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Research Article

Innovating Construction Supply Chains for Sustainability: Lessons from Aerospace

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Abstract

This study investigates how the aerospace industry's Concurrent Engineering (CE) practices can be used to improve construction supply chain efficiency, integration, sustainability, and intelligence. CE is a collaborative, interdisciplinary approach that allows simultaneous product and process development. It provides a framework for proactive, integrated supply chain management (SCM) that promotes innovation, resource optimisation, and reduced environmental impact, making construction supply chains sustainable and smart. Mixed-methods research included quantitative survey data from construction experts with qualitative interviews from six large South African construction projects. The survey found various CE enablers relevant to construction, including functional knowledge, shared product ownership, optimal resource utilisation, and increased communication and problem-solving. Interview data supported quantitative outcomes by emphasizing early supplier participation, adaptive scheduling, collaborative decision-making, and continuous improvement. Construction can learn from aerospace by using CE supply chains with multidisciplinary teamwork, early supplier-contractor integration, and shared accountability for project outcomes as key themes. These strategies reduce waste and promote data-driven decision-making to improve project efficiency and sustainability. The paper provides a systematic framework for using CE principles in construction SCM to promote sustainability and innovation.

Keywords: Aerospace Industry; Concurrent Engineering (CE); Construction Supply Chains; Innovation in Construction; Smart Construction; Sustainable Construction.

Highlights

- Adapting aerospace CE principles strengthens integration and fosters sustainable supply chains.
- The CE-CSCF operationalises early supplier integration, interoperable environments, and ESG-aligned metrics by porting aerospace methods into construction SCM.
- Empirical evidence shows CE enhances collaboration, resource efficiency and smart sustainability.

1 Introduction

Concurrent Engineering (CE) is a powerful, system-oriented methodology long established in the aerospace manufacturing industry, where it has consistently delivered significant achievements in project optimisation, schedule adherence, and cost efficiency (Aniekwu et al., 2013). Originally conceived as a dynamic collaborative process for enabling the simultaneous development of products and processes, CE has proven especially effective in fostering interdisciplinary collaboration, building trust across project teams, and integrating diverse expertise early in the project life cycle (Jahnke, Martelo, Fischer, & Lange, 2018). Moreover, CE in aerospace manufacturing leverages digital tools to ensure cross-functional design and operations, knowledge sharing and informed decision-making. CE in construction has been well established to achieve interdisciplinary collaboration integration of integration and sustainability (Anumba, et al., 2000; Komarzynska-Swiesciak, et al., 2025). While CE's success in aerospace is well documented, its adoption in the construction industry has been limited and largely confined to the design stage and/or concurrent execution (Kunz & Fischer, 2020; Wang & Feng, 2023). Moreover, literature on CE in the construction industry, although conceptualized over two decades ago, has largely remained an abstract and underdeveloped technique (Akunyumu et al., 2020). This narrow focus overlooks CE's broader potential to influence project planning, execution, and supply chain (SC) integration – areas where construction projects frequently suffer from fragmentation, rework, and delayed scheduling. By embedding CE principles from aerospace into the entire construction project lifecycle, including supply integration, planning, and management, there is an opportunity to improve stakeholder engagement and alignment, and create a more proactive, collaborative, and sustainable SC (Aslam et al., 2021).

This paper addresses this by adapting CE's holistic, proven, multidisciplinary, and trust-based approach from aerospace to construction's unique SC challenges. It presents the findings from survey responses validated through case-study interviews to develop the concurrent engineering driven construction supply chain framework. This empirically grounded model is designed to operationalize CE beyond the design phase, aligning strategic project goals, collaborative learning, and sustainability targets to transform construction supply chains into smart innovative networks. This paper starts with a theoretical analysis of aerospace and its application of CE. This is followed by a description of the methodology adopted for this study. Thirdly, the results of the data collection are discussed and presented along with the proposed framework. Finally, the discussion and conclusion sections of the paper are presented along with recommendations for further investigation.

