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Adaptive Strategies and Sustainable Innovations of Chinese Contractors in the Belt and Road Initiative: A Social Network and Supply Chain Integration Perspective

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Abstract: As global economic integration and rapid technological advancements transform international business, international engineering contracting has become essential for achieving sustainable development goals (SDGs). This paper investigates the significant impact of China's strategic initiatives, notably the "Going Global" strategy and the Belt and Road Initiative (BRI), on the operational practices of Chinese enterprises involved in overseas investments. Central to this transformation is the Engineering, Procurement, and Construction (EPC) model, which emphasizes the integration of supply chain management and stakeholder collaboration to enhance performance in international EPC projects and underscores the crucial role of these elements in promoting sustainability. Incorporating insights from social network data analysis, this study reveals that contractors collaborating with various stakeholders—such as owners/consulting engineers, domestic and foreign customs departments, and group headquarters/design parties—exhibit a high degree of similarity in personnel profiles. This suggests that the internal organizational structure and personnel allocation of contractors could be optimized to enhance operational efficiency, aligning with the collaborative patterns identified. This study addresses a critical research gap by exploring how effective supply chain management and collaborative stakeholder engagement within multinational EPC projects contribute to sustainable outcomes. Employing advanced social network analysis software, the research examines the complex interactions among stakeholders and their influence on procurement dynamics. Findings indicate that strong relational networks and strategic collaborations significantly enhance procurement efficiency and project success, underscoring the importance of supply chain integration. Ultimately, integrating supply chain management principles into the EPC model not only offers innovative perspectives for advancing sustainability in international projects but also provides actionable insights for improving project outcomes within the BRI framework. This research underscores the pivotal role of supply chain organization and stakeholder cooperation in achieving sustainability objectives, thereby enriching the discourse on sustainable enterprise operation and supply chain management in the context of global initiatives.

Keywords: supply chain integration; social network analysis; international engineering projects and sustainability; sustainable procurement management; stakeholder engagement and relationships; EPC model; sustainable development

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1. Introduction

An era of rapid technical breakthroughs and faster globalization is bringing about significant transformations in the global engineering contracting sector, which are required to achieve sustainability. The amalgamation of strategic economic methodologies and innovative project management techniques is altering worldwide market dynamics. The Belt and Road Initiative (BRI) and China's "Going Global" strategy are essential components of this transformation; they have emerged as influential mechanisms driving the global expansion of Chinese firms while prioritizing sustainable development.

In addition to helping the Engineering, Procurement, and Construction (EPC) model gain traction, these strategic frameworks have given Chinese enterprises the ability to interact with and exert influence over intricate global stakeholder networks. The substantial rise in revenue from international contracting, escalating from USD 13.84 billion in 2003 to USD 154.07 billion in 2015, indicates remarkable growth. Nevertheless, the reduction in growth rates since 2010 emphasizes wider global economic difficulties and reveals the sector's susceptibility to variable market conditions.

The fall observed in 2018, influenced by factors such as sluggish global trade, reduced foreign investment, escalating global debt, and financial instability, underscores the complexity of the business. Despite a temporary enhancement at the close of 2019, the primary growth trajectory has largely been downward, with forecasts suggesting a small increase to USD 133.3 billion by 2022. This trend illustrates the ongoing necessity for the sector to adapt to evolving global economic conditions and to proactively engage in sustainable practices.

This paper provides a comprehensive analysis of how Chinese foreign contractors are adapting their strategies inside the BRI framework to promote sustainability in response to these challenges. This study utilizes advanced analytical techniques to offer novel insights into how these firms strengthen their procurement management and increase sustainability outcomes through optimized stakeholder engagement. The sector witnessed a significant increase in 2021, with external contracts amounting to USD 258.49 billion, reflecting a 1.2% year-on-year gain. This signifies a positive transformation and a renewed confidence in the industry. The continuous growth in 2022, marked by a 3.0% rise in new contract values to USD 195.66 billion, underscores a robust recovery and a strengthened commitment to sustainable development.

In addition, this study examines how contractors utilize the EPC model to manage systemic risks, capitalize on new possibilities, and enhance both economic and environmental sustainability. This study aims to improve the understanding of key factors contributing to success in international engineering contracting via the integration of contemporary analytical methods and empirical evidence. Gaining fresh insights will enhance theoretical frameworks and assist industry stakeholders in applying beneficial recommendations that promote sustainable and productive practices in the global marketplace.

As Figure 1 illustrates, the foreign engineering contracting industry in China had substantial growth between 2003 and 2023. The present boom phase has been driven by strategic initiatives, including the "Going Global" strategy and the Belt and Road Initiative (BRI). In recent years, the growth rate has decelerated, attributable to global economic uncertainties and market volatility. Nonetheless, the data also reveal a recent uptick in market activity and optimism. The current expansion in the sector can be partially attributed to the aggressive economic stimulus initiatives enacted by numerous governments in response to the COVID-19 pandemic. As the global health crisis diminishes, it is expected that these stimulus programs will significantly rejuvenate the need for infrastructure. Governments globally are anticipated to pursue extensive construction and development initiatives to expedite economic recovery. These measures possess the capacity to revitalize the engineering sector, perhaps reversing previous declines and fostering a more dynamic market environment.

It is anticipated that the post-pandemic economy will recover, which is encouraging for the engineering community worldwide. We can expect a substantial increase in demand for engineering services, with the continuation and initiation of various infrastructure projects. Enhanced investment in infrastructure is anticipated to stimulate economic activity, generating prospects for global expansion and technological improvements. As governments and enterprises invest resources to enhance infrastructure, the industry is anticipated to experience substantial advancement.

Chinese firms are strategically positioned to enhance their market share and influence in the international engineering contracts sector. China's involvement in international infrastructure development will be augmented by the growing demand for infrastructure and the proliferation of project opportunities. The evolving nature of this situation under-

scores the strategic significance of China and its capacity to advance international projects, illustrating its vital role in shaping the future of global engineering.

