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LEVERAGING THE SUPPLIER'S EXPERTISE THROUGH AN INNOVATIVE ORGANIZATIONAL STRUCTURE

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ABSTRACT

Effective procurement practices drive innovation, improve collaboration, and achieve timely, cost-efficient outcomes in construction projects. However, the industry faces persistent inefficiencies, including cost overruns, delays, limited technology adoption, and adversarial relationships rooted in traditional procurement methods. While collaborative approaches promote early stakeholder engagement, they often overlook explicit mechanisms to integrate external suppliers' expertise early enough to meaningfully influence design decisions. Specifically, current procurement models either emphasize price competition, requiring nearly complete designs before supplier selection, or rely on unclear compensation structures, failing to incentivize early-stage supplier contributions. To address these critical gaps, this study introduces an Integrated Coordination Framework (ICF) that strategically embeds early supplier involvement through adaptive contractual incentives and structured compensation mechanisms. Leveraging agent-based modeling, the research evaluates and observes trends in the proposed framework. Results demonstrate significant improvements under the ICF, including a 38% increase in design productivity, a 3% reduction in rework, and a 37% rise in technology adoption. By expanding on successful elements of P21+, such as Guaranteed Maximum Price (GMP) agreements and structured gainshare arrangements, the ICF ensures compensation clarity, timely GMP finalization, and strategic alignment of supplier incentives with value-driven outcomes. Ultimately, this study advances lean construction procurement by providing empirical evidence that structured, early supplier involvement, supported by clearly defined compensation structures, drives innovation, enhances efficiency, and reduces waste in the design phase.

KEYWORDS

Integrated Coordination Framework, organizational structure, agent-based modeling, pull, collaboration/ collaborative.

INTRODUCTION

A substantial body of literature exists on lean construction theory, procurement approaches, collaboration, and its applications, emphasizing the elimination of waste, continuous improvement, and process optimization to enhance value delivery (Ballard and Tommelein, 2021). Although design management research emphasizes shifting from purely transformational to value-generation approaches (Ballard, 2000), and lean practices promote early stakeholder involvement (Tommelein, 1998), external technology suppliers are rarely

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included early enough to significantly influence materials and methods. Traditional procurement models frequently miss opportunities to integrate specialized supplier expertise early in the design phase, mainly due to rigid contracts, fragmented decision-making, and lowest-bid selection methods (Ballard and Howell, 2003). The undesirable outcomes of the existing procurement system include adversarial relationships between agents, "win/lose" attitudes, and a makeshift focus. These issues lead to less clear communication, hindering long-term relationships, and forcing agents to operate in silos with minimal collaboration, negatively impacting coordinated decision-making (Simonsen et al., 2023; Xue et al., 2005; Raoufi and Fayek, 2018). Furthermore, risks are often disproportionately allocated, discouraging agents from adopting innovative solutions. Collaborative procurement approaches such as Integrated Project Delivery (IPD), Target Value Design (TVD), and Early Contractor Involvement (ECI) aim to enhance integration but often overlook explicit mechanisms for involving external suppliers. Similarly, ProCure21+ (P21+) has successfully delivered cost certainty through integrated supply chains along with Early GMP finalization to enhance procurement efficiency and promote transparent risk-sharing. Collaborative procurement models limit early supplier involvement due to rigid contracts and cost-driven selection, requiring near-complete designs. Without clear incentives, suppliers have less motivation to contribute expertise early, leading to missed opportunities for innovation. Therefore, this study builds upon the principles by creating an integrated and adaptable approach.

The objectives of this study are: (1) To identify areas of improvement in current collaborative procurement approaches and address them by proposing an Integrated Coordination Framework (ICF) with a central coordination agent (CCA) through agent-based modeling (ABM); (2) To explore ICF's potential to enhance current collaborative practices by reducing rework, boosting productivity, and facilitating early technology adoption by aligning contractual relationships with external suppliers and contractors. This study aims to shed light on the following questions: (a) How does the early integration of specialized suppliers within an adaptive procurement framework impact design productivity, rework reduction, and technology adoption? (b) To what extent does the ICF contribute to existing collaborative procurement models in terms of early supplier expertise through early GMP finalization? (c) What role does a CCA play in optimizing supplier engagement, aligning contractual relationships, and mitigating inefficiencies in decision-making? (d) How do compensation structures, including GMP finalization and risk-sharing mechanisms, influence performance outcomes?

