Construction Logistics Conceptualization: A Comprehensive Framework and Existing Challenges

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Abstract. Playing a key role in the nation's infrastructure development, construction industry has been studied extensively for several decades. However, there is a need of systemizing knowledge on construction logistics – a crucial element in improving performance of the industry. Combining multiple case study and literature review methods, this research offers a comprehensive framework for construction logistics with construction logistics activities positioned throughout construction project phases. Additionally, it explores practical challenges in on-site and prefabricated construction logistics operation, through which offering valuable insights into areas to be further developed and suggesting improvement ideas for practitioners and policymakers in construction and similar Engineer-to-Order industries.

Keywords: Construction logistics · Construction operation management · Engineer · to · order logistics · Engineer · to · order operation management

1 Introduction

Construction industry - the industry that performs necessary services to create long-lasting structures and building works [1] - is a crucial part of the country development process, as it fulfils the infrastructure demand of the social, cultural, and economic growth. The industry is significant to the growth of the economy along with the population explosion [2]. Together with customized machineries and ships manufacturing, construction is a typical engineer-to-order (ETO) industry [3]. It involves various tasks such as establishing new buildings, making modifications, conducting repairs, and carrying out demolitions [1]. A construction project is the product of the construction industry, which is normally done through a three-phase process, which is Design – Procurement – Installation [4] or Engineering – Procurement – Construction (EPC) [5]. The Design or Engineering phase transforms customer needs and technical requirements into a feasible model or design of the project. The Procurement phase helps acquire resources needed to complete the designed project from the previous phase. Lastly, the Installation phase contains assembly and installation of components integral to buildings or constructions.

In conventional construction, most of the construction activities happen on the construction site (on-site construction), while prefabricated construction is an approach in which majority of the on-site tasks are conducted in a factory setting away from the construction site [6]. Typically, construction projects are highly customized and implemented on a case-by-case foundation, characterized by limited instances of repeated orders, all while facing challenges related to cost and delivery time constraints [7]. In a few cases, multiple similar construction projects are undertaken, such as mountain cabins, beach cottages, student residences, military accommodations [8].

The construction industry is facing various performance problems [9] for which improvement opportunities could be initiated from logistics [10]. Generally, logistics is the process of coordinating, arranging, and managing the movement of materials and information from their source to the destination [11]. Appeared commonly in the literature, logistics in construction or construction logistics is a term covering the material and information flows to sustainably plan, execute, and control the right resources – humans, materials, equipment, and information - from the source of resources to the construction sites and during on-site operation at the right time, in the right quantity, with the right quality [12–14]. Figure 1 illustrates an overview of construction logistics, in which material and information flows link different key actors in the supply chain network such as suppliers, transporters, prefabrication factories, and operators on the construction site.