2 Literature Review

The aerospace sector has long been recognized as a high-technology industry that drives innovation across multiple fields including telecommunications, transport, and energy (Dong et al., 2015). Within the sector, the production of aeronautical vehicles is delivered through multi-organisational supply networks that manage complex, high-value systems under intense competitive pressures (Seidl & Kleiner, 1999). To meet demands for reduced costs, shorter lead times, and sustained quality, aerospace firms pioneered advanced approaches such as robotics, digitalisation, and CE (Brogue, 2018). CE has become a permanent framework in aerospace for achieving efficiency through early integration, collaborative workflows, and lifecycle optimisation.

Parallels with construction are clear: both industries rely on diverse expertise, multi-tier SC, and project-based integration of numerous stakeholders. However, unlike aerospace, construction often enters production/execution stages without fully resolved designs (Tookey et al., 2005). This difference underscores the potential for construction to adopt CE principles to reduce inefficiencies, improve coordination, and strengthen fragmented SCs.

2.1 Nature of Aerospace SCs

Aerospace SCs are tiered, globally distributed, and highly integrated, typically ranging from raw material suppliers (Tier 4) to component suppliers (Tier 3), subsystem providers (Tier 1-2), and finally assembly by prime contractors acting as system integrators (Rebolledo & Nollet, 2011). These SCs function effectively through well-developed communication platforms, collaborative meetings, and information-sharing mechanisms that enables rapid responses to design or production changes (Anumba, Siemieniuch, & Sinclair, 2000). Prime contractors set integration styles and allocate risk across the chain (Williams, Maull, & Ellis, 2002; Barbosa, et al., 2019). The transferable lessons for construction are twofold: (i) early involvement of contractors and suppliers to minimise downstream changes, and (ii) the establishment of collaborative platforms to ensure alignment across distributed teams.

2.2 Critical Success Factors, Enablers, and Barriers

There are several critical success factors (CSFs) for CE in aerospace, including multidisciplinary collaboration, interface control, synchronization of workflows, permanent traceability of configuration of data, and process integration for quality and efficiency (Pardessus, 2004). These are reinforced by mutual benefit structures and transparent information sharing that encourage collaboration rather than protectionism.

There have been countless recommendations to adopt CE for construction, and subsequent studies confirm that simultaneous processes, lifecycle consideration, and early supplier integration could strengthen construction supply chains (CSCs) (Kamara, Anumba, & Evbuomwan, 2000; Tookey et al., 2005). The reported benefits of CE include faster communication, reduced bureaucracy, better supplier training, and more efficient use of resources. However, barriers remain – these include duplication of services, unclear roles, skills shortages, late supplier involvement, and client unfamiliarity with CE (Zidane et al., 2015). Successful CE implementation in construction therefore requires leadership support, cross-functional coordination, and the adoption of enabling technologies. Digital tools are particularly important, as advances in information and communications technology (ICT) allow for higher levels of integration and collaboration across distributed SCs (Fras, et al., 2004; Anumba, Siemieniuch, & Sinclair, 2000).

2.3 Lessons for Construction and Theoretical Implications

The aerospace experience demonstrates that CE is not merely a design philosophy but a SC strategy, one that integrates planning, execution, and lifecycle management. Construction can apply these insights by:

- Embedding early contractor and supplier involvement.
- Using collaborative contracts and digital platforms to enhance transparency and trust.
- Applying CE-driven metrics (e.g., iteration speed, communication efficiency, ESG performance) to evaluate project responsiveness.