LITERATURE REVIEW,

CONCEPTS OF LEAN CONSTRUCTION AND CONSTRUCTION PROCUREMENT

Existing lean construction studies predominantly focus on on-site activities and workflow, often placing less emphasis on the procurement phase, where adversarial relationships and inefficiencies are more apparent (Kim, 2019; Sarhan et al., 2018). While lean practices have been shown to improve efficiency, reduce costs, and foster collaboration among project stakeholders (Xue et al., 2010; Zhang and Chen, 2016), critical gaps remain in integrating these principles within the design phase. Industry-driven procurement initiatives in the UK—exemplified by Rethinking Construction (Egan, 1998; Department of Trade and Industry, 1998) and the P21+ Guide, which is a public-sector response, have challenged the construction sector to adopt earlier supplier engagement. P21+ addresses procurement inefficiencies through the structured use of a GMP, defined collaboratively by clients and Principal Supply Chain Partners after substantial design completion and risk assessment. The GMP process follows transparent, open-book principles, where about 80% of the cost typically derives from market-tested subcontracted packages. Critical to this approach is timely GMP agreement—setting it too early increases risk uncertainty, while a well-timed GMP fosters accurate pricing and clear risk allocation (Chan et al. 2010). The evolution of collaborative procurement frameworks in lean construction has been extensively studied, with well-documented models emphasizing early stakeholder engagement and integrated risk-sharing. According to Egan (1998), the rationale behind an integrated process is the efficiency of project delivery constrained by the largely separated processes through which they are generally planned, reflecting a fragmented and confrontational culture. Although effective, this predetermined contractual arrangement may limit flexibility in current collaborative procurement approaches. Building upon these insights, a critical review of existing collaborative models further reveals the areas of improvement.

CRITICAL REVIEW OF COLLABORATIVE PROCUREMENT MODELS

Collaborative procurement frameworks, such as IPD, TVD, and P21+, have emerged to foster early stakeholder involvement and address longstanding procurement inefficiencies. IPD integrates owners, architects, and contractors (both general and specialty) into a single contractual framework, improving risk management, innovation, and efficiency (Kim and Dossick, 2011; Kent & Becerik-Gerber, 2010; El Asmar et al., 2013). A key advantage of IPD is early specialty trade involvement, reducing design conflicts, and enhancing constructability (Azari et al., 2011; Evans and Farrell, 2023). However, challenges such as complex multi-party contracts and difficulties in risk-sharing within IPD have hindered its broader adoption. A critical limitation of TVD within IPD is the lack of a defined contractual structure between external suppliers and contractors. A critical limitation of TVD within IPD is the absence of clearly defined contractual incentives for integrating external supplier expertise early, discouraging innovation precisely when it is most beneficial. Furthermore, to effectively leverage price competition, owners or general contractors (acting as contractees) typically require completed or near-complete designs before selecting suppliers, thus prioritizing cost savings over integrating external suppliers' expertise during the early design stage. Nevertheless, since external suppliers in key areas (façade, MEP) possess significant expertise in new materials and methods, their inclusion in early design remains essential. Additionally, the compensation structures within current collaborative procurement models frequently lack clear incentive alignments, fostering competition and further exacerbating inefficiencies (Chan et al., 2010; Kim & Rhee, 2024). Therefore, a gap remains in existing collaborative procurement frameworks, which prioritize cost savings over early supplier integration. To address these challenges P21+ framework, particularly in healthcare construction, improves cost certainty and supplier performance through standardized procurement routes, long-term partnerships, and identifies the optimum time to agree on the GMP (Shehadeh et al. 2022). The relationships in P21+ are structured primarily between Owners and Principal Supply Chain Partners under a long-term framework agreement. Building on the foundational principles of P21+, which structures procurement relationships between owners and suppliers, this study expands its approach by proposing a framework that facilitates dynamic interactions between general contractors, external suppliers, and subcontractors, enabling a more flexible and adaptive model applicable across other collaborative procurement models.