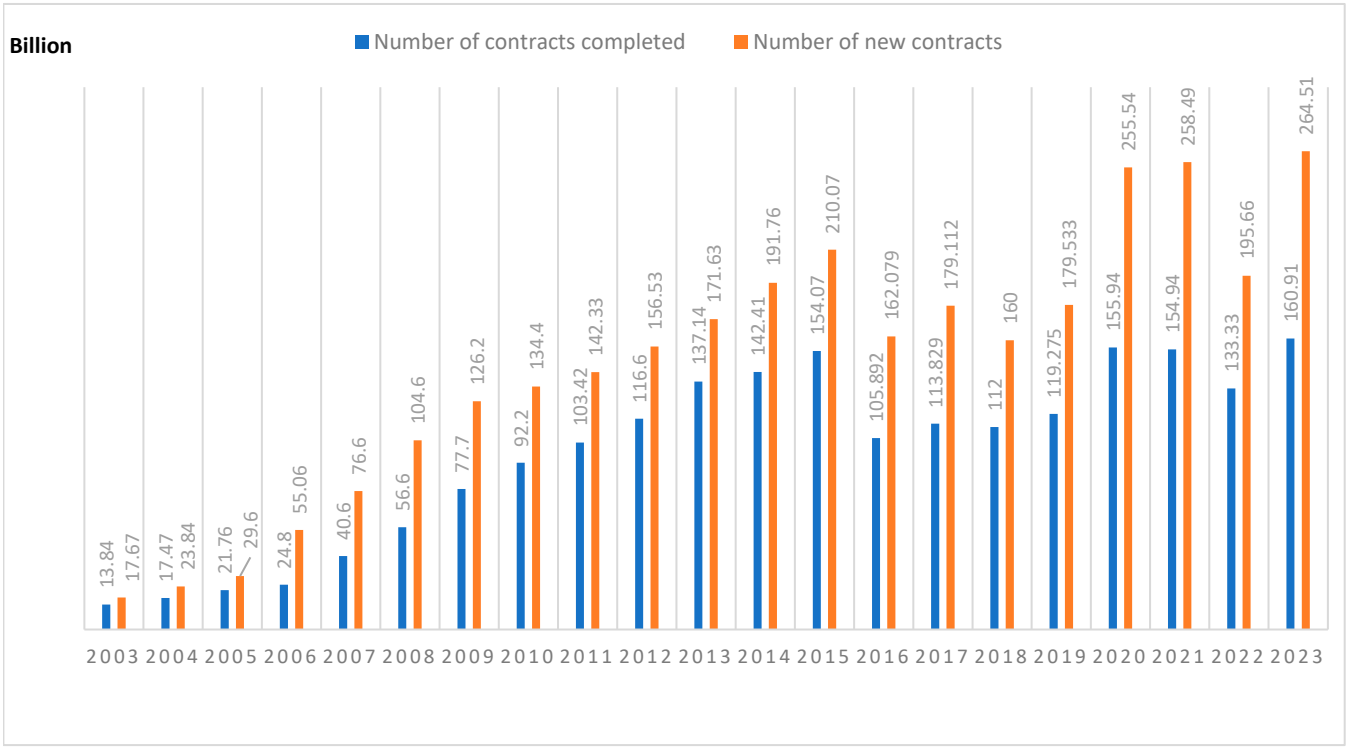

Figure 1. An analysis of the developments in China's overseas engineering contracting industry from 2003 to 2023. Data Source: Ministry of Commerce, China (2003–2023).

Strategic planning for international engineering projects is increasingly prioritizing sustainability. As global awareness of environmental and social repercussions rises, there is an intensified focus on integrating sustainable practices into engineering and construction endeavors. Chinese enterprises are anticipated to spearhead the adoption of eco-friendly technologies and sustainable practices, thereby enhancing their competitive edge and contributing to global sustainability goals.

The evolving dynamics of the global engineering sector underscore the vital necessity for proactive investment and strategic adaptation. Chinese companies are well-positioned to spearhead future global growth and development by using emerging opportunities and aligning their strategy with sustainability objectives. Their continual focus on sustainable development will enhance their impact and success in the international arena, thereby contributing to a more resilient and equitable global infrastructure landscape.

Due to the essential function and intrinsic complexity of procurement in international engineering EPC projects, general contractors must implement new techniques to enhance their procurement management. Historically, ties among stakeholders—such as contractors, suppliers, owners, and consulting engineers—are frequently regarded as transient contractual agreements. This mentality cultivates competitive behaviors motivated by divergent objectives and interests, resulting in difficulties such as insufficient collaboration, poor interface management, inefficient processes, and heightened transaction costs stemming from knowledge asymmetry. Ultimately, these challenges may lead to increased construction expenses and diminished quality, emphasizing the necessity for a more collaborative methodology.

To address these challenges, many scholars advocate for integrating supply chain concepts into project management within the construction sector. This approach aims to consolidate fragmented processes, reducing costs and saving time [1–3]. Supply chain integration emphasizes long-term collaboration among stakeholders, allowing for better

coordination of the complex and diverse procurement processes [4,5]. By fostering cooperation and trust, this integration aligns the objectives and interests of all parties, leading to more effective decision-making and resource-sharing.

The essence of supply chain integration is in the elimination of obstacles within and among businesses, facilitating the seamless transfer of information and resources across participant boundaries. This reduces management and technological redundancies, hence improving overall supply chain efficiency [6,7]. Recent research suggests that general contractors ought to adopt a value creation approach to procurement management, aiming to optimize the contributions of each participant involved in multinational engineering EPC projects. Emphasizing collaboration among stakeholders is crucial for attaining optimal procurement performance and securing a competitive advantage.

In summary, supply chain integration has been a highly successful advanced management technique that has been well-supported in the manufacturing sector. The construction sector can derive insights from the manufacturing sector by adopting innovative approaches to supply chain integration. Examining procurement management in multinational engineering EPC projects through the perspective of supply chain integration and stakeholder collaboration holds considerable theoretical and practical significance. By cultivating collaborative partnerships, general contractors can improve procurement efficiency, decrease expenses, and ultimately guarantee superior quality results in their projects. This comprehensive strategy not only tackles current obstacles but also enables contractors to excel in a progressively competitive environment.

2. The Literature Review

2.1. An Overview of Procurement Management in Multinational Engineering EPC Projects

The growing complexity of global engineering EPC projects has rendered good procurement management increasingly vital. These projects necessitate a diverse array of materials and equipment, encompassing fundamental construction supplies as well as specialized machinery and maintenance components [8]. Procurement management is essential for linking the design and construction phases, guaranteeing that the project is operational and proceeds seamlessly [9]. Nonetheless, the substantial costs associated with procurement—along with dependence on external suppliers and logistics providers—often render this factor more challenging to manage than other project elements, particularly due to extended lead times [10,11]. The incorporation of bespoke components in EPC projects exacerbates the complexities of inventory and procurement management [12,13]. Consequently, procurement optimization is essential for enhancing overall project efficiency [14,15]; nevertheless, it presents challenges such as intricate coordination, diverse stakeholder engagement, and the potential for delays and cost overruns resulting from process overlaps [16].

A recent study emphasizes the various strategies used to address these procurement challenges; the proposed techniques include integrating parallel engineering [17], employing lean building procedures [18], and forming strategic partnerships [19]. The primary recommendations encompass streamlining procurement processes, selecting reliable suppliers [8], including downstream stakeholders early in upstream activities [20,21], restructuring workflows, and employing advanced information technology. To mitigate procurement uncertainties and enhance supply chain integration [22], it is essential to develop robust inter-organizational communication, coordination, and collaboration, along with implementing incentive contracts and risk assessment models. These strategies aim to optimize procurement methods, increase efficiency, and effectively manage the inherent complexities of EPC project management.

Considering the complex nature of procurement management in international engineering EPC projects, it is essential to tackle these difficulties using the previously outlined strategies. As the intricacies of these undertakings advance, the incorporation of sophisticated approaches and technology becomes essential. Utilizing digital tools for real-time tracking and predictive analytics can substantially improve procurement efficiency and

decision-making. Furthermore, utilizing data-driven insights to predict demand and enhance inventory management might alleviate certain conventional hazards linked to custom components and prolonged lead times [23].

2.2. Stakeholder Management

As derived from Figure 2, when stakeholders are not well-defined, the phrase "network of relationships" is frequently used to describe the complex, non-linear, and iterative dynamics of stakeholder interactions in construction projects [24]. Conventional analyses often focus on internal and contractual relationships and analyze stakeholder interactions from a two-dimensional perspective, typically involving only two parties [25]; however, the interactions inside a project are inherently more complex [26]. With the ability to map and understand the intricate web of contacts, social network analysis has become a vital tool for managing potential stakeholder relationships [27].