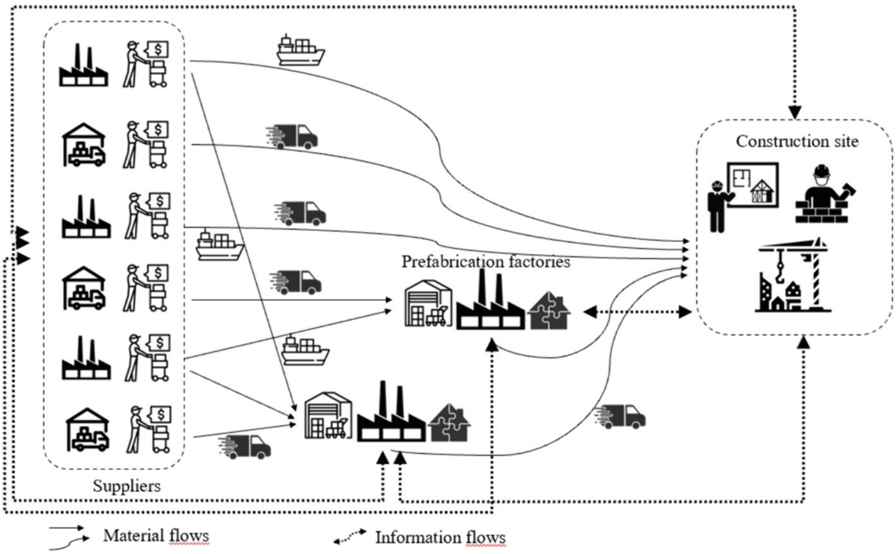

Fig. 1. Construction logistics

To ensure the efficiency and effectiveness of the flows in construction logistics, various tasks or activities should be undertaken, namely construction logistics activities. These activities are critical for maintaining the project schedule and budget, placing significant impact on the performance of the industry [15]. Because construction projects become more demanding and must adapt quickly to the dynamic economy, it is critical to ensure efficient and effective logistics. The unique characteristics of the construction combined with the extensive scale and lifecycle complexities contribute to the complex nature of logistics and supply chain management within the industry [16]. To improve construction logistics, it is important to build a comprehensive understanding of the topic. Similar to other ETO industries, construction is typically more experience-based, conservative and slow-moving than other industries [15, 17]. Therefore, there is a need for more formal, research-based knowledge on construction logistics. In order to be able to measure and improve their performance, the activities belonging to construction logistics need to be identified and clearly described. Furthermore, needs and challenges need to be mapped in order to define relevant paths for future research. This study attempts to fulfil these needs by answering the following research questions:

RQ1: What are activities of construction logistics along construction project phases?
RQ2: What are challenges and needs of construction logistics?

RQ1 aims to describe construction logistics activities and their positions corresponding to construction project phases. The expected answer to this question is a conceptual framework on construction logistics with logistics activities, aligned with the construction project phases and indicating their extent of overlap. Based on that, RQ2 helps explore existing challenges and needs of construction logistic, revealing opportunities to expectedly enhance the performance of logistics management.

The paper is structured as follows: chapter 2 outlines the methodology including research design and description of case studies. In the chapter 3 and 4, the research findings are synthesized and discussed to answer RQ1 and RQ2 accordingly. Lastly, chapter 5 finishes the paper by summarizing its contributions, acknowledging limitations, discussing implications, and suggestion of further research.

2 Research Method

2.1 Research Design

Both research questions are answered by a combination of literature review and multiple case studies. The literature review is used to gather theoretical knowledge from conference papers, journal articles, books, and other academic materials from SCOPUS database from the scope of the literature search also covered other ETO sectors than construction, such as shipbuilding and customized machinery production. Specifically, activities and challenges of construction logistics are gathered from the literature as a part of the answer for the RQ1 and RQ2 respectively.

The findings from literature search were then validated and expanded with case studies conducted at construction companies in Norway to enrich what has been discussed in the literature, fulfilling answers of the two research questions. The multiple case study method explores practical knowledge of the field with data collected from semi-structured interviews, industry documents, field notes, etc., Qualitative data analysis approach is then employed to analyze collected data from the literature search and the cases.

2.2 Data Collection

The data used for this study is collected through a combination of literature search and a multiple case study. The literature review is based on the guideline of [18], gathering relevant publications found from SCOPUS databases including journal articles, conferences papers, books, professional reports, etc.,. The search related to RQ1 was done for keywords combination of "Construction" OR "Yard" OR "Engineer-to-order" AND "Logistics" OR "Supply Chain Management", then adding "Challenges" OR "Barriers" OR "Problems" for RQ2. There are five construction companies involved in the study, with ten interviews completed and two site visits. Besides, other documents such as company workflows and internal documentations were also provided as inputs for the study analysis. The case companies are located in various places of Norway with varying working scopes. Two out of the five cases (case A, B) focus on prefabricated construction, while the scope of the other three is mainly on-site construction (case C, D, E). Table 1 presents the cases and the interviewees involved in each case. Interview recordings were transcribed and analyzed under tabular forms. The findings are presented in chapter 3 and 4.

Table 1. Case companies and corresponding interviewees

Case	Case description	Interviewees
A	Producing prefabricated elements for residential buildings, supplying prefabricated elements, constructing residential projects (cabins, houses, garages, and so forth)	Technical drawing engineer, Purchasing manager, Production leader, Sales manager
B	Engaging in the production and distribution of prefabricated concrete construction elements	Transportation engineer, Planning and transport team, Project manager
C	Constructing public infrastructures, industrial infrastructures, residential structures, and rehabilitation projects	Purchasing manager
D	Constructing public infrastructures, industrial infrastructures, residential structures, and rehabilitation projects, alongside the production of prefabricated elements	Project engineer
E	Constructing various types of structures including public infra-structures, industrial facilities, residential buildings, rehabilitation projects, and offshore installations	Production manager

3 Construction Logistics Activities and Construction Logistics Framework

3.1 Result from Literature Review

Adapting the views about construction project phases from [4, 5], this study refers construction project to be done through three-phase process of Design – Procurement - Fabrication and Construction, as it is compatible with the logistical perspective of the study. Construction industry possesses certain unique features that impact the logistical aspects, such as its distinctive project design, temporary location, irregular material supplies, specific sequence of the tasks [19], and many more. Therefore, it is essential for its actors to ensure the timely and precisely logistics activities. The specific features of the construction work can pose barriers to construction logistics activities, many of which are mentioned in the literature, and many await to be explored through practical experiences.