INTEGRATED COORDINATION FRAMEWORK

Building on identified gaps—existing models prioritize short-term cost savings over long-term value, lack aligned compensation structures for early supplier contributions, and often inadequately distribute risk—this study proposes early GMP agreements to foster collaborative design processes. As illustrated in Figure 1. coordinated linkages begin during the Design Development Phase, where the Owner, A/E Consultants, and the Central Coordination Agent (CCA) jointly define project scope and compensation structures. The subsequent Primary Design Assist phase involves targeted coordination among the General Contractor, CCA, and design consultants, while the Secondary Design Assist phase strategically integrates specialized suppliers early, leveraging their expertise to enhance innovation and efficiency. The CCA serves as an independent supply chain coordinator, primarily working with a specific GC while maintaining a network of collaborative suppliers.

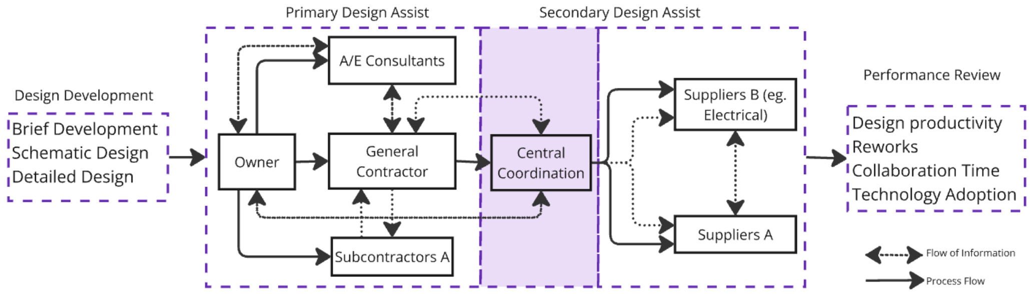

Figure 1. Proposed Integrated Coordination Framework with Central Coordination

This network is built on long-term relationships, enabling the CCA to leverage the expertise and knowledge of multiple suppliers as needed throughout the design process. In this model, the CCA acts as a bridge between the GC, subcontractors, and suppliers, ensuring that their contributions are aligned with the project goals and design requirements. This proactive involvement allows the CCA to optimize resource allocation and decision-making, ultimately streamlining the design and procurement workflow.

RESEARCH METHODOLOGY

ABM has been widely used in construction research to simulate complex interactions between stakeholders, offering insights into collaborative design processes, supply chain coordination, and procurement behaviors (Hao et al., 2006; Tang, 2004). Compared to System Dynamics (SD) and Discrete-Event Simulation (DES), ABM captures emergent behaviors arising from individual agent decisions, making it particularly suitable for modeling procurement scenarios with dynamic supplier interactions (Wooldridge & Jennings, 1995; Khodabandelu & Park, 2021). Unlike SD, which aggregates behaviors into continuous flows, ABM models individual agent decisions and interactions, preserving the granularity necessary to analyze real-time collaboration and incentive alignment (Xue et al., 2010). While DES is effective for process-based simulations, it lacks the flexibility to model adaptive decision-making and negotiation mechanisms among suppliers, contractors, and designers (Ahn & Lee, 2015). This study employs ABM to simulate procurement under the ICF framework, assessing how supplier engagement, incentive structures, and coordination strategies impact project performance. The ability of ABM to capture emergent dynamics allows for a more detailed investigation into how compensation schemes and coordination rules influence key outcomes. The model is undergoing multiple rounds of face validation and expert feedback with organizations applying elements of the ICF. These insights help refine and align the simulation logic with real-world practices. A sensitivity analysis will quantify how variations in key parameters—such as GMP timing, cost variance, and risk-sharing attitudes—affect performance and help identify priority areas for improvement.

