests that actors with dual exposure to both supply chain logistics and project delivery responsibilities feel transportation stress more acutely than traditional owners. Conversely, manufacturers and raw suppliers show minimal impact, indicating that transportation challenges primarily affect the distribution and final delivery segments rather than production origins.

- *Quality* challenges (Figure 6, right) show a role-based pattern where responsibility for quality assurance creates concentrated stress at specific nodes. Quality control node exhibits maximum intensity, reflecting their direct accountability for identifying quality issues throughout the project lifecycle. The procurement office shows the second-highest intensity, indicating its critical role in translating quality specifications into vendor requirements. Designers experience a notable impact as the originators of quality specifications, bearing responsibility when unclear or inadequate design requirements lead to failures. General contractors and manufacturers show moderate intensity as the primary implementers and producers who must translate quality requirements into deliverable outcomes.
- *Project-based* challenges (Figure 7, left) show relatively uniform low intensity across most network nodes, with only general contractors experiencing moderate impact. This pattern confirms that project-specific complexities primarily affect actors responsible for overall project execution rather than creating widespread stress across the network. The minimal intensity at other nodes indicates that a form of structural buffering exists where central coordination nodes shield peripheral supply chain actors from project-specific variability.
- *External/global* challenges are most intensely felt by raw material suppliers, the stakeholders furthest upstream in the chain. This distribution reflects the structural perception of reality that global disruptions primarily affect actors positioned at the origin points of material supply chains. Raw suppliers, who directly interface with global commodity markets and international trade flows, bear the immediate burden of external pressures.

While the burden of each challenge type varies by role, all challenges originate as localized perceptions. These are not objective system measures but rather stakeholder-reported exposures that reflect how individuals experience risk from their network position. For instance, external volatility may appear to concern only suppliers, but in a dynamic network, such pressures ripple downstream.

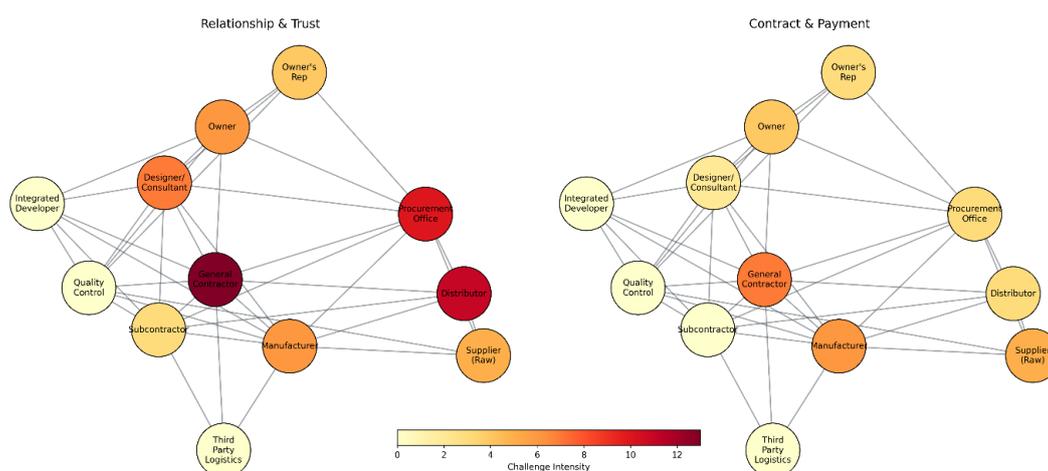


Figure 5. Challenge intensity heatmaps: relationship & trust (left) and contract & payment (right).