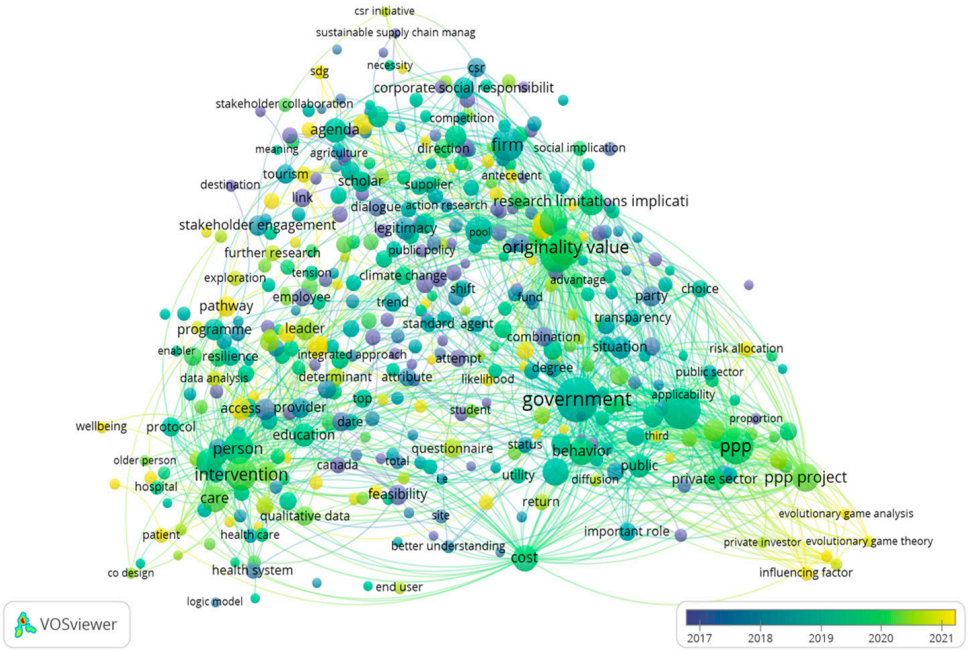

Figure 2. A network that shows how studies on stakeholder management occur together.

Furthermore, the application of advanced network analysis techniques aligns with the broad sustainability goals of encouraging open and cooperative project environments. These approaches make it easier to develop strong and adaptable stakeholder engagement plans, which are necessary to achieve long-term project success and sustainability. Social network analysis can provide insights that are essential for promoting more sustainable and equitable project outcomes, as environmental and social concerns are becoming more frequently prioritized in projects.

2.3. Supply Chain Integration

The important terms "chain partner", "management practice", and "chain flexibility" are prominently displayed in Figures 3 and 4, suggesting a strong emphasis on cooperative and flexible management practices in supply chains. The terms "integration", "modelling", "information", and "cycle" indicate a focus on the systematic and cyclical characteristics of supply chain operations.

The proximity of the terms "speed", "robustness", and "flexibility" may signify the significance of responsiveness and resilience in supply chain management. The inclusion of "agile supply chain strategy", "transparency", and "accountability" indicates an emphasis on contemporary, dynamic, and responsible supply chain practices. The color gradient from yellow to blue signifies the period from 2005 to 2020, with blue phrases indicating

more recent entries. This signifies the evolution of conversations or the aspects that have gained prominence over time.

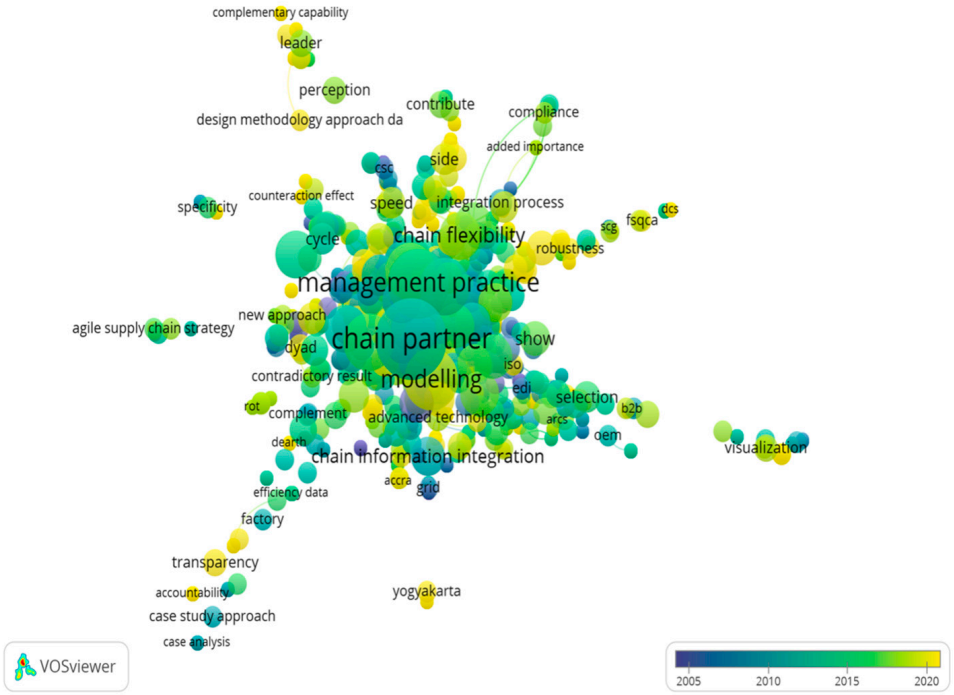

Figure 3. Co-occurring network for supply chain integration research.

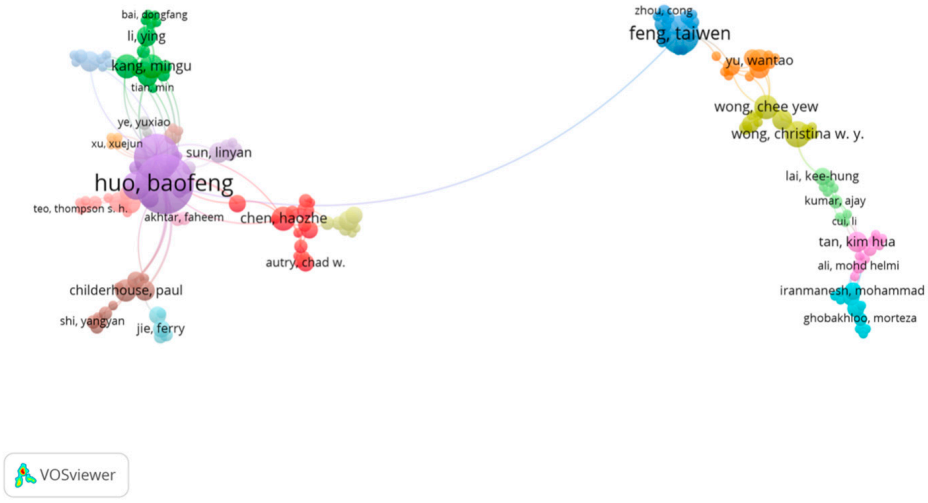

Figure 4. Network of coauthors on supply chain integration studies.

Comprehensive studies have shown the substantial impact of supply chain integration on improving organizational efficiency and market positioning [28]. Building on fundamental studies by Stock et al. [29] and Wood [30], it is evident that successful integration can enhance profitability and strengthen competitive positioning. This necessitates the creation of uninterrupted communication lines across organizational and functional divisions.

A thorough examination of the integration tactics used by 322 multinational manufacturing companies is given by Fohlich et al. [31], who identified five important strategies: internal, boundary, supplier, customer, and external integration. Their findings indicate that companies employing comprehensive integration strategies that connect suppliers and customers realize the most substantial performance enhancements [32]. Olhager et al. [33] investigated supply chain management techniques in 128 Swedish manufacturing firms,

emphasizing supply chain architecture, integration, and stakeholder communication [34]. Despite the acknowledged significance of collaboration, numerous organizations continue to exhibit unsatisfactory performance, suggesting that although the advantages of integration are increasingly recognized, substantial potential for additional enhancement persists.

In summary, supply chain integration confers substantial competitive advantages by augmenting organizational skills, expanding flexibility, and promoting innovation. The strategic advantages of these synergies may not always be immediately apparent but provide significant long-term value.