SIMULATION ENVIRONMENT SETUP

DEFINING AGENT BEHAVIORS

Statecharts are graphical representations used in ABM to define agent behaviors, capturing their distinct states and transitions. They provide a structured framework to model decision-making, coordination, and workflow dynamics, ensuring consistency in agent interactions and process execution (Ahn and Lee 2015). Agent behaviors are modeled through clearly defined states and transitions, illustrating distinct roles and responsibilities (Figure 2, Table 1). The workflow starts with the Owner setting project objectives in the In Progress state and delegating design tasks. After design approval, the CCA manages the Integrating and Collaborating state to align technology integration. Feedback is managed in the Under Review state, with Owner involvement limited to escalations, before the design phase concludes with a formal handover to the GC. The GC's structured workflow similarly begins with design review (In Progress) and transitions to procurement coordination (Integrating and Collaborating), managed by the CCA. Following subcontractor engagement and systematic review (Under Review), the GC's tasks conclude with a final handover back to the CCA (Feedback Approval).

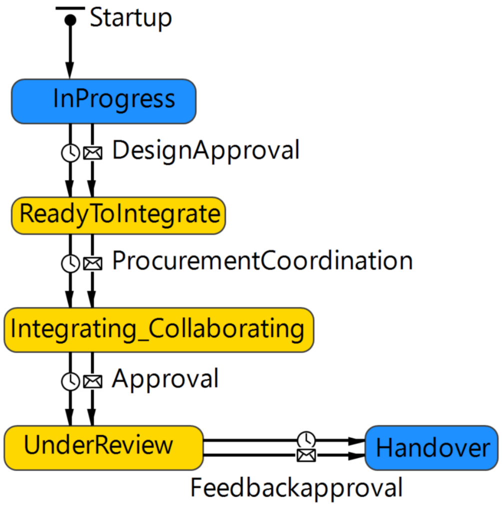

Figure 2. State Chart of an Agent (Owner and General Contractor)

Table 1. Description of GC and Owner agent states and transition

State	Description	Transition process
In Progress	The design/ engineering is actively under development.	Moves to Compensation Structure Definition.
ReadyToIntegrate	Agent documents designs and shares the work.	When complete, the agent moves to the next state Integrating Collaboration.
Integrating_Collaborating	Agents align tasks to ensure consistency and resolve issues.	Upon completion of the coordinating process, agents decide on acceptance or rejection based on constraints.
UnderReview	The work/design is under scrutiny by CCA.	If it passes review, transition to Performance Review; if errors are found, transition to Redesign.
Handover	Final state where the design is handed off to the next agent.	Marks completion, if any last-minute issues arise, transitions to Under Review.

The CCA's state chart, shown in Figure 3, Table 2, outlines its central role in coordination and decision-making. The process begins with the Compensation Structure Definition to motivate technology adoption, followed by Ready to Integrate, where suppliers and subcontractors align on goals followed by the Technology Adoption state that facilitates innovation. Outputs are assessed in the Under Review state, with bottlenecks addressed in the Re-design loop before transitioning to Further Progress and the Performance Review state.