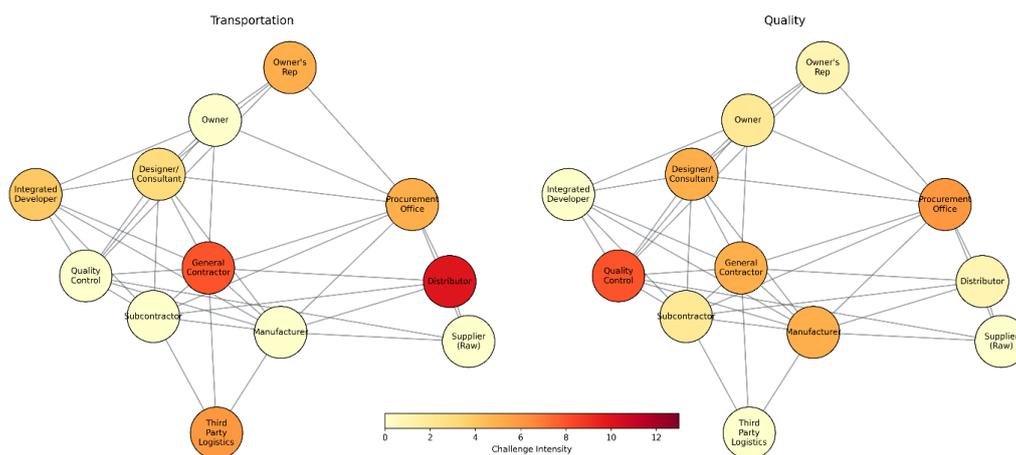


Figure 6. Challenge intensity heatmaps: transportation (left) and quality (right).

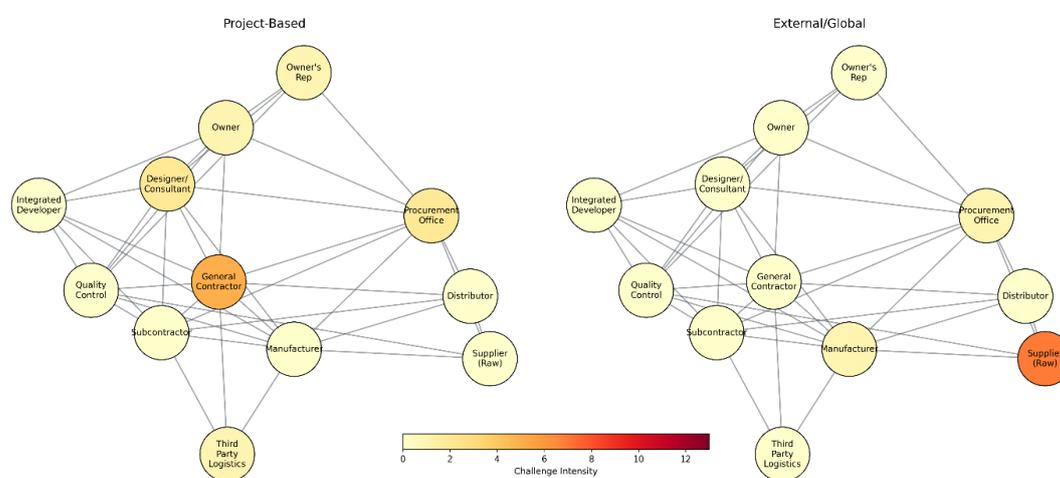


Figure 7. Challenge intensity heatmaps: project-based (left) and external/global (right).

4.3. Will Technology Save the Day?

The interviews depict a construction supply chain caught between digital promise and operational reality. This section outlines stakeholder expectations and operational needs that could drive meaningful technology transformation in construction supply chains. Despite growing experimentation with platforms ranging from basic inventory software to simple AI-enabled procurement systems, technology remains far from its potential in practice. Role-based needs that can inform technology choice are detailed in the radar charts of Figure 8. Raw suppliers, quality control, and owner roles are excluded from this analysis as no participants explicitly identified themselves in these specific roles. Overall, paperless record-keeping and traceability received the highest priority score (4.2/5), followed by data security (3.3/5), while payments automation (2.9/5), cash flow management (2.9/5), and credit-making (2.7/5) received moderate scores.