In construction, SCs are typically divided into primary, support, and human resource networks (Khalfan et al., 2001). These networks are characterized by interdependencies and fragmentation, with stakeholders often resistant to collaboration (Lavikka, Smeds, & Faatinen, 2015). This fragmentation leads to arms-length relationships, adversarial behaviours, and limited information sharing - problems that CE is designed to overcome (Curran, Zhao, & Verhagen, 2015). Despite progress through Building Information Modelling (BIM), Value Engineering (VE), and Lifecycle Costing (LCC), these tools remain inconsistently applied. BIM's collaborative potential is rarely realised in practice (Oraee, et al., 2019), VE suffers from late contractor involvement and limited awareness (Fong & Shen, 2000), and LCC is hindered by non-standardisation and professional unfamiliarity (Olubodun, Kangwa, Oladapo, & Thompson, 2010). Addressing these gaps requires not only technological adoption but also structural and cultural change, including collaborative procurement methods, early integration of the SC, and targeted training. These provide the theoretical basis for the Concurrent Engineering-Driven Construction Supply Chain Framework (CE-CSCF) developed empirically in this study.

3 Methodology

We used a contemporaneous triangulation mixed-method strategy to gather, evaluate, and compare qualitative and quantitative results (Agyeiwaah, 2022). This included quantitative data from 17 expert survey respondents and qualitative interview data from 6 South African case studies. The 17 study respondents revealed 64.7% client-design team links, 17.6% client-main contractor linkages, 11.8% subcontractor engagement, and 5.9% supplier contracts, demonstrating various construction SC contractual agreements. The qualitative data came from 71 on-site interviews on roles, material management, and project dynamics from six construction projects in four South African provinces. While part of a contemporaneous triangulation mixed-method approach, qualitative data mostly verified and compared 17 survey results.

The survey used an inverted 5-point Likert scale (1 = Strongly agree to 5 = Strongly disagree) to assess participants' perspectives on CE and construction projects. Researchers used a reverse-coded structure to improve statistical sensitivity and reduce acquiescence bias, when respondents agree with items regardless of their substance (García-Fernández, et al., 2022). Table 1shows Question 21, which covered CE aspects such as product complexity management, interface control, and synchronisation, making agreement analysis easier. We carefully designed all psychometric statements to fit the construction environment and pre-tested them with 5 specialists to reduce confusion from reversed items. The reverse-coded method made statistical interpretation easier since lower mean scores consistently suggested stronger CE traits, agreeing with behavioural and project management research criteria for appropriate answer collecting (İlhan, Güler, Teker, & Ergenekon, 2024). All responder data was protected and used for professional and research objectives. Faculty Ethics and Plagiarism Committee approved the work.

The study used quantitative and qualitative methods to analyse data. Quantitative data was cleaned and processed using SPSS Statistics software and out of 17 total survey responses 13 were found to be valid and complete for statistical analysis, yielding a 76.5% success rate. Analysis of CE enabler and trait responses included descriptive statistics comprising of mean, standard deviation, skewness, and kurtosis. Results were classed by consensus levels utilising CE perception research methods like Love et al. (Love & Gunasekaran, 1997) and shown using figures and tables to show agreement and dispersion patterns. The qualitative component used thematic content analysis to identify CE practices, collaboration, integration, and innovation topics. The study's triangulation technique used open coding to examine transcripts and quantitative data to validate or contrast responses. The complexity of CE in construction requires both quantitative and qualitative data to understand (Maqbool, Arul, & Ashfaq, 2023). Triangulation increases internal validity through cross-verification (Maqbool, Arul, & Ashfaq, 2023), while case studies provide contextually rich insights into team dynamics and supply chain coordination, supporting Koskela (2002)'s systems-thinking paradigm.

4 Results- Key Findings

The quantitative survey findings, represented in Table 1, indicate a strong consensus among experts regarding critical enablers and advantages of Concurrent Engineering (CE) in construction projects. Access to functional expertise, clear product ownership, supplier training, idea sharing, optimal resource utilisation, and efficient problem-solving are essential components. All received low mean scores (1.86–2.21 on a 5-point scale), indicating a strong consensus. This is consistent with the principles of multidisciplinary collaboration and integrated processes in CE. In contrast, faster communication (M=2.21) constituted a distinct cluster: most respondents acknowledged it as a benefit of CE, although the positive skew and kurtosis indicate that a minority remained neutral. Innovative solutions, in-depth product knowledge, and reduced bureaucracy exhibited means of 2.00–2.29, with distributions that were normal, indicating general consensus but with a broader variability.