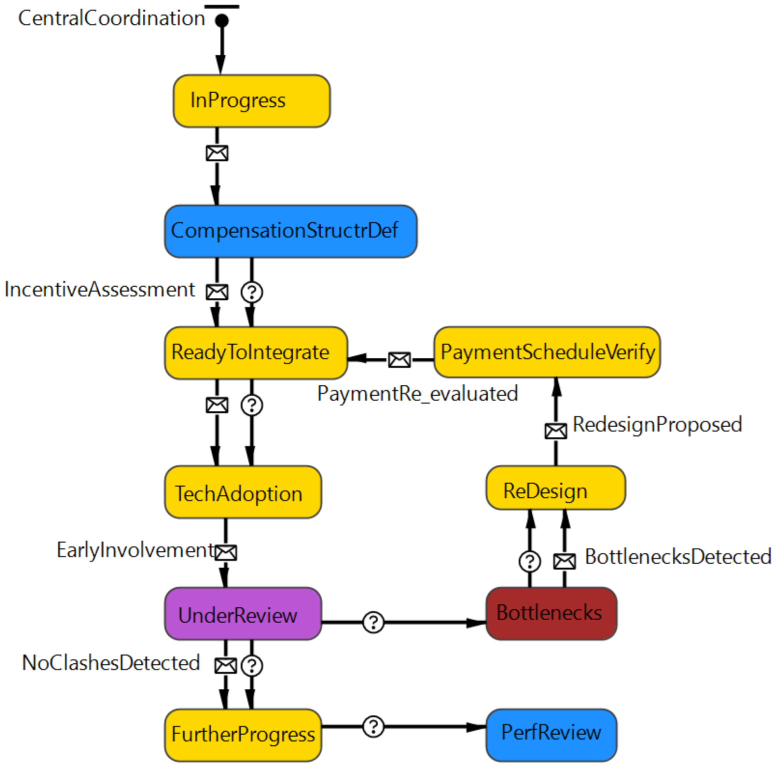

Figure 3. State Chart of Central Coordination Agent (CCA)

Table 2. Description of CCA agent States and their Transitions

State	Description	Transition process
In Progress	The design/ engineering is actively under development.	Moves to Compensation Structure Definition.
ReadyToIntegrate	Agent documents the designs and shares the work.	When complete, the agent moves to the next state either Technology adoption.
TechAdoption	Focus on integrating new technology.	Moves to UnderReview if Constraints are detected.
UnderReview	The work/design is under scrutiny by CCA.	If it passes review, transition to Performance Review; if errors are found, transition to ReDesign.
Performance Review	A formal check of the design, typically near completion.	If accepted, transition to Handover; if major changes are required, transition to ReDesign.
Bottlenecks/ Constraint	Indicates the process hit constraints	Moves to ReDesign once constraints are addressed or rework decision.
Redesign	Revise design to fix problems found in the review.	Share the payment schedule revisions if design changes affect payment.
PaymentScheduleVerify	Confirming the payment schedule is correct.	If verification is successful transition to the Collaborating loop again.

Quantifying the Performance Metrics

To set up the ABM model, several inputs for the model and agents are required: number of teams, number of designs produced per agent, number of members per team, number of rework iterations per agent, connections between members, number of revisions done per agent, time needed to design/model, to collaborate, to rework per agent, frequency of collaborating per agent, and designing (one or several designs). The input values are specified based on the initial data collection process. The performance metrics adapted from Hattab and Hamzeh (2018) quantify key design outcomes, including design productivity, rework, collaboration, and technology adoption. Design Rate (DR) measures the percentage of designs completed, highlighting the concurrent availability of design information, while Design Time (DT) tracks daily hours spent on value-added design tasks. The Rework Rate (RR) identifies the proportion of designs requiring revision, and Rework Time (RT) quantifies daily efforts spent correcting these errors. Collaboration Time (CT) measures daily coordination efforts among project teams, indicating productive communication and potential overhead balance. Lastly, Technology Adoption (TA) assesses how successfully proposed innovations are incorporated into the design, reflecting the effectiveness of early collaboration in improving overall design quality and reducing rework. The metric, quantification formula, and input values are listed in Table 3. These metrics collectively enable a comprehensive analysis of how early supplier integration, compensation alignment, and proactive coordination affect key design outcomes and serve as a structured basis for empirically comparing the proposed ICF against traditional procurement practices.

Table 3. Description of the Performance Metrics and input values

Metric	Formula	Input values
Design Productivity	$DR = \frac{\sum_{i=0}^{TM} nDi,t}{\sum_{i=0}^{TM} TDi} * 100$	nDi,t = number of designs produced by member i at time t TDi = total number of designs produced by member I TM = total number of members working on the project
	$DT = \frac{\sum_{i=0}^{TM} nDHi,t}{TM*TT} * 100$	nDHi,t = number of hours designing by member i at time t. TM = total number of members working on the project TT = total number of working hours per working day
Rework Metric	$RR = \frac{\sum_{i=0}^{TM} nRi,t}{\sum_{i=0}^{TM} TDRi} * 100$	nRi,t = number of designs reworked by member i at time t TDRi = total number of designs reworked by member i TM = total number of members working on the project
	$RT = \frac{\sum_{i=0}^{TM} nRHi,t}{TM*TT} * 100$	nRHi,t = number of hours reworking by member i at time t TM= total number of members working on the project TT= total number of working hours per working day
Collaboration Time	$CT = \frac{\sum_{i=0}^{TM} nCHi,t}{TM*TT} * 100$	nCHi,t= number of hours collaborating by member i at time t TM= total number of members working on the project TT= total number of working hours per working day
Technology Adoption	$TA = \frac{\sum_{i=0}^{TM} nTAi,t}{\sum_{i=0}^{TM} nTPi,t} * 100$	nTAi,t= total number of technologies adopted nTPi,t= total number of technologies proposed TM= total number of members working on the project