Procurement challenges reveal significant gaps between current practice and technological potential. Interviewees highlighted confusion around responsibility for purchasing, especially for long-lead items. While a sparse number of teams use platforms to link material use with labor progress or perform automated invoice checks, others rely on manual scheduling and email chains. Even where platforms exist, their impact is often constrained by inconsistent data entry or unclear scopes. Stakeholders voiced strong interest in systems that could assign procurement ownership, surface delays, and forecast risk, cautioning that even the best tools fail without proper usage. Communication and coordination emerged as another primary area for improvement. Many teams rely on paper-based records and meetings to manage procurement milestones, design changes, or

delivery updates. Existing digital tools are seen more as repositories than active coordinators. The opportunity lies in developing platforms that transform passive information storage into dynamic coordination systems.

Emerging technologies present both immediate opportunities and long-term uncertainties for construction supply chains. AI is gradually entering the sector through chatbots, used for summarizing technical documents or comparing specifications. Several interviewees expressed interest in AI's potential to forecast material volatility, benchmark costs, or flag procurement gaps. However, stakeholders view AI as a helpful assistant rather than a replacement for human judgment. They demand explainable outputs and the ability to verify results before acting. Notably, none of the interviewees reported using AI for autonomous decision-making. Responses regarding AI adoption reveal cautious acceptance with apparent network effects, where stakeholders show significantly higher adoption likelihood when AI becomes an industry-wide practice versus isolated implementation (Figure 9).

As another example, blockchain awareness exists, but practical adoption remains minimal. Most participants viewed blockchain as either decades away or fundamentally mismatched with current practices. This skepticism may stem from association with cryptocurrency rather than understanding blockchain's full potential. However, the industry's reliance on relational trust, institutional procedures, and regulatory complexity creates genuine barriers to implementing smart contracts and distributed ledgers. In public sector work particularly, blockchain was dismissed as incompatible with existing procurement workflows and documentation requirements.

The path forward is shaped by the conditions in which potential tools operate. Supply chains can function as socio-technical systems where technology adoption depends as much on relationships and cultural norms as on technical capability. This suggests a core principle that the successful integration of technologies will consider both technical capabilities and existing organizational practices. Organizations that can overcome cultural resistance while creating clear accountability structures are more likely to realize the full potential of technologies.