2.4. The Advantages of an Integrated Supply Chain

Numerous studies have investigated the correlation between supply chain integration and performance [35,36]. A standard organization's supply chain constitutes 60% to 80% of its expenses, and a 10% improvement in the supply chain can yield a 40% to 50% rise in profit. The research conducted by Fohlich et al. (2001) [31]—which analyzed the integration strategies of 322 manufacturing firms globally—developed a metric for assessing supply chain integration and delineated five distinct strategies for integrating suppliers and customers: internal, boundary, supplier, customer, and external integration strategies. The study indicates that companies with extensive supply chain integration between suppliers and customers have the most significant performance enhancement. These strategies exemplify vertical integration, either upward or downward. Research conducted by Olhager et al. (2003) [32] analyzed the supply chain management strategies and practices of 128 Swedish manufacturing firms, focusing on aspects such as supply chain design, integration, and communication with customers and suppliers. Despite respondents' conviction that supply chain collaboration is essential for their organization, subpar performance has been documented, indicating that enterprises are increasingly recognizing the need of supply chain integration. Nonetheless, a considerable amount of effort remains to fully leverage the benefits of supply chain integration. Bagchi et al. (2005) [37] conducted an analysis of the extent and attributes of supply chain integration in 149 European firms, revealing that the degree of integration influences operational performance, costs, and efficiency.

Research indicates that supply chain integration yields cooperative competitive advantages, signifying strategic benefits over market rivals derived from such integration. Vangen et al. (2003) [38] assert that cooperative benefit arises from a synergistic amalgamation of cooperative conduct. Ralston et al. (2015) [39] observed that integration can amplify the advantages of collaboration and yield more benefits for all stakeholders. Beyond cost savings derived from the dissemination of best practices, supply chain integration also improves the efficacy and adaptability of shared behaviors, augments decision-making, amplifies advantages through resource synergy, and stimulates innovation through the amalgamation and interaction of ideas. Business synergies may not be immediately evident; however, they can yield long-term strategic benefits. According to Cao et al. (2011) [40], supply chain integration is defined by five advantages: process efficiency, flexibility, business synergy, quality, and innovation.

2.5. Necessity of Integration of the Procurement Management Supply Chain for International Engineering EPC Projects

Global economic integration has driven transnational firms to optimize supply chain integration, managing complex, multi-regional operations. Companies like IBM and Walmart have achieved global manufacturing success through effective supply chain management [41]. Similarly, international engineering EPC projects face procurement challenges due to their large-scale and non-standard nature [42].

While supply chain integration has proven effective in manufacturing, the construction industry is still adopting these methodologies [43]. Currently, it remains primarily an academic concept with limited practical application in construction. Effective strategies

include collaborating with a select number of suppliers, building long-term relationships, and fostering trust to enhance performance [43].

Construction project managers often make daily supply chain decisions without formally recognizing their role in supply chain management [44]. While real-time information improves service and accountability, managing extensive data can be overwhelming [45]. The construction sector needs flexible supply chain management to address its unique project-oriented characteristics [46].

Given the unpredictable global environment, international EPC contractors must unify their supply chains to leverage stakeholder expertise and resources [19,43]. This study aims to explore how contractors can effectively integrate their internal and external supply chains, identify procurement bottlenecks through constraint theory, and enhance procurement management to boost project efficiency and economic outcomes.

3. Materials and Methods

3.1. Methodological Approach and Data Analysis

3.1.1. Social Network Analysis Insights

Social network analysis (SNA) clarifies stakeholder relationship structures and enables the assessment of network resilience. Through the assessment of the network's resilience, organizations can pinpoint potential vulnerabilities and formulate plans to fortify these aspects. This is essential for preserving continuity and stability amidst disturbances, especially in intricate EPC projects characterized by significant interdependencies among stakeholders. Improving network resilience via specific initiatives helps guarantee that the supply chain remains operational and adaptive during emergencies.

The optimization of partnerships and strategic alliances throughout the supply chain is another area where SNA was applied. By identifying pivotal influencers and central nodes, companies can deliberately connect with these entities to enhance joint initiatives and utilize their impact. This strategic involvement can foster robust relationships and enhance collaboration, which is crucial for attaining project objectives and promoting innovation in EPC projects.

3.1.2. Research Object and Project Situation

This study selected the top ten Chinese international contractors from the ENR250 list for investigation, specifically focusing on four major international engineering EPC (Engineering, Procurement, and Construction) project contractors. These contractors operate across regions including Asia, Africa, Latin America, and Oceania, and are involved in sectors such as energy, building construction, municipal projects, road and bridge construction, and mining. The research targeted management personnel with extensive experience in international engineering EPC projects and procurement.

Field surveys were conducted with headquarters management staff, while online surveys targeted overseas project management personnel. A total of 130 questionnaires were distributed, yielding 117 valid responses at a response rate of 90%. The following sections provide detailed insights into the survey subjects and the projects under investigation.

In the realm of EPC (Engineering, Procurement, and Construction) projects, the surveyed individuals predominantly occupy roles closely associated with procurement activities. Notably, over 34% of respondents are directly involved in procurement. Over the past five years, the average number of international EPC projects each respondent has participated in stands at 1.79. These data reflect a well-aligned distribution of roles among the respondents and indicate their substantial experience in managing international EPC projects.

The survey encompasses 45 EPC projects across 23 countries in Africa, Asia, Latin America, the Middle East, and Oceania. This geographic distribution closely mirrors the international business spread discussed in the Introduction, with a focus on regions highlighted by the "Going Global" initiative and the Belt and Road Strategy. Such distribu-

tion underscores the representativeness and relevance of the survey, reflecting the overall engagement of Chinese enterprises in international EPC projects.

The analysis of the 117 survey respondents was conducted using social network analysis methodology. This approach allows for a comprehensive examination of the relationships and interactions among the participants, shedding light on the network dynamics and collaboration patterns within the context of EPC projects. By applying social network analysis, we can gain deeper insights into the structural and relational aspects of the respondents' professional engagements, further elucidating the roles and connections that influence their involvement in international EPC projects. This analysis will facilitate a more nuanced understanding of the interrelationships and collaborative frameworks that underpin the management and execution of these projects.

3.1.3. Analyzing Stakeholder Connectivity and Interaction through UCINET Software

This study utilized advanced analytical approaches with UCINET 7 software to rigorously analyze quantitative data obtained from the extensive surveys, building upon the first analysis of stakeholder interactions. This research employed an integrative strategy that amalgamates diverse analytical methodologies to provide a comprehensive knowledge of the interactions and dynamics among stakeholders within the network.

The data collection process was meticulously designed to ensure robustness and representativeness, incorporating both field surveys and online questionnaires. This study examined prominent Chinese international contractors from the 2023 ENR250 list, engaging management specialists from four major EPC firms across several sectors and geographical areas. Of the 180 issued surveys, 117 valid replies were obtained, resulting in a response rate of 65%. The response rate indicates significant participation from essential industry stakeholders, hence ensuring data trustworthiness.

The outcomes of the social network analysis are depicted in a comprehensive diagram that delineates the collaborative links and interactions among stakeholders. Figure 5 illustrates a detailed representation of the network structure, emphasizing the relationships between the general contractor and many stakeholders. Each red dot in the diagram signifies one of the one hundred and seventeen research subjects, with the dot's size denoting intermediate centrality, which reflects the stakeholder's impact within the network. The position of the dot indicates its significance, while the distances between dots represent the level of similarity among stakeholders. This representation is crucial for recognizing key participants and comprehending their functions inside the network.