DATA ANALYSIS

ICF ensures early supplier involvement during Design Development, Design Assist I, and II, enabling faster error detection, reduced rework, and enhanced design accuracy. As shown in Figures 4 and 5, and Table 4, the ICF achieves a Design Rate of 57.43% (38% improvement over traditional), and a Design Time of 62.31% (25% increase), reflecting better concurrent workflow and reduced idle time. The ICF also reduces the Rework Rate to 1.57% (3% decrease) and Rework Time to 1.87% (2% decrease), attributed directly to the early integration of supplier expertise. Although Collaboration Time slightly decreases (23.34% vs. 25.38%), ICF promotes more strategic and focused collaboration. ICF significantly improves Technology Adoption to 55.55%, a 37% increase over the traditional model. By facilitating proactive detection and resolution of errors, the ICF aligns closely with lean construction principles, minimizing waste and streamlining project workflows.

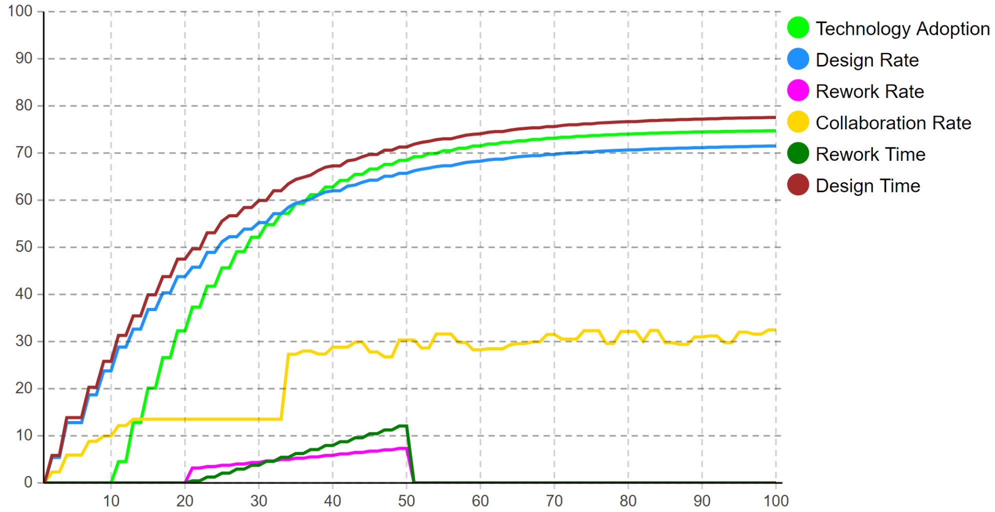

Figure 4. Integrated Coordination Framework KPI trends

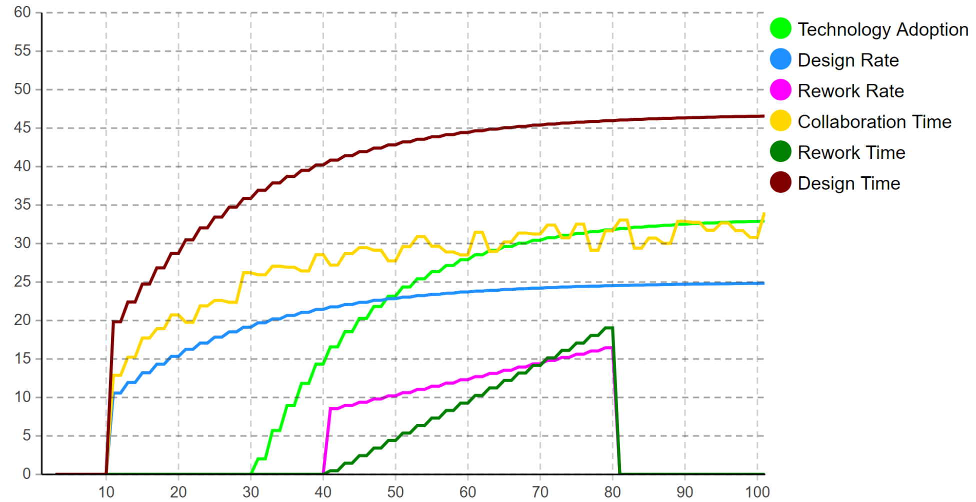

Figure 5. Typical Construction Procurement KPI Trends

Table 4. Comparison between the two models

KPI metrics	Exp 1 (ICF)	Exp 2 (Traditional)	Change	Insights
Design Rate	57.43%	19.75%	38%	Significant improvement due to streamlining
Rework Rate	1.57%	5.00%	-3%	Early integration of expertise minimizes errors, reducing reworks.
Technology Adoption	55.55%	18.39%	37%	Supplier involvement for expertise allows better integration of innovative solutions.