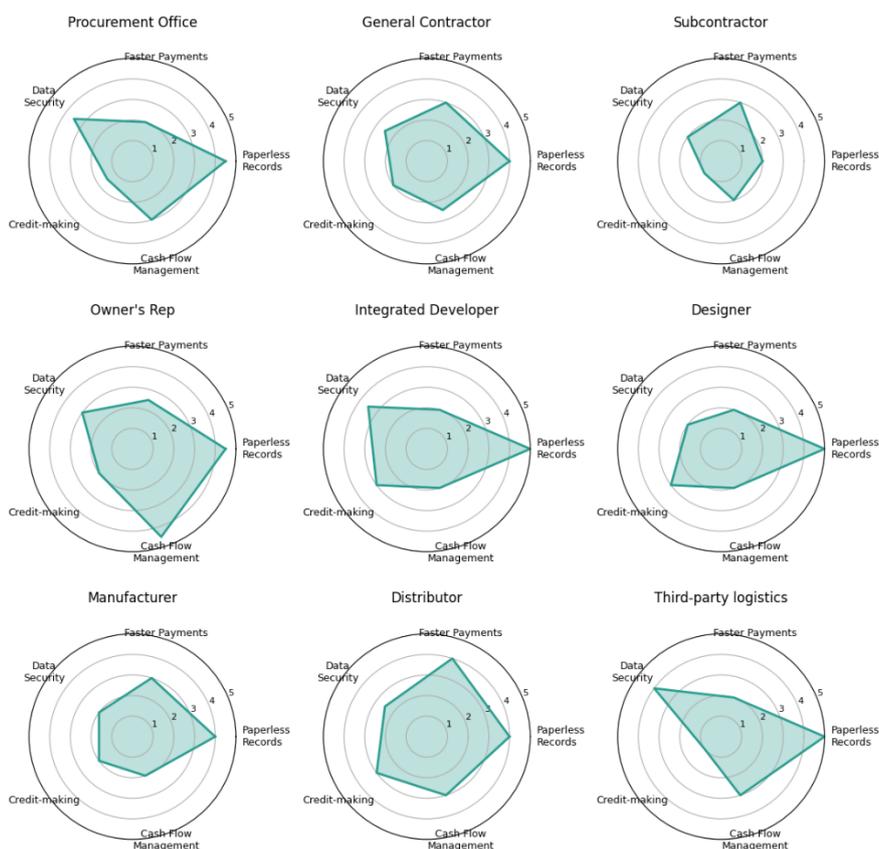


Figure 8. Technology preference patterns by stakeholder role.

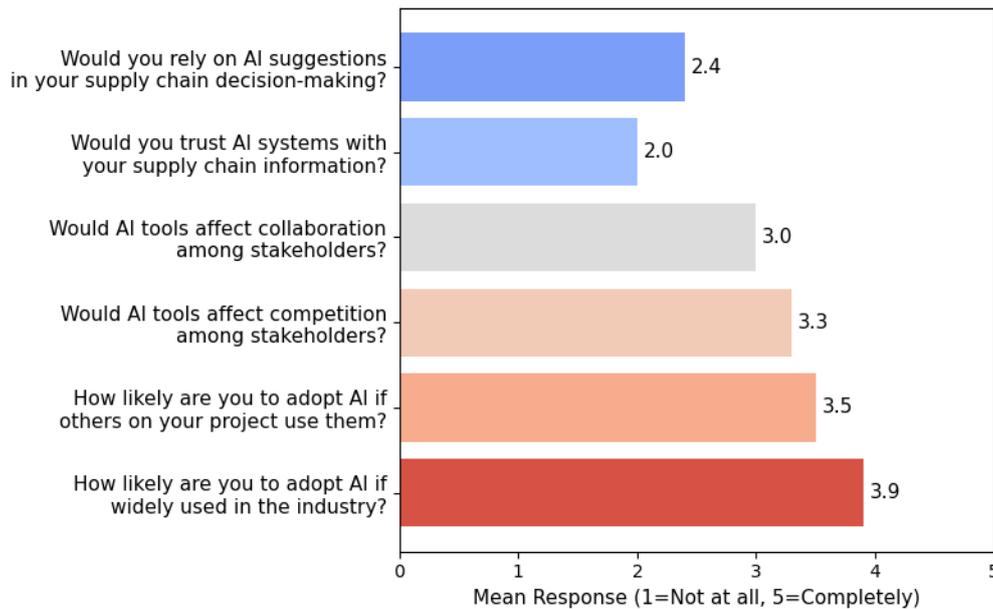


Figure 9. AI acceptance and adoption likelihood scores.

5. Discussion

The findings advance network-theoretic understanding of the construction supply chain, and the quantitative metrics further enrich this perspective. Although procurement offices lie outside the traditional power core, their low Burt constraint scores mark them as natural brokers able to bridge structural holes between production, oversight, and field execution. However, findings reveal that when these roles exist, they are under-resourced and excluded from strategic planning, while many firms lack dedicated procurement offices entirely. Unlocking their brokerage potential through expanded coordination authority and real-time data access could enable early risk identification before problems escalate. More broadly, the moderate overall network density (0.59) suggests that redundancy is sufficient for robustness, but not so high that innovation is stifled. Targeted network bridging around sparsely connected nodes, such as owner-representative and 3PL nodes, could improve information reachability without creating costly over-embeddedness.