This study also delineates clusters within the network, wherein groupings of stakeholders have robust intra-group connections and diminished inter-group interactions. These clusters may indicate specialized sub-networks characterized by unique collaboration patterns and communication flows. Comprehending these clusters is essential for customizing stakeholder engagement tactics and enhancing overall network cohesion.

Furthermore, this study emphasizes the necessity for adaptive stakeholder management strategies that respond to the changing dynamics of the global engineering environment. As projects get more intricate and international, the capacity to adeptly manage and utilize stakeholder connections is crucial for attaining project success and sustainability.

To sum up, the utilization of UCINET for social network analysis offers valuable perspectives on the complex network of connections among stakeholders in the global EPC contracting industry. The results highlight essential elements of collaborative dynamics, stakeholder centrality, and network structure, which are vital for effective project implementation. These insights provide theoretical contributions and practical direction, enabling practitioners with actionable techniques to effectively navigate the difficulties of global EPC projects. Future research may investigate the long-term implications of stakeholder relationships on project outcomes, enhancing our comprehension of network dynamics and performance.

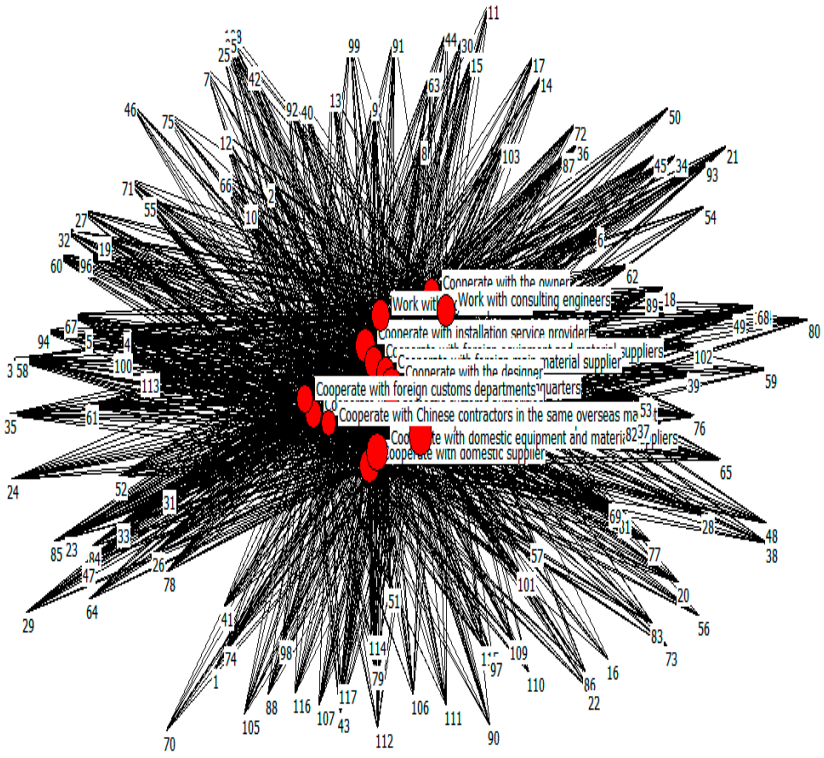

Figure 5. Stakeholder collaboration networks.

From Figure 5, the social network map not only identifies significant nodes and their relative importance but also elucidates the structure of inter-stakeholder interactions. Examining these relationships facilitates the recognition of collaborative tendencies and the identification of potential bottlenecks or places of resistance within the network. By acknowledging these dynamics, project managers may deliberately mitigate vulnerabilities and cultivate robust partnerships, ultimately enhancing overall project coherence and efficiency.

The graphic elucidates the influence of stakeholder centrality on project performance. Key stakeholders, positioned centrally within the network, frequently contribute significantly to the success of projects. Comprehending their influence and interactions with other stakeholders helps inform the creation of focused engagement initiatives. This guarantees that essential stakeholders are appropriately utilized to support project objectives and address any disputes.

The stakeholder network diagram was deliberately streamlined to sharpen the analytical emphasis and improve interpretability. This improvement enables a clearer representation of the fundamental collaborative links and interactions inside the network, hence permitting a more accurate understanding of the core dynamics.

Consequently, Figure 6 depicts the optimized configuration of stakeholder collaboration, highlighting a diminished complexity in the network architecture. This enhanced visualization emphasizes the key links and interactions, providing a clearer comprehension of the essential stakeholder relationships and their impact on project outcomes. The simplification highlights essential collaborative patterns, offering significant insights into the strategic interactions and operational efficiencies within the stakeholder network.

Based on intermediate centrality criteria, Table 1 provides a comprehensive ranking of stakeholder cooperation by methodically grouping stakeholders by their prominence and connectedness within the collaborative network. This table facilitates a detailed examination of stakeholder influence, illustrating how key actors contribute to and shape network dynamics. Analyzing the intermediate centrality of stakeholders allows us to pinpoint individuals in pivotal roles within the network, hence offering insights into their potential influence on project results.

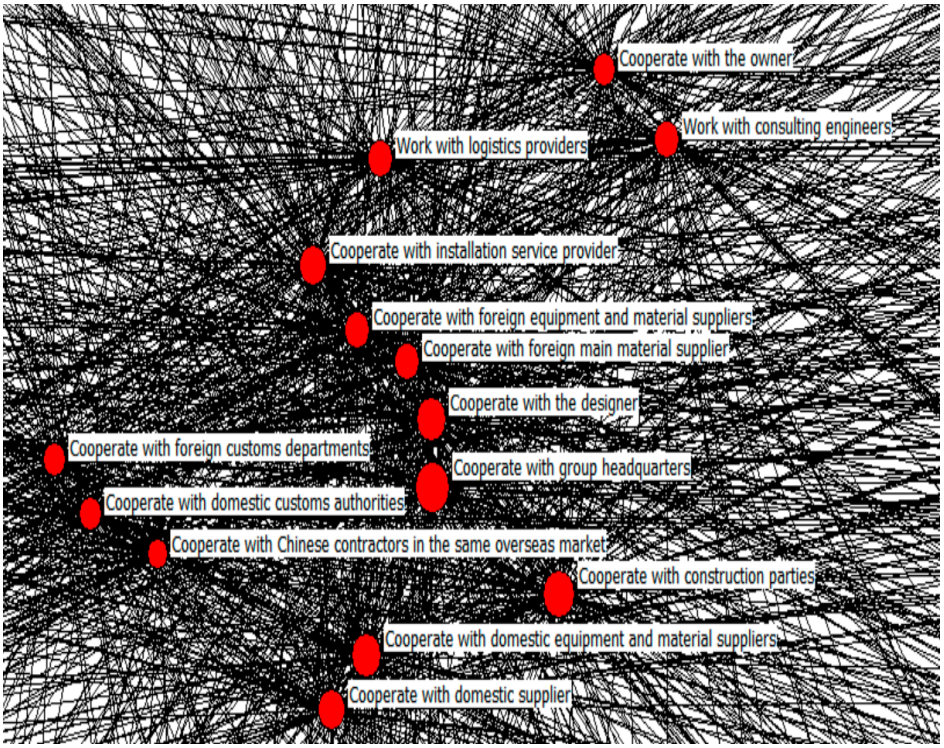

Figure 6. Enlarged visualization of stakeholder collaboration.

Table 1. Metrics of intermediary centrality in promoting stakeholder collaboration.