The results can be classified in 3 distinct groups:

- Group 1 (Strong Agreement, M<2.0): Access to functional expertise (M=1.86), clear product ownership (M=1.86), supplier training (M=1.92), sharing of ideas (M=1.86), and optimal resource utilisation (M=1.86). The items exhibit a tight clustering (negative kurtosis), indicating a near-unanimous consensus that they represent CE benefits. CE literature highlights the importance of cross-functional expertise and knowledge-sharing during the initial design phases
- Group 2 (exhibits moderate agreement with long tail M=2.1) regarding the significance of expedited communication and the relevance of problems, with a mean score of approximately 2.21. A positive skew/kurtosis suggests that the majority of respondents provided high ratings, while a minority exhibited ambivalence. The parallel workflow of CE necessitates proactive communication; however, this outcome indicates variability in the effectiveness of project execution in this regard
- Group 3 (General Agreement, M=2.0–2.3): The benefits identified include innovative solutions (M=2.07), deep product knowledge (M=2.00), and reduced bureaucracy (M=2.29), all of which have means close to the midpoint. The approximately normal distributions indicate a moderate level of consensus. The items highlight that CE promotes creativity and the integration of knowledge, although the reduction of management layers may not be uniformly valued

Table I. Descriptive Statistics for CE Enablers and Benefits

CE Enabler/Benefit	Min	Max	Mean	SD	Sk[1]	SE (Sk)	Ku[2]	SE (Ku)[3]
Innovative solutions - Managing product complexity	1	3	1.86	.770	.264	.597	-1.123	1.154
In-depth product knowledge - Utilising product information	1	4	2.29	.994	.425	.597	-.552	1.154
Controlling interfaces – Interface management across domains	1	5	2.21	1.122	1.039	.597	1.605	1.154
Efficient problem-solving - Synchronisation for effective development	1	4	2.21	.893	.278	.597	-.327	1.154
Access to functional expertise - Multidisciplinary engineering	1	3	2.07	.616	-.024	.597	.302	1.154
Faster communication and problem relevance - Collaboration through the supply chain	1	3	1.86	.663	.151	.597	-.310	1.154
Permanent traceability of design data – permanent record of product configuration information facilitating changes and updates	1	3	2.00	.679	.000	.597	-.394	1.154
Reduced management bureaucracy – process-based team coordination	1	3	1.92	.760	.136	.616	-1.053	1.154
Product ownership -streamlined workflow and process quality	1	3	1.86	.770	.264	.597	-1.123	1.154
Optimal resource allocation – process-based team coordination	1	3	1.86	.864	.306	.597	-1.635	1.154

Notes: Definition:[1]Sk = Skewness; [2]Ku = Kurtosis; [3]SE = Standard Error.
N = 13 valid responses after data cleaning
Scales: Notes: 1-Strongly agree; 2-Agree; 3-Neutral; 4-Disagree; 5-Strongly disagree

The survey evaluated nine fundamental attributes of CE in projects as presented in Table 2. Responses were categorised into high, moderate, and low consensus groups according to their mean scores. High Consensus (M < 2.0): Management of interfaces (M=1.92) and optimisation of workflow and process quality M=1.93 received the highest positive ratings. The process-centric attributes exhibited modest skewness and kurtosis, suggesting a general consensus. This indicates that practitioners acknowledge the necessity of carefully managing team interfaces and sustaining efficient, high-quality workflows in CE. One study indicates that the key features of CE encompass “concurrent and parallel scheduling of all activities” and the “integration of the supply chain through effective collaboration, communication, and coordination.” Managing interfaces is essential in CE to ensure that the outputs of each team are properly aligned.