The analysis also demonstrates the uneven acceptance of digital tools. Stakeholders sitting in the network core articulate needs for predictive analytics and automated coordination because they must orchestrate exchanges. Peripheral actors prioritize traceability and secure record-keeping that protects them from compliance audits. Overall, stakeholder reluctance toward blockchain and preference for human-supervised and validated AI reflect protective attitudes toward established norms. Technologies gain acceptance when they strengthen existing coordination patterns rather than threatening established brokerage roles. Hence, successful deployment of blockchain and AI in particular can: (1) embed explainable AI modules inside tools already trusted by central brokers; (2) use simple distributed-ledger components first for immutable audit trails, and (3) stage adoption wave-by-wave, following network diffusion paths that start with high-constraint brokers and cascade outward.

Theoretically, the work reframes chronic construction inefficiencies as emergent properties of complex networks. Practically, it signals that performance improvements will come less from universal best practices than from role-matched interventions: relationship-building incentives for central coordinators, cash flow support mechanisms for financially exposed brokers, and transparency enhancers for peripheral suppliers. Therefore, digitalization strategies should be sequenced to close critical structural holes before overlaying advanced analytics. Otherwise, technology may fail to gain adoption or accelerate the flow of bad data or mistrust.

Results of this study directly contribute to actionable strategies for practice. First, elevate supply chain managers (or equivalent organizational roles) to project coordinators during preconstruction phases. This role is found to function as natural brokers with the lowest constraint scores, yet they remain underutilized. Authorizing them to convene cross-tier coordination meetings and early supplier engagement capitalizes their unique position bridging production, oversight, and field execution. Second, track a simple commitment reliability score for the percentage of weekly promises kept (e.g., delivery dates met, RFIs answered) on a shared spreadsheet for social accountability and timely highlights emerging bottlenecks. Third, establish supplier advisory panels with peripheral actors like raw material suppliers, who our network analysis shows experience the highest external volatility but have limited voice in project planning. Fourth, create and maintain a living map of the project's supply network. Visualizing the full system on a simple diagram aligns everyone's understanding and reveals the hidden brokers and bottlenecks identified in this study. Furthermore, it provides a way to monitor whether interventions like cross-tier meetings are creating the intended network connections.

6. Conclusion

Construction supply chains represent a critical nexus in the global economy. Yet despite their economic significance, the complex multi-stakeholder structure that governs these systems remains underexplored in existing literature. To probe the roots of these persistent inefficiencies, this study reframes the supply chain not as a linear flow of materials but as a networked system of interdependent actors. From this perspective, the research examined how network structures shaped operational practices, how stakeholder positioning influenced challenge exposure, and how structural roles drove technology adoption preferences.

The analysis revealed that construction supply chains function as networks where operational challenges and solution needs emerge predictably from stakeholder positioning. Challenge domains concentrate systematically rather than randomly. Relationship and payment strain accumulate at high-centrality brokers like general contractors and manufacturers, where they cascade rapidly across network tiers. Meanwhile, peripheral suppliers absorb external price shocks and logistics delays, creating initial insulation that masks underlying system vulnerability. Procurement and quality-control roles occupy structurally powerful brokerage positions yet remain under-resourced, which potentially traps early warning signals in organizational silos. Furthermore, technology adoption patterns follow network logic. Central coordinators seek predictive analytics and automation tools, while peripheral actors prioritize traceability and audit capabilities. Technologies gain acceptance only when they strengthen existing coordination patterns rather than threatening established relationships.

Findings of the study yield several contributions to theory and practice. Theoretically, the study extends network theory to temporary project networks. Methodologically, it develops a challenge-topology approach that overlays qualitative evidence on quantitative network metrics. Therefore, this approach enables researchers to visualize where and why risks concentrate rather than simply whether they exist. Additionally, the finding that technology adoption follows structural logic rather than individual preferences contributes to innovation diffusion theory by identifying position-based adoption drivers. Practically, this study translates insights into actionable interventions, such as commitment reliability tracking, supplier advisory panels, and updatable network mapping that teams can implement without technology investment to prevent coordination failures.