Stakeholder	Intermediate Centrality	Ranking
Cooperate with group headquarters	615.742	1
Cooperate with construction parties	584.654	2
Cooperate with domestic equipment and material suppliers	556.251	3
Cooperate with the designer	539.057	4
Cooperate with domestic supplier	537.365	5
Cooperate with installation service provider	507.989	6
Cooperate with foreign equipment and material suppliers	506.173	7
Cooperate with foreign main material supplier	503.481	8
Work with consulting engineers	488.688	9
Work with logistics providers	482.999	10
Cooperate with the owner	470.269	11
Cooperate with domestic customs authorities	461.882	12
Cooperate with foreign customs departments	423.144	13
Cooperate with Chinese contractors in the same overseas market	419.306	14

The rankings in Table 1 provide a useful framework for comprehending the hierarchical organization of stakeholder connections. Stakeholders with elevated centrality ratings frequently assume crucial roles in enhancing communication, decision-making, and resource distribution. Identifying these principal actors enables project managers to concentrate their engagement strategies on the most significant stakeholders, ensuring that their requirements and expectations are adequately met. This focused strategy enhances stakeholder engagement and aligns it with the project's strategic objectives.

Table 1 offers a nuanced perspective that underpins the creation of a more advanced stakeholder management framework, thereby enhancing project outcomes and promoting long-term success.

Upon further examination of stakeholder interactions within the project network, it is clear that intermediary centrality significantly influences the efficacy of procurement processes. The analysis indicates that specific stakeholders demonstrate considerable influ-

ence and connection, significantly affecting the entire dynamics of procurement and project execution. This observation underscores the need to comprehend the relational dynamics among diverse stakeholders to refine procurement strategies and improve project outcomes.

The general contractor currently sustains strong ties with various stakeholders and excels in collaboration. Table 1 indicates that the group office possesses the highest intermediary centrality score among all stakeholders, signifying its crucial involvement in the network. The significant point size of the group office signifies its considerable impact and pivotal role in expediting procurement operations. The engagement with the group offices substantially modifies the procurement process owing to their rigorous protocols and management frameworks, which guarantee thorough supervision of essential electrical and mechanical systems procurement. The group office, in conjunction with construction firms, local material suppliers, and designers, executes significant intermediary responsibilities, encompassing planning and procurement, underscoring its vital role in enhancing the efficiency of the procurement process.

The significance of intermediate centrality in enhancing information dissemination and decision-making within the network is paramount. Stakeholders possessing significant intermediary centrality frequently serve as channels for essential information, guaranteeing the efficient distribution of pertinent data and insights throughout the network. This job is crucial for achieving alignment among stakeholders and facilitating the smooth execution of procurement activities in accordance with project specifications. By consolidating essential contacts and information exchanges, these stakeholders improve the overall coherence and efficiency of the procurement process.

The conclusions from the stakeholder network analysis indicate that promoting collaboration among high-centrality stakeholders can produce significant advantages. Collaborative initiatives that prioritize collective problem-solving and resource allocation are expected to enhance procurement results and facilitate project success. This collaborative strategy corresponds with sustainable practices by enhancing resource efficiency and minimizing waste through coordinated initiatives.

3.2. Case Study—Zambian Hydroelectric Project

1 An overview of the project

As is shown in the above, we can see that Figure 7 presents images from the construction phase of the Zambian hydroelectric project. In the southern province of Zambia, the Zambia hydropower project is located in Chumo City, with an installed capacity of 2X60MW. The main project consists of infrastructure (owner camp, water supply and power supply systems, sewage treatment, and line renovation), and permanent works (power station, surge well, and switch station) in two parts. The project is an EPC general contract—it is a joint venture between Zambia National Power Company and India's Tata Group, and the total value of the EPC contract is USD 156 million. With the completion of the project, Zambia will be able to alleviate its power shortage situation as well as export electricity to neighboring countries suffering from power shortages.

2 The key issues in procurement management

There are several key procurement issues in the Zambia hydropower project:

- Financing is a problem for the owners. It is important for the general contractor to continue working when the owner has financial difficulties and no funds are available in order to facilitate brand building and ultimately market development;
- A large number of the main materials are selected to be procured locally due to the high transportation costs associated with third country procurement. However, there are few local manufacturers and few suppliers available, for example, only one local cement factory meets the requirements, resulting in limited supplier options;
- Goods are subject to wide fluctuations in price. Prices of cement, diesel oil, and other goods often fluctuate greatly due to a scarcity of local raw materials and fluctuations in exchange rates. The timing of procurement also has an impact on the cost of the goods.

Figure 7. Zambian hydroelectric project.

3 A strategy for procurement management in this project

Outlined below are the specific strategies of procurement management used for this hydropower project in Zambia:

- Efficient stakeholder interface management is crucial for general contractors to manage complex interactions in large-scale projects. Contractors can improve project implementation efficiency by enhancing communication and coordination among the stakeholders. It is essential to address potential delays in design approvals for vital components, such as bottleneck materials. To accelerate the approval process for a transformer procured from China, the general contractor convened a design review with the project owner, enabling direct communication with the supplier. This proactive strategy expedited approvals and enhanced procurement efficiency by minimizing misconceptions. Fostering robust supplier connections is essential for obtaining critical commodities and remaining apprised of pricing fluctuations. The strong relationship with the local cement supplier guaranteed prioritized assistance, whilst early notifications from the fly ash provider regarding price escalations exemplify the advantages of partnership. Robust ties with domestic equipment suppliers facilitate seamless manufacturing and delivery, even with finance delays. Ultimately, cultivating trust and communication with suppliers is essential for project success;
- A perfect logistics management mechanism must be in place. A transportation company with robust capabilities was chosen to manage the transportation and customs clearance of equipment and materials procured in China, ensuring transportation quality; the mechanical and electrical equipment department at the general contractor's headquarters was tasked with packaging and shipping these items and established specific transportation management protocols. When determining the loading location, it is essential to consider factors such as the site for loading large equipment, the quality of packaging for aesthetically demanding equipment, and the necessary precautions for equipment and materials with specific requirements, such as moisture protection. The general contractor designated specific personnel to liaise with the logistics company, providing real-time updates on transportation progress, ensuring the transport of equipment and materials, promptly addressing transportation issues, and coordinating with insurance companies for compensation claims.

4. Results

Based on the preceding analysis and conclusions, we propose a comprehensive supply chain model tailored for sustainable management in international Engineering, Procurement, and Construction (EPC) projects. This model underscores the critical role of the general contractor in fostering collaborative relationships among procurement stakeholders, which is essential for achieving supply chain integration.

As outlined by Crespin-Mazet et al. (2007) [47], procurement activities within international EPC projects occur both internally and externally among stakeholders. When operational processes are fragmented and relationships among participants such as owners, general contractors, suppliers, and designers are hostile, procurement inefficiencies arise. The general contractor is particularly crucial in this context, being responsible for a significant portion of procurement work and acting as the linchpin for effective supply chain integration [48].

To ensure the efficient acquisition and integration of resources, the general contractor must establish cooperative relationships with procurement stakeholders. This involves joint management of the procurement process and the coordination of both upstream and downstream industrial chains to enhance overall supply chain efficiency, ultimately leading to improved procurement performance. The general contractor oversees the flow of information, capital, and logistics, managing everything from the procurement of equipment and materials to their transportation, warehousing, usage, delivery, and after-sales service.

A functional network chain structure comprises various supply chain participants, including owners, consultants, suppliers, designers, construction parties, logistics service providers, installation service providers, and other related activities [43]. For effective execution, the general contractor must strengthen inter-organizational linkages, enabling efficient resource flow—including products, services, information, funds, and decision-making processes—between organizations. This integration of process chains enhances operational efficiency and facilitates information sharing, thereby improving decision-making effectiveness [36,49].

The integration of supply chains is widely believed to enhance the procurement management processes for general contractors, ultimately resulting in improved procurement performance in international engineering EPC projects [35,40,50–53].