In the existing research works, different activities can be considered under construction logistics: planning of supply and planning of the tasks and personals [20–22]; specification and acquisition of supply resource [21, 22]; material receipt, handling and transportation [15, 23]; arrangement of machinery operations on the site [24]; storage and installation of materials on the site [15, 20, 24]; movements of materials, machineries, workers, and waste [15, 20]; creating the arrangement of the site and addressing conflicts among different construction teams on the site [22]; progress monitoring and reporting [23]. Popularly, logistics functions in construction can be grouped into supply logistics and on-site logistics [22, 25]. As can be seen, most of the scholars have been viewing construction logistics under the conventional on-site construction view. For prefabricated construction logistics, it is recommended to look at the manufacturing sector but not replicating it due to difference in work features [15]. Because construction logistics activities are fragmented in the literature, a framework is needed to organize these activities across different phases of a construction project. This will help connect and systemize our understanding towards construction logistics.

3.2 Result from Multiple Case Studies

Based on the knowledge about construction logistics from the literature, eight construction logistics activities are synthesized as following. The cases confirm the findings from the literature.

1. *Planning and coordination:* setting the objectives, schedules and allocation of necessary tasks and resources (personnel, materials, equipment, tools, funding) needed to achieve overall goal of the construction project.
2. *Resource acquisition:* obtaining the necessary personnel, materials, equipment, tools, funding required in alignment with the planned objectives and schedules. Long-term strategic activities such as personnel training, supplier relationship management, or long-term fundraising are excluded from the scope.
3. *Resource transportation:* moving, loading, and handling of necessary personnel, materials, equipment, and tools.

4. *Resource storage and handling:* receiving, handling, maintaining, and monitoring of construction materials and elements.
5. *Element fabrication:* production activities of construction elements ready for the on-site installation.
6. *Element installation:* integrating and assembling different construction components and elements to produce construction structures.
7. *Environmental management:* controlling environmental standards of the materials and production, handling, and disposal of various types of waste generated during element production and on-site construction activities.
8. *Progress monitoring and reporting:* recording, monitoring, and updating reports of the above activities.

Based on the findings from the cases and abovementioned construction logistics activities, a framework for construction logistics is proposed as illustrated in Fig. 2. In this framework, logistics activities are positioned through a three-phase construction project, with dashed arrows indicating feedback loops and communication between the activities. In particular, the "Planning and coordination" activity is highly connected to the "Progress monitoring and Reporting" activity, while each of them is in communication with the other activities. Additionally, the activities relating to the resource (Resource acquisition, Resource transportation, Resource storage and handling) are combined. Besides, the cases' findings separate two types of resource, namely project-specific resource and standard resource, which will be discussed in the later text.