Despite the benefits of this review study, it is not free of limitations. The study's scope is limited to U.S.-focused professionals and relies on self-reported relationships, which affects the generalizability of qualitative methods. Furthermore, the study does not control for confounding variables such as project size, complexity, procurement method, or regional differences. Additionally, the resulting network represents a static snapshot as it cannot capture how ties strengthen, dissolve, or re-form as projects evolve. Future research can build on this study's findings in four directions. First, broaden the empirical base by comparing multiple regions and delivery methods and by

integrating objective data streams, such as shipment logs or job-site sensor feeds, to triangulate self-reports. Second, adopt longitudinal and dynamic-network approaches that allow researchers to observe how structural positions and challenge diffusion change over time. Third, leverage deep-learning techniques to extract stakeholder ties from open-source data (news, contracts, permits, industry reports) to map inter-project or cross-industry supply webs, thereby moving beyond single-project boundaries and illuminating how construction supply chains interact with wider regional and global networks. Fourth, examine how supply chain disruptions (e.g., tariffs) transmit to broader economic outcomes, particularly investigating whether market responses to material cost shocks proportionally reflect actual supply constraints or amplify through behavioral over-reactions that distort housing markets.

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Appendix A

Interview questions:

Pre-interview survey: Introduction of the person, organization, expertise, and roles

- Can you briefly describe yours and your organization's role in the construction supply chain and your personal involvement in supply chain management?

Theme 1: Supply chain models and processes implemented.

- Question 1: Briefly define the supply chain procedure. Do you use a similar procedure for supply chain and procurement management in different projects?
 - Follow-up 1: What factors influence your decisions when choosing supply chain procedures for different materials?
- Question 2: From your experience, do the supply chains you work with fit more into a vertical model (close coordination with a few key partners) or a horizontal model (dealing with a wider range of suppliers across projects)? Can you provide an example of how these relationships affect your work, particularly when dealing with important materials (such as concrete, steel, or other building supplies)? How else? Does it depend on the project? Who are the people you deal with for supplying a certain material?

In construction projects, relationships between companies can be organized in different ways:

- i. A vertical supply chain is where a contractor works closely with a few specific partners, such as main subcontractors or material suppliers, to complete a project step by step.
 - ii. A horizontal supply chain involves a broader group of companies that might supply similar materials or services across multiple projects at the same time (e.g., different suppliers providing concrete or steel for various projects).
 - Follow-up 1: How do the relationships between these stakeholders affect decision-making and the flow of information?
- Question 3: How do you approach stakeholder collaboration in your supply chain processes?

- Follow-up 1: Can you describe how your preferences affect how you share or receive information from others on the project?
- Question 4: Do you believe there is a willingness among stakeholders to share information more openly? What are the barriers and motivators to this?
- Question 5: The proactive management in handling supply chain uncertainties is getting more attention. Do you have experience taking such approach?
- Question 6: In competitive supply chain scenarios, stakeholders often need to balance their own objectives with the needs of others. Please rank the following strategies from 1 to 5 based on how often you use them.

Strategy	1 (least often)	2	3	4	5 (most often)
Negotiating for win-win solutions (collaborative problem-solving)					
Prioritizing long-term relationships (yielding)					
Clearly communicating constraints					
Risk and benefit sharing (compromise)					
Leveraging your position and connections for advantage					

- Follow-up 1: In your experience, what other strategies have you found effective in balancing your objectives with the needs of other stakeholders in competitive situations?
- Follow-up 2: Can you describe a specific situation where you had to balance your objectives with those of other stakeholders? What approach did you take, and what was the outcome?
- Follow-up 3: From 1 to 5, how would you say your approach changes when dealing with long-term partners versus one-time collaborators?

Theme 2: Supply chain issues in different aspects.