Moderate Consensus (M = 2.0–2.14) of six attributes were identified: managing product complexity, synchronisation for effective development, multidisciplinary engineering, utilisation of product information, supply-chain collaboration, and permanent traceability of information. The means (2.00–2.14) and light-tailed distributions suggest predominantly positive yet diverse perceptions. The attributes align with CE principles; for instance, the formation of multidisciplinary teams and the utilisation of integrated data are fundamental to CE practices. The proximity of most means to 2.0 indicates that these are recognised as CE characteristics; however, the variation in responses implies the need for improved cohesion in understanding, potentially through training or standardised practices.

The process-based paradigm achieved a score of M=2.23, characterised by high kurtosis and positive skew, indicating strong consensus among many while a significant minority expressed disagreement. This suggests that some perceive CE as comprising of formalised, consistent processes, whereas others regard it as more adaptable. The pronounced peak indicates that the issue is polarising, potentially reflecting varying organisational cultures concerning the rigidity of CE process implementation.

Table 2. Descriptive Statistics for CE Attributes in a Construction Project

CE Attribute	Min	Max	Mean	SD	Sk[1]	SE (Sk)[2]	Ku[3]	SE (Ku)
Managing product complexity	1	3	2.00	.816	.000	.616	-1.445	1.191
Utilising product information	1	3	2.08	.862	-.164	.616	-1.680	1.191
Controlling interfaces	1	4	1.92	.954	.854	.616	.221	1.191
Synchronisation for effective development	1	3	2.00	.707	.000	.616	-.618	1.191
Multidisciplinary engineering	1	4	2.00	.913	.777	.616	.441	1.191
Supply chain collaboration	1	3	1.93	.616	.024	.597	.302	1.154
Traceability of product information	1	3	2.14	.770	-.264	.597	-1.123	1.154
Process-based paradigm	1	5	2.23	1.092	1.281	.616	2.548	1.191
Streamlined workflow and quality	1	3	1.93	.730	.113	.597	-.856	1.154

Notes: Definition: [1]Sk = Skewness; [2]Ku = Kurtosis; [3]SE = Standard Error.
N = 13 valid responses after data cleaning
Scales: Notes: 1-Strongly agree; 2-Agree; 3-Neutral; 4-Disagree; 5-Strongly disagree

4.1 Concurrent Engineering-Driven Construction Supply Chain Framework

Figure 1 presents the concurrent engineering-driven construction supply chain framework (CE-CSCF), a five-stage model developed from the research findings to address persistent construction SC challenges such as fragmentation, delayed coordination, and inefficiencies. Strategic alignment forms the foundation, integrating cross-functional teams, early supplier involvement, digital platforms, and CE-compatible contracts to harmonise objectives and processes. The collaborative innovation and learning platform operationalise CE through co-development, lessons learned, targeted training, and lean synergy, fostering a responsive and knowledge driven network. CE-driven performance and sustainability metrics introduces KPIs tailored to CE adoption alongside ESG targets, balancing efficiency with sustainability. Feedback loops and system adaptation ensure continuous improvement through post-project audits, maturity models, and process updates. Collectively, these stages enable the transformation of CSC into smart, sustainable, and innovation-oriented systems, mirroring aerospace's proven capacity for efficiency, adaptability, and long-term performance gains.