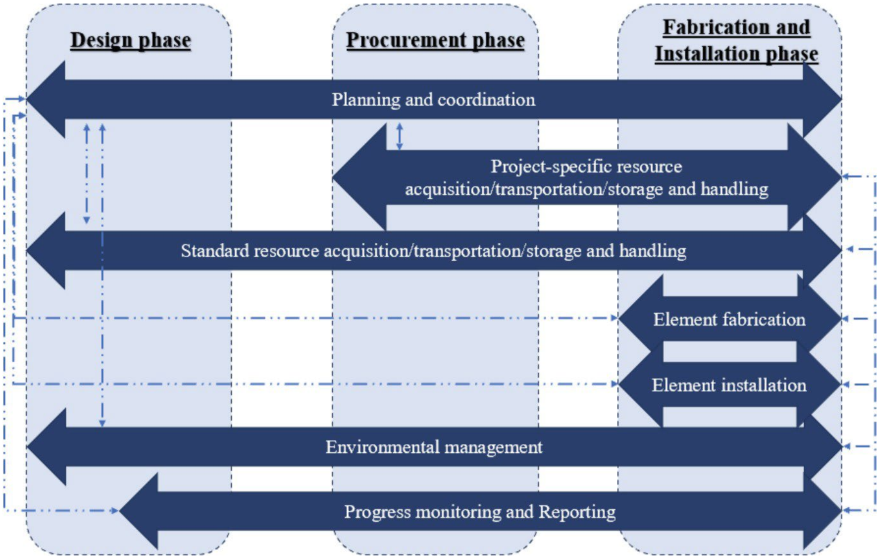

Fig. 2. Construction logistics framework

The cases studies suggest that "Project handling" and "Cleaning and finishing" could be added to the project phases (case C, D). However, they are considered as an ending part of the Fabrication and Installation phase and there is no specific logistics activity fitted particularly to them. Thus, they are not considered to be added to the framework.

The "Planning and coordination" activity should be initiated once the Design phase starts, even before contract signing (case B) so that resources and production capabilities are planned in alignment with the customer requirements of the project. Moreover, this activity must be repeatedly conducted along the project phases to timely adapt any changes in the design, resource control and production (case B, D, E), which is consistent with the discussion of [22].

The activity of "Resource acquisition" starting together with Procurement phase should only be applicable for project-specific materials, which are materials and components that suit specifically for a project (designed doors, structural steels, interior bricks, specialized equipment, etc.,.). For the standard materials and components that are consumed generally in every project (screw, hammer, drill, cement, tape, etc.,.), frequently procurement is executed based on standard reorder point method regardless of the project phase (case B). This separation of the resource types also happens to the "Resource storage and handling" and "Resource transportation" activities. These three resource-related activities should be conducted continuously until the last phase of the project is finished (case B, E). It is necessary to monitor and optimize resource movements as this is significant to the efficient logistics within and around the construction site, especially for the projects in urban areas with limited space and urban traffic congestion (case B, E).

The activity of "Element fabrication" and "Element installation" are completed in the third phase of the construction project – Fabrication and Installation phase. In this phase, the raw materials and construction modules are assembled, either on the site (installation) or within a factory (fabrication). This is confirmed by prefabricated construction companies (case A, B).

It is highlighted that the environmental concern is getting more and more attention in the industry (case A, C, D). The BREEAM (Building Research Establishment Environmental Assessment Method) certificate standard [26] is now becoming an important criterion in choosing material supply for almost all the projects, together with waste management (case C, D). For prefabricated construction (case A), reducing waste is one of the key criteria to achieve lean manufacturing. Because the activity of "Environmental management" is put under consideration from designing the project until when the whole project is finished, this activity span across all three phases.

Most of the cases agree that "Progress monitoring and reporting" is one of the most important logistics activities together with "Planning and coordination" (case B, D, E). It should start right after the contract is signed and be monitored in a tight communication or feedback loop with the "Planning and coordination" (case B). In case D and E, there are frequent weekly meetings, monthly meetings, and reporting scheme to ensure the activities are on track together with the project's overall progress.

"Quality inspection" is suggested to be added to the logistics activities (case B). Indeed, it is part of "Progress monitoring and reporting". An interesting finding is found that the proposed activities are positioned and planned by time sequence along the project phases. However, in the actual operation, they should be planned backward, starting from the expected delivery date of the whole project due the pull-based strategy of the industry (case A, C).

During the execution of the construction logistics activities, numerous challenges and needs must be identified and addressed to enhance construction logistics. Chapter 4 synthesizes this knowledge from previous research works and case studies.

4 Construction Logistics Challenges and Needs

4.1 Result from Literature Review

The construction industry is encountering critical challenges on performance [9, 27, 28]. Based on the logistics activities, the literature search identifies many characteristics of the construction industry that place substantial impacts on logistics, as mentioned by different scholars. It was mentioned that the construction industry is manual task based, conservative, lacking incentive to change and low-tech advancement [15, 29, 30]. The material supplies vary according to the construction phase, and any delay in one activity will affect the sequence of the other tasks and overall progress of the project [19]. Next, the work setting is one-off and temporary, thus hindering long-term optimization [15, 19, 30]. Employment is usually fragmented with the use of short-term and outsourced labor, thus reducing trust and hurting information sharing [15, 31]. Also, the communication between project owner, main contractors and subcontractors is poor [30, 32].