- Question 7: Literature has identified several high-level factors as main underlying problems in construction supply chains that lead to excess costs and schedule pressures. Please rank the following issues from 1 to 5 based on their seriousness in your experience.

Factor	1 (least serious)	2	3	4	5 (most serious)
Lack of transparency and information sharing					
Payment delays and cash flow issues					
Poor coordination and communication among stakeholders					
Inefficient material tracking and logistics					
Quality control and compliance issues					

- Follow-up 1: What specific supply chain-related issues have you personally experienced in your projects that relate to these factors?
- Follow-up 2: Can you suggest any other root causes for supply chain problems in construction that are not mentioned here?

- Question 8: Can you walk me through your typical decision-making process when dealing with supply chain issues? encourage the competition,
- Question 9: Have you faced communication or coordination challenges between stakeholders in your supply chain (e.g., contractors, suppliers, subcontractors)? If so, how have these challenges impacted the timelines and budgets of your projects?
- Question 10: What are the most common operational inefficiencies or bottlenecks you face in your supply chain?
 - Follow-up 1: What external factors (e.g., economic conditions, supplier issues) tend to create the most significant bottlenecks?

Theme 3: Technology adoption/ solution oriented.

- Question 11: In the context of construction supply chain management, please rank the following potential improvements (1 being least important, 5 being most important).

Potential improvement	1 (least important)	2	3	4	5 (most important)
Paperless (digital) record-keeping and traceability of materials and information					
Automated and faster payments and financial transactions					
Improved supply chain data security					
Credit-making for all					
Enhanced cash flow management (investing if you are positive)					

Would you add anything to this list?

- Are you familiar with blockchain technology?
 - ✓ [Yes]: What are your thoughts on the potential of blockchain technology to address challenges in construction supply chain management? Have you had any experience with blockchain in your operations?
 - ✓ [No]: Blockchain is a decentralized, digital ledger technology that allows for secure, transparent, and tamper-resistant record-keeping. It can potentially address some of the challenges in construction supply chain management through features like smart contracts and being the bedrock for future technological integrations.

Given this explanation, what potential benefits or challenges do you see in applying blockchain technology to construction supply chain management?

- Question 12: Are you familiar with generative AI?
 - Have you personally used any generative AI tools? Could you briefly describe your experience?
 - Have you or your organization used generative AI specifically for supply chain management tasks? Please provide examples.
 - In your opinion, what are the most promising potential applications of generative AI in construction supply chain management?
- Question 13: How would you adjust your decision if an AI tool provided an alternative solution?
- Question 14:
 - On a scale of 1 to 5, where 1 is 'not at all' and 5 is 'completely', how much would you rely on AI suggestions in your supply chain decision-making processes?

- Using the same 1 to 5 scale, how much would you trust AI systems with the security of your supply chain information?
 - Could you explain your rating? What factors influence your level of trust in AI suggestions for supply chain management?
 - On a scale of 1 to 5, how do you think AI tools would affect collaboration among stakeholders in the supply chain? (1 being 'significantly decrease collaboration', 3 being 'no effect', and 5 being 'significantly increase collaboration')
 - Using the same 1 to 5 scale, how do you think AI tools would affect competition among stakeholders in the supply chain? (1 being 'significantly decrease competition', 3 being 'no effect', and 5 being 'significantly increase competition')
 - On a scale of 1 to 5, how likely would you be to adopt AI tools if you knew other stakeholders on your project were using them? (1 being 'much less likely', 3 being 'no change', and 5 being 'much more likely'). Could you explain your rating? How might others' use of AI influence your decision to adopt it?
 - On a scale of 1 to 5, how likely would you be to adopt AI tools if they became widely used in the construction industry? (1 being 'much less likely', 3 being 'no change', and 5 being 'much more likely')
 - Based on your perspective, what do you see as the main potential benefits and challenges of adopting AI in construction supply chain management?
- *) Would you like your name/ company to be acknowledged in the publications?

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