Figure 1: Concurrent Engineering-Driven Construction Supply Chain Framework (CE-CSC)

5 Discussion

The strong agreement on CE enablers on Group 1 items suggests that CE is widely recognised for enhancing teamwork and resource efficiency. This might be due to CE's structured integration of design, engineering, procurement, and construction functions, enabling faster decision making and fewer downstream conflicts (Asad, Purushothaman, & Poshdar, 2025). The near unanimous agreement on interface management and workflow quality reflects the perceived value of aligning interdependent tasks to minimise delays and errors. In contrast, variability in communication speed and bureaucracy reduction may result from inconsistent adoption of digital collaboration systems or differences in governance approaches. While some teams use mature integrated platforms to coordinate information flows, others operate with fragmented tools, leading to uneven outcomes. Similarly, polarised views on process formalisation may stem from sector-wide debates on whether rigid standardisation improves consistency or hinders adaptability. The moderate consensus on multidisciplinary engineering, product information utilisation, and traceability suggests that while these principles are recognised as valuable, their practical application may vary between organisations. This variation, Elkhayat et al (2024) posits might be due to differences in training, technology adoption, or the maturity of data management systems, which in turn influence the effectiveness of CE practices.

The findings from this study align with research on Integrated Project Delivery (IPD), which similarly underscores the importance of early stakeholder engagement, contractual alignment, and shared incentives in driving collaborative success (Asad, Purushothaman, & Poshdar, 2025). Th emphasis on communication and coordination mirrors results from studies on collaborative contracts that show integrated digital platforms and clear process governance enhance information flow and decision quality (Whyte, et al., 2025). The high priority given to interface control and workflow quality is consistent with established CE theory, which stresses concurrent scheduling and integration across the SC. This is further supported by BIM-enabled circularity frameworks, where digital modelling and ontological data integration enhance both coordination and sustainability performance (Sivashanmugam, Meng, Rodriguez, & Rahimian, 2025). The divergence in views on process formalisation reflects ongoing discourse in the literature. While digital technology reviews demonstrate that BIM, IoT, and digital twins can bring structure and measurability to CE processes (Chen et al., 2025), other studies caution over-standardisation, which may reduce responsiveness. The CE-CSCF developed in this study addresses this tension by incorporating feedback loops and adaptation mechanisms to balance standardisation with flexibility. Moreover, the link between CE and SC responsiveness is reinforced by AI-based SC optimisation models, which show that predictive analytics can improve procurement timing and reduce unnecessary stockholding (Mtope et al., 2025). The integration of performance measurement frameworks, as discussed in logistics KPI research (Jafari, Mottee, & Whyte, 2025; Jonsson & Rudberg, 2017), further validates the CE-CSCF's inclusion of tailored KPIs and ESG metrics to drive continuous improvement.

6 Conclusions

This study demonstrates that CE, as practised in aerospace, can be adapted to address fragmentation and inefficiency in CSCs by embedding early integration, cross-functional collaboration, and digital enablement. Empirical evidence from surveys and interviews validates keys CE enablers-interface control, supplier involvement, and resource optimisation-and motivated the Concurrent Engineering-Driven Construction Supply Chain Framework (CE-CSCF). The CE-CSCF offers a pragmatic framework for implementing CE throughout the CSC, with specific ramifications for practice, research, and policy. The framework necessitates a transition in industry from project-centric silos to integrated, supplier-inclusive programs: construction projects must restructure contracting and governance to facilitate early supplier engagement, invest in interoperable digital platforms and CE-focused training, and implement CE-aligned KPIs to monitor iteration speed, interface control, and sustainability outcomes. The CE-CSCF identifies key areas for empirical investigation: validating the framework's stages via longitudinal and intervention studies, refining CE-specific metrics (including ESG indicators), and assessing technology-human interactions that facilitate adaptive feedback loops. The framework indicates that policy and professional organisations require supportive tools, including procurement models that incentivise cooperation, defined methodologies for LCC/VE/BIM integration, and capacity-building initiatives to enhance client and consultant CE literacy. Collectively, these implications establish the CE-CSCF as a catalyst for expedited, environmentally sustainable, and more robust CSCs.

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Data Availability Statement

Due to ongoing manuscript submissions and confidentiality agreements with participating organizations, the data supporting this study are not publicly available. Aggregated or anonymized data may be made available from the corresponding author upon reasonable request and subject to institutional approval.

Conflicts of Interest

The authors declare no conflict of interest.

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