The characteristics of the construction industry are blamed to prevent it from successfully addressing the logistics [15]. In specific, various logistical problems have been mentioned in the previous research works. One of the problems is the poor management of construction equipment, tools, and materials [25]. Next, there is insufficient planning of material transportation, material deliveries and unloading [31, 33]. Planning is highly uncertain and affected by external factors such as weather changes and site topography [15]. Besides, there is lack of trust and coordination among actors due to inadequate information flow and communication [21, 30, 34]. High logistics costs due to traditional trading method is also another logistical problem [35], along with the subsequent delays and waste of materials due to delay in supply [36]. On the construction site, machineries are not utilized well [37] as well as vehicle arrivals are not optimized due to limited storage area in urban projects and uncontrolled vehicle arrangement at site [15]. Construction logistics is also facing lack of unified material acquisition procedure [33], lack of IT system used [38], and unsatisfactory in communication between material suppliers and subcontractors [31].

When it comes to the research methodology employed in previous studies, many of the challenges/barriers in construction logistics are discovered through reviewing literature, discussing concepts, or analyzing synthetic simulated data. However, it is crucial to gather insights from real-world experiences to fully understand these challenges. Moreover, specific challenges of the prefabricated construction have not been stated. The present study aims to contribute to filling these gaps with results from multiple cases presented in the next section.

4.2 Result from Multiple Case Studies

Based on the data collected from the semi-structured interviews and company visits, fifteen challenges in construction logistics have been grounded and presented in Table 2. Also, domains of challenges and possible consequences are presented in the table.

In general, there are four domains that might be used to categorize these construction logistics challenges: Logistics operations, IT infrastructure, Culture and working habits, and Externalities. These challenge domains are discussed further in Table 3. The challenges found from the case studies are accused of causing different consequences in logistics of the construction industry. Challenges #1 to #5 are blamed as a reason of information loss, thus creating inefficient planning and control of the logistics. Challenges #6 to #9 could lead to damages of materials and elements, while challenges #10 to #12 about poor planning activities are affecting construction progress in a negative way. The rest of the challenges are causing miscellaneous problems such as inappropriate performance measurement, repetitive human mistakes, and more cost incurred.

Most of the above challenges have been existing for a long time and consistent with what has been discussed by other scholars. For example, challenge #1 and #7 are consistent with findings of [21, 30, 34], which mentions the lack of trust and coordination due to poor information flow and communication among actors. [38] mentioned something similar to challenge #3 and #4 about a lack of unified system to share information and update changes among all actors, or challenge #9, #15 about limited storage in urban sites together with challenge #8 about weather condition have been mentioned by [15].

Noticeably, there are several challenges found from the case studies that have not been discussed widely in the literature, even though they have been existing for a while in the industry. Specifically, case company C mentioned the risk of extraordinary circumstances such as currency or exchange rate fluctuations, global disease, or wars that could affect material supply, causing supply uncertainties and possible supply chain disruptions (challenge #6). Next, the challenge #13 about inappropriate performance measurement is another obstacle, when some performance indicators are suitable for this logistics activity, or this project may be not applicable for the others. This could negatively impact performance assessment accuracy and demotivate construction logistics actors. For example, case company B is now using hour per ton to measure average time needed to produce a ton of finished good as a performance indicator for worker productivity. However, this indicator depreciates the difference in complexity level of different products or projects, making workers feeling that their performance is unfairly assessed.

Challenge #5 about human personalities and #10 about human resource planning are interesting. A change in staffing due to sick leave or unexpected circumstances could create subsequent delays in logistics activities, and misunderstandings caused by personality problems may severely affect the communication, long-term coordination, and hurt the trust among logistics actors. This might be further emphasized now due to an increased frequency of hiring, firing, and turnover among workers, greater reliance on foreign labor, and more frequent fluctuations in the industry.