Collaboration Time	23.34%	25.38%	-2%	While slightly reduced, collaboration under ICF remains focused and strategic.
Design Time	62.31%	37.03%	25%	Reduced idle time, less downtime, and faster task completion.
Rework Time	1.87%	3.90%	-2%	Better planning, and early supplier expertise result in reduced rework duration.

Contextual Metrics: Compensation Structure

Compensation structures—GMP timing, payment reliability, perceived fairness, and overall acceptability—significantly influence agent behaviors and procurement efficiency. Three scenarios evaluate the impact of GMP timing, payment reliability, and fairness perceptions on project outcomes, utilizing metrics such as Base Acceptance (BA), penalties for late GMP finalization (LGMPp), delayed payments (Dpp), and perceived fairness (Fp). Figure 6 highlights that early GMP finalization results in slightly higher Design Time (79.27% vs. 77.21%), suggesting more thorough processes. Importantly, Early GMP reduces Collaboration Time (32.2% vs. 40%) and substantially increases Technology Adoption (75.06% vs. 25.06%), emphasizing the value of early supplier involvement.

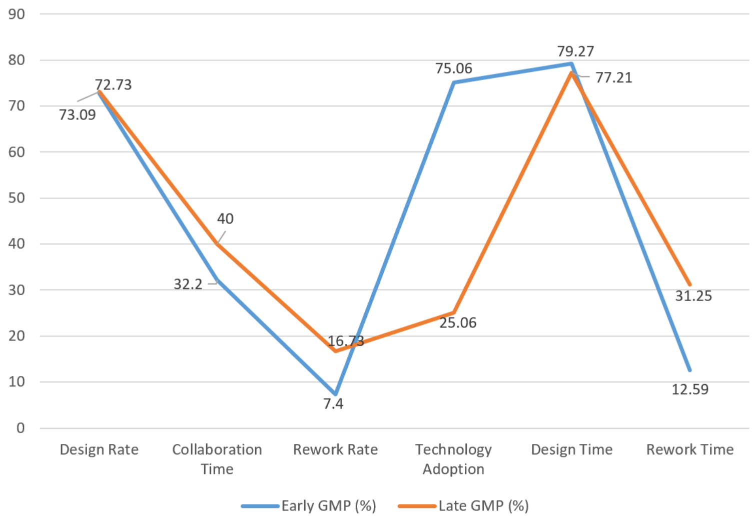

Figure 6. Impact of Early and Late GMP finalization on Project Performance metrics

Conversely, Late GMP finalization leads to a significantly higher Rework Rate (16.7% vs. 7.4%) and Rework Time (31.25% vs. 12.59%), reflecting inefficiencies from delayed error detection. Further research will explore how GMP timing and compensation mechanisms shape agent behaviors and attitudes toward risk-sharing.