The purpose of this section is to develop a theoretical model for procurement management in international engineering EPC projects based on the principles of supply chain integration, as illustrated in Figure 8 below. This model not only aims to enhance procurement efficiency but also aligns with the principles of sustainable management, thereby addressing the complexities of international EPC project delivery.

In this model, the roles of stakeholders, inter-organizational linkages, process management, and information management are clearly defined, particularly highlighting the critical function of the general contractor. The general contractor is responsible for managing various aspects of the EPC bidding process, including procurement plan management, supplier management, procurement contract management, and quality management of mechanical and electrical equipment. Additionally, this role encompasses logistics, warehousing, and the delivery of mechanical and electrical equipment as well as overseeing operations, the after-sales service, and procurement performance assessment.

By integrating these functions, the model aims to enhance procurement quality, optimize costs, improve scheduling, and strengthen contract management, logistics, warehousing, and overall operational performance. Importantly, these improvements are closely linked to sustainability objectives. By fostering efficient resource use and reducing waste throughout the procurement process, the model not only contributes to enhanced project outcomes but also aligns with broader sustainability goals, ensuring that international EPC projects are not only economically viable but also environmentally responsible and socially equitable.

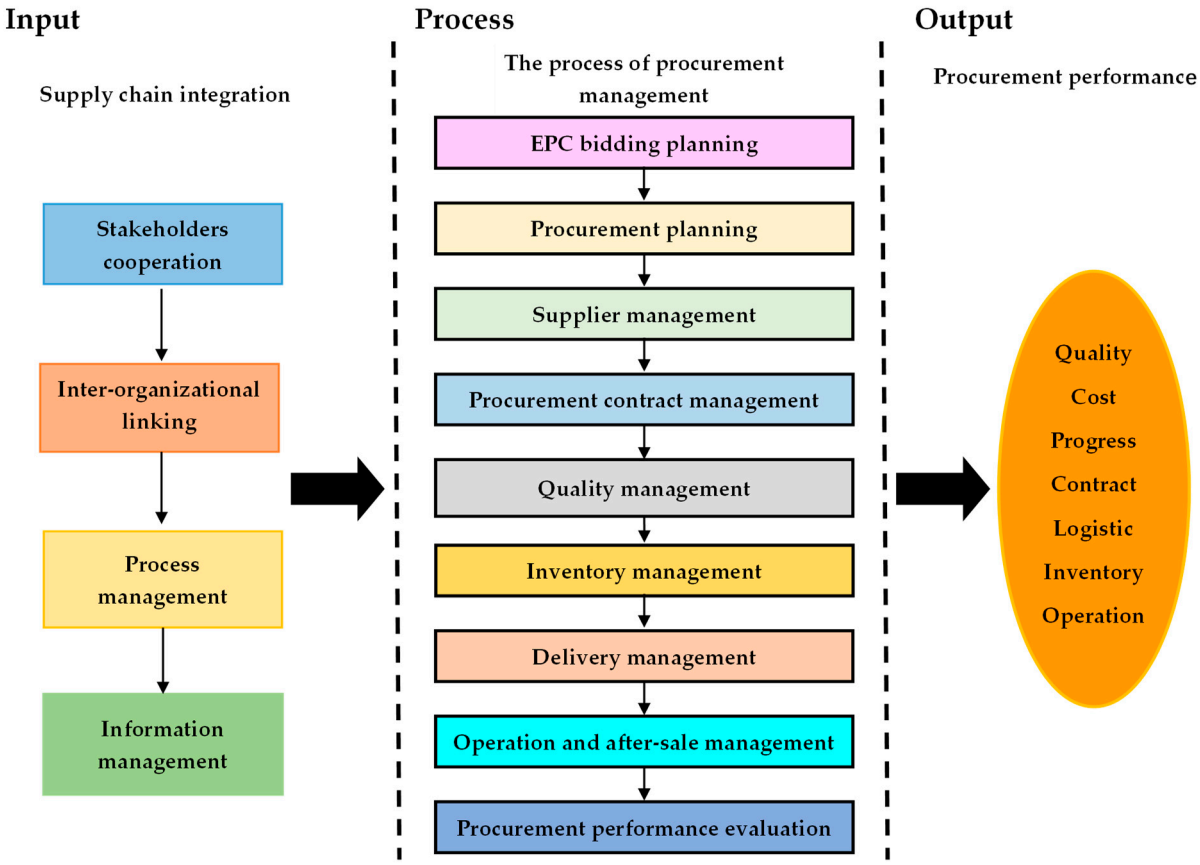

Figure 8. Procurement management model of internal EPC project from the perspective of supply chain integration.

This model presents a comprehensive framework that integrates stakeholder roles and management processes, promoting a sustainable approach to procurement in international engineering EPC projects. This holistic perspective facilitates the development of more resilient supply chains, ultimately leading to enhanced procurement performance and sustainable project delivery.

Establishing partnerships with key stakeholders globally is essential for enhancing the procurement management process and fostering collaboration among participants [8]. International EPC project general contractors must prioritize the development of these partnerships, emphasizing behavioral elements such as shared goals, trust, commitment, and open communication.

Furthermore, effective partnerships improve procurement supply chain relationships, safeguarding the interests of all parties while addressing their needs promptly to enhance operational efficiency. General contractors should cultivate global procurement skills and establish extensive networks with potential suppliers worldwide. The choice of partners should align with the specific project requirements and supplier characteristics since each procurement approach has unique advantages and challenges.

An efficient supplier selection process can significantly enhance supply chain performance [54,55], making strategic partnerships critical to project success [56]. General contractors must implement a robust supplier selection system, rigorously prequalifying suppliers based on their performance, financial stability, and quality management. Establishing strategic partnerships based on trust and equitable risk-sharing is crucial for ensuring reliable supply and quality assurance, ultimately yielding long-term cost and schedule advantages.

During procurement implementation, dynamic supplier assessments drive real-time improvements. Post-procurement evaluations of suppliers—focusing on quality, price,

capacity, and service—offer insights for future collaboration and enhance procurement efficiency. By building partnerships with key suppliers, general contractors can expand their procurement supply chain and foster agile, strategic contract development that streamlines the procurement process.

Additionally, partnerships with designers are vital for achieving win-win outcomes across the supply chain. General contractors must integrate procurement management and cost control from a holistic supply chain perspective, forming partnerships that emphasize fair benefit and risk-sharing mechanisms [57–59]. Early design optimization and active procurement engagement during the design phase can significantly reduce implementation costs and uncertainties.

Trust-based partnerships facilitate resource sharing and complementary strengths among supply chain stakeholders, reducing transaction and supervision costs and fostering collaborative success [60]. Effective communication is critical for swift information exchange, ensuring a sustainable and healthy development of the procurement supply chain in international engineering EPC projects. By promoting innovation, value engineering, and comprehensive quality management, these partnerships ultimately contribute to the successful implementation of projects while aligning with sustainability goals.

To sum up, strengthening global partnerships and supply chain integration are strategic recommendations for enhancing procurement management in international EPC projects, facilitating both operational efficiency and sustainable development.

5. Discussion

As an advanced management method, supply chain integration has been extensively promoted in the manufacturing industry, resulting in significant achievements. Briscoe et al. (2005) [43] indicate that the construction industry could benefit greatly from these innovative concepts.

However, supply chain integration remains underutilized in the construction sector, particularly in the international EPC contracting area. Researchers like Schoenherr et al. (2012) [1] emphasize that adopting these methods is crucial for enhancing procurement management in construction.