Table 2. Challenges in construction logistics from case studies

Challenge	Challenge domain	Consequences
1. Inefficient information flow and coordination among the teams, or between internal teams and subcontractors	IT infrastructure, Culture and working habits	Loss of information, mismatch in client specifications and production capabilities, poor planning, overload/underload operation, progress delays
2. Traceability of materials due to inefficient inventory control	IT infrastructure, Logistics operations	Information loss leading to inefficient planning, material damages and wastes
3. Manual documentation	IT infrastructure	Loss of information
4. Fragmented tools, lack of unified system	IT infrastructure	Information loss, poor planning
5. Human personalities	Culture and working habits	Ineffective communication, loss of information
6. Supply uncertainties (supply lead time, market fluctuation, currency changes, war, etc.,)	Externalities	Supply chain disruption and resource (time and money) wastes
7. Conflict of interests between different departments	Culture and working habits	Inefficient decision-making, resource waste
8. Weather challenge (extreme weather conditions, changes in weather)	Externalities	Material damages, resource waste, delays in progress
9. Limited in storage capability and transportation in urban projects	Logistics operations, Externalities	Material damages, progress delays
10. Ineffective human resource planning	Logistics operations	Production inefficiency and delays
11. Sudden changes in operation due to poor planning	Logistics operations, IT infrastructure	Waste of resource, progress delays
12. Poor planning between delivery and on-site traffic	Logistics operations	Waste of resource, progress delays
13. Inappropriate performance measurement	Logistics operations	Ineffective assessment on the logistics performance

(*continued*)

Table 2. (*continued*)

Challenge	Challenge domain	Consequences
14. Experience-based working method	Logistics operations, Culture and working habits	Possible human repetitive mistakes
15. Special restriction on vehicle accessibility to the site	Logistics operations	More cost incurred

The construction logistics challenges found could be classified into four groups of challenge domains as shown in Table 3. These are the primary needs that should be considered by construction logistics practitioners and managers. The Logistics operation challenges are directly related to logistics operation (planning, resource acquisition, resource transportation, etc.,.). The IT infrastructure challenges are about the lack or inefficiency in technological systems and tools to support and enhance logistics operations. Next, the Cultural and working habit challenges are about human personalities and their working manners. Lastly, the Externalities challenges are related to extraordinary circumstances or uncontrollable external factors. These challenge domains are interdependent to each other. For instance, the lack of efficient IT infrastructure might create barriers in logistics operation, and Externalities challenges such as wars could result in worker psychological problems, thereby causing working habit challenges or logistics operation challenges. Therefore, it is important that the management pays attention to address all these four domains of challenges simultaneously, thereby sustainably improve the construction logistics.

The suggestive remedies to mitigate these challenges are also presented in Table 3. To overcome challenges from logistics operations, it is suggested to focus on improving information flows among stakeholders, standardize operating procedures, or consider utilizing third-party logistics services. To mitigate IT infrastructure challenges, construction companies should consider developing a unified IT system to support logistics activities. Next, improving communication, implementing standard operating procedures, and providing logistics training are recommended to address challenges in culture and working habits. Lastly, construction companies could address challenges from externalities by predicting them promptly, adopting a multi-sourcing strategy, and maintaining effective inventory control to handle sudden supply changes.

Table 3. Construction logistics challenge domains and suggested remedies

Challenge domain	Suggested remedies
Logistics operations	Improve information flows among all stakeholders Implement standard operation procedures to minimize reliance on experienced-based operations Consider using third-party logistics services
IT infrastructure	Develop comprehensive IT tools to support various logistics functions like supply management, warehouse operations, planning, and production management. Prefer integrated systems over fragmented ones
Culture and working habits	Improve communication between internal staffs and subcontractors Implement and adhere to standard operating procedures Provide logistics-specific training for the workforce
Externalities	Promptly predict and respond to external circumstances Adopt multi-sourcing strategy to mitigate risks Manage inventory effectively to handle supply chain disruptions

5 Conclusion

The study contributes to the knowledge of the field with two primary outcomes. Firstly, it presents a comprehensive framework on construction logistics describing the logistics activities and their alignment across construction project phases. Secondly, the study explores existing practical construction logistics challenges and needs, with four domains of the challenges and suggested remedies to mitigate them. These outcomes contribute not only to systemizing knowledge within the field of construction logistics but also to offering practical insights for practitioners and policymakers in the construction operation management in general. Furthermore, the findings are expected to be useful for similar ETO industries.

This scope of this study is limited by its reliance on a small number of case studies, which may hinder the generalization of findings. Additionally, some interviewees may not have comprehensive insights into all aspects of their company's logistics functions, potentially restricting their views. These limitations emphasize the need for cautions when applying the study conclusions to broader contexts and highlight opportunities for future research to address these gaps. Besides that, future research is suggested to put an emphasis on analyzing prefabricated construction logistics, proposing analytical models to quantitatively validate the found challenges, and applying new IT technologies in improving construction logistics.

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