DISCUSSIONS AND LIMITATIONS

Empirical results demonstrate that early supplier integration within the ICF reduces rework by 3% and enhances technology adoption by 37%. These improvements align closely with empirical outcomes documented in the P21+ initiative, which between 2003 and 2010 successfully delivered 572 schemes worth nearly £4 billion, achieving up to 97% on-time completions and 95–98% client satisfaction rates. P21+ utilized standardized procurement pathways, GMP agreements, and transparent gainshare mechanisms to deliver predictability, effective risk allocation, and zero litigation. Building on the P21+ principles, which establishes structured procurement relationships between owners and suppliers under a long-term framework agreement, this study advances the concept by developing a framework that facilitates dynamic interactions between general contractors, external suppliers, and subcontractors, making it adaptable across all collaborative procurement models. Critical to this success was the careful timing of GMP agreements—ideally set at substantial design completion—to accurately forecast costs and appropriately allocate risks. Unlike current collaborative procurement practices that prioritize cost competition by delaying supplier selection until designs are nearly complete, the ICF strategically aligns compensation structures to reward early supplier collaboration which aligns with Egan’s (1998) and Moradi & Sormunen's (2023) recommendations for integrated, value-driven procurement approaches.

This study, grounded in simulations, highlights the need for real-world validation through case studies to uncover practical challenges, refine the framework, and offer empirical evidence. Future steps include empirical validation through survey-based studies and industry case applications to enhance real-world applicability. The reliance on predefined agent behaviors and interaction rules in the ABM limits its ability to fully reflect the complexities of procurement ecosystems. In practice, implementing the ICF may encounter significant barriers such as organizational resistance and cultural inertia—where entrenched hierarchies and siloed operations resist the collaborative shift—as well as financial feasibility concerns regarding the upfront investments required for process re-engineering. Moreover, substantial contractual and legal adjustments will likely be necessary to accommodate early supplier involvement and innovative, risk-sharing compensation structures. Future research should investigate how factors like project size, complexity, and regional or cultural differences impact the framework’s applicability, while also exploring trust-building, conflict resolution, and negotiation strategies. To facilitate industry adoption of ICF, several key steps should be undertaken. Pilot testing on small- to medium-scale projects will help refine the framework and demonstrate tangible benefits. Additionally, standardized contractual templates should be developed to explicitly define supplier roles, compensation structures, and collaboration mechanisms. To support implementation, capacity-building programs and industry training initiatives should be introduced to equip project teams.

CONCLUSIONS

Effective procurement strategies are critical to fostering innovation, improving collaboration, and achieving cost-efficient project delivery. However, persistent inefficiencies in traditional procurement, such as cost overruns, project delays, limited technology adoption, and adversarial relationships, underscore the need for a structured approach to early supplier involvement. Specifically, current procurement models either emphasize price competition, requiring nearly complete designs before supplier selection, or rely on unclear compensation structures, failing to incentivize early-stage supplier contributions. This price-based dynamic discourages supplier innovation, as incentives are not structured to integrate supplier expertise when it is most valuable, during the early design stages. This study introduced the Integrated Coordination Framework to address these gaps, embedding early supplier involvement through structured compensation mechanisms.

However, the study relies on simulation data, which, while valuable for observing trends, requires real-world validation. Agent-based modeling captures key procurement dynamics but cannot fully reflect the complexities of industry relationships, contractual negotiations, or behavioral variations. Future research should conduct case studies and survey-based validation to refine the framework's applicability. For industry adoption, implementation should begin with pilot projects and training programs to assess feasibility and optimize coordination strategies. Standardized contractual templates must be developed to define supplier roles, risk-sharing terms, and compensation structures. Training programs should equip project teams with the skills to navigate early supplier engagement, and performance-based compensation models should incentivize proactive collaboration.

We believe that our work sheds light on the potential for early supplier engagement, adopting structured compensation agreements, and the seamless integration of innovative technologies, essential for maximizing the benefits of lean construction. This study is not merely a solution for current inefficiencies—it is a pathway to redefine procurement practices. We invite both industry professionals and academic researchers to join our efforts in advancing early supplier expertise with clear contractual terms in lean construction. This collective pursuit has the potential to not only address today’s challenges but also establish a forward-thinking foundation for the construction industry’s future.

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