This paper argues that supply chain integration can help international EPC contractors consolidate procurement processes and improve resource management through strategic partnerships, leading to greater efficiency. Despite frequent interactions with the supply chain, many professionals in engineering and construction, including project managers, may not fully grasp its complexities or recognize the impact of their decisions [43]. Embracing innovation is vital to meet the diverse needs of stakeholders in this evolving landscape.

The volatility of the international environment further necessitates that general contractors leverage the collective resources of procurement stakeholders through integrated supply chains [43]. Thus, incorporating supply chain integration management into research on international EPC project procurement is essential for understanding how contractors can effectively unify their internal and external supply chains. By addressing procurement management constraints, this approach aims to refine processes and provide general contractors with theoretical and practical insights, ultimately enhancing project execution efficiency and economic outcomes.

Establishing partnerships with key stakeholders worldwide is critical for enhancing procurement management processes and fostering collaboration among participants [15]. For international EPC project general contractors, cultivating these global partnerships is essential to achieving sustainable development. Emphasizing behavioral elements such as shared goals, trust, fairness, and commitment alongside effective communication practices creates a conducive environment for successful collaboration. Such partnerships not only safeguard the interests of all parties but also enhance the efficiency of supply chain operations, ultimately contributing to sustainable practices.

General contractors must develop a robust global procurement vision, forging extensive partnerships with potential suppliers across the globe. This involves creating a global

supplier network that allows for resource acquisition and information integration, recognizing that different procurement strategies possess distinct advantages and challenges. Selecting the right partners based on the project's specific needs and supplier characteristics is vital. The effectiveness of the supply chain can be significantly enhanced through a well-structured supplier selection process [56], with strategic supplier partnerships being paramount to project success [57].

To establish reliable material and equipment suppliers, general contractors must implement comprehensive prequalification processes. This entails developing a rigorous supplier selection system that evaluates performance capabilities, financial stability, quality management, and production organization, thereby determining the supplier's overall strength. Establishing long-term, win-win partnerships grounded in trust and equitable benefit/risk sharing is essential for ensuring the reliable supply of equipment and materials while maintaining quality assurance. This, in turn, delivers significant cost and schedule benefits over the long term.

Furthermore, dynamic assessments of suppliers during procurement execution allow for real-time improvements based on performance evaluations. Post-procurement, comprehensive evaluations of suppliers' quality, price, supply capacity, and service enable effective follow-up cooperation, fostering continuous improvement and enhancing procurement efficiency.

In light of these findings, further exploration of emerging technologies such as artificial intelligence (AI) and blockchain is necessary. AI can transform decision-making through enhanced predictive analytics and automation, while blockchain can improve transparency, efficiency, and security across the supply chain. Investigating the applicability and implications of these technologies may yield substantial advancements in procurement methods and stakeholder engagement, ultimately promoting sustainable practices.

Moreover, conducting comparative analyses across various regions and industries can reveal optimal practices and innovative strategies in procurement and stakeholder management. Such research should identify regional challenges and opportunities, providing a nuanced understanding of global EPC dynamics. By acknowledging these contextual differences, stakeholders can devise sophisticated strategies tailored to di-verse operational contexts.

Finally, continuous research and adaptation are imperative for advancing the global engineering contracting sector. By focusing on these areas, stakeholders can strengthen strategic competencies, adapt to evolving trends, and contribute to a more resilient and efficient global infrastructure system. Pursuing these pathways not only drives sustainable progress but also ensures long-term success in an increasingly complex and dynamic global market. Integrating supply chain practices with stakeholder collaboration is fundamental to achieving these goals and fostering sustainable development.

6. Conclusions

Future research and constraints must be meticulously evaluated within the framework of this study. The data for this research are solely obtained from Chinese enterprises, hence constraining its generalizability. To strengthen the validity of future studies, it is recommended to broaden the data sources to encompass enterprises from diverse nations. This expansion will enhance the dataset and bolster the applicability of the findings across various cultural and legal situations.

Furthermore, multinational EPC projects encounter many worldwide risks, such as geopolitical concerns, regulatory discrepancies, and market volatility. Subsequent studies should employ a more holistic methodology to investigate the influence of these varied risk factors on the procurement process. Analyzing the relationships among these risks and their cumulative impact on project outcomes is critical.

Moreover, including sustainable development into this framework is essential. Subsequent research should investigate how efficient procurement management can both alleviate risks and promote sustainability objectives. This entails examining procurement

options that guarantee resource efficiency, reduce environmental consequences, and foster social fairness.

By exploring these variables, researchers can offer more refined insights on the resilience and adaptability of procurement strategies in international EPC projects. This methodology will substantially enhance the discourse on sustainable development, emphasizing the importance of procurement management in attaining project success and overarching sustainability goals, especially within an increasingly linked global context.

In addition, establishing partnerships with key stakeholders worldwide is critical for enhancing the procurement management process and fostering collaboration among participants [15]. For international EPC project general contractors, forming these global partnerships is essential. Effective partnerships emphasize behavioral elements such as shared goals, trust, commitment, and fairness as well as communication aspects that promote an open atmosphere, team building, effective problem-solving, and timely feedback. Such collaborative relationships not only safeguard the interests of all parties but also meet their needs in a timely manner, thus increasing the efficiency of supply chain operations [61].

To achieve these objectives, general contractors should cultivate global procurement skills and develop extensive partnerships with potential suppliers worldwide. A robust global supplier network enables contractors to access resources and integrate diverse market information. Choosing the right partners based on the project's specifics and supplier characteristics is crucial as each procurement approach presents unique advantages and disadvantages. An efficient supplier selection process can significantly improve supply chain performance [62], while strategic partnerships are vital for project success [57].

To ensure reliable supply, contractors must rigorously prequalify suppliers, establishing a sound selection system that evaluates performance, financial stability, quality management, and production capabilities [63]. This comprehensive evaluation is a fundamental component of the procurement process. Additionally, establishing long-term strategic partnerships based on trust and equitable risk-sharing is essential for securing a dependable supply of materials and quality assurance. Such partnerships can deliver long-term cost savings and scheduling advantages [64].

Dynamic assessments of suppliers throughout the procurement process encourage real-time improvements, enhancing overall procurement efficiency [65]. Post-procurement evaluations of key performance indicators—such as quality, price, supply capacity, and service—inform future collaboration and enable continuous improvement [66].

These findings highlight the necessity of further exploration in several critical areas. For instance, examining the influence of emerging technologies like artificial intelligence (AI) and blockchain on procurement processes and stakeholder engagement is essential [65]. AI can transform decision-making through enhanced predictive analytics and automation, while blockchain promises to increase transparency, efficiency, and security across the supply chain [67]. Assessing these technologies' applicability and impacts could lead to substantial advancements in procurement methods and stakeholder collaboration, ultimately supporting sustainable development by improving resource management and reducing waste.

Furthermore, conducting comparative analyses across different regions and industries can yield valuable insights into optimal practices and innovative strategies for procurement and stakeholder management. This research should aim to uncover region-specific challenges and opportunities, providing a nuanced understanding of global EPC dynamics. By recognizing these contextual differences, stakeholders can develop more sophisticated strategies tailored to diverse operational scenarios.

Thus, evaluating the effectiveness of digital tools and platforms for stakeholder participation is crucial in an era of digital transformation. Understanding how these tools can enhance communication and collaboration will optimize procurement processes and project outcomes, contributing to sustainability initiatives.

In conclusion, continuous research and adaptation are vital for advancing the global engineering contracting sector. Focusing on these areas will empower stakeholders to enhance their strategic competencies, adapt to evolving trends, and build a more resilient and efficient global infrastructure system. By pursuing these avenues, the industry can drive sustainable progress and achieve long-term success in an increasingly complex and dynamic global market.

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