UNB | Off-site Construction Research Centre

Northumbria University NEWCASTLE

Transforming Construction with Off-site Methods and Technologies (TCOT) Conference: Designing Tomorrow's Construction, Today

August 20-22, 2024, Fredericton, New Brunswick, Canada

Analysis And Mitigation Strategies of Installation Work Interruptions in Precast Concrete Columns: A Case Study in Korean Logistics Facility

Jeong, E.[1], Jang, J.[1], Lee, S.[1], and Kim, T. W.[1,*]

[1] Division of Architecture and Urban Design, Incheon National University, 119 Academy-ro, Yeonsu-gu, Incheon 22012, Republic of Korea

[*] taewkim@inu.ac.kr

Abstract: This study observes and quantitatively analyzes work interruptions during the installation of precast concrete (PC) columns at a logistics facility center construction project in Korea, identifying the causes, frequency, and duration of interruptions. Work interruptions were categorized into pre-installation and during-installation based on when they occurred, the causes were classified into eight flows, and the probability of work interruptions was calculated for each work step. Common causes include labor issues, materials delays, and equipment malfunctions, impacting project time and cost. The research suggests mitigation strategies such as increasing the number of labors, preparing equipment and materials, conducting crane maintenance, and training in equipment usage to enhance work efficiency and manage interruptions effectively. This study provides valuable baseline data for improving PC project management, serving as a reference for future projects to reduce time and costs and contributing to overall project success. Future research should expand data collection across various sites and component types to refine interruption probability calculations and develop more sophisticated installation planning and resource management strategies.

Keywords: Precast concrete; Work interruption; Frequency; Probability

1 INTRODUCTION

The Precast Concrete (PC) method is manufacturing components in a factory and transporting them to the site for installation (Lee et al., 2022; Zhang et al., 2023). Field managers of PC projects predict the installation times of PC components to establish an installation plan. However, despite thorough planning, work interruptions frequent occur due to various factors such as delays in component delivery, crane malfunctions, overestimation of workforce productivity, adverse weather, or unexpected site conditions (Abd El-Razek et al., 2008; Toor and Ogunlana, 2008; Thomas and Oloufa, 1995). Interruptions in PC projects can extend the overall construction period, impact other trades, and increase site congestion due to waiting trailers and loaded PC components, thus hindering installation work (Wu et al., 2013; Liu et al., 2020). Therefore, identifying and analyzing the factors causing interruptions to improve schedule performance is crucial (Ji et al., 2018).

This study aims to identify and quantitatively analyze the causes of work interruptions by observing and recording the installation process of PC columns in a logistics facility center construction project in Korea. The research differentiates between two types of interruptions: pre-installation interruptions and during-installation interruptions (Figure 1). It also calculates the probability of interruptions occurring at each work step and proposes strategies to avoid them. This will contribute to enhancing schedule prediction and management in PC projects and improving their efficiency.

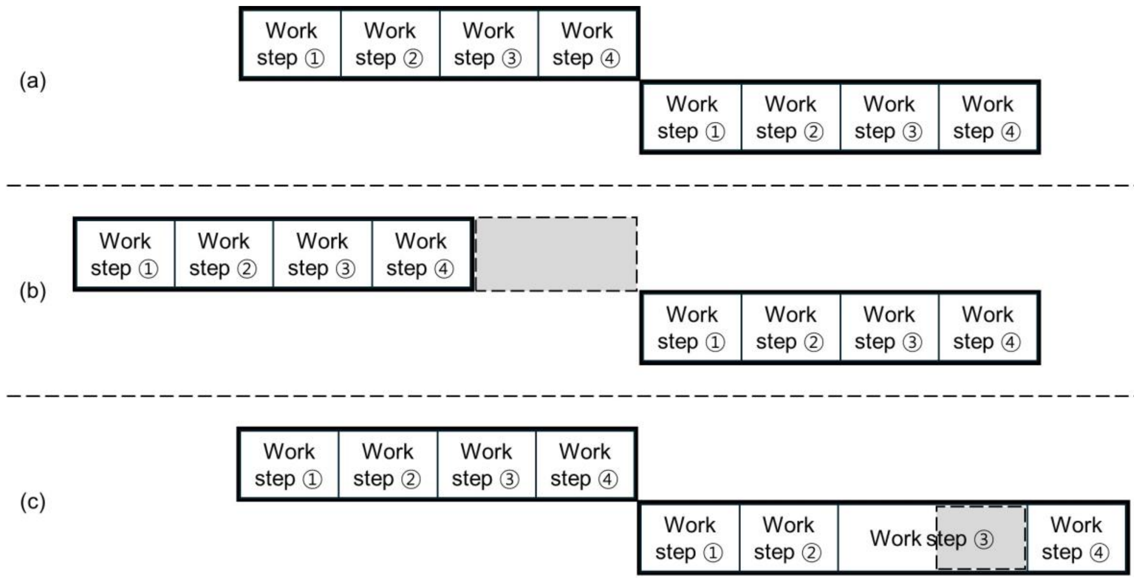

Figure 1: Types of work interruptions in this study: (a) No interruptions; (b) Pre-installation interruptions; and (c) During-installation interruptions

2 LITERATURE REVIEW

2.1 Interruption in Construction

In construction projects, work interruptions refer to unexpected delays or halts that occur during the project process (Aziz and Abdel-Hakam, 2016). These interruptions can arise from various causes such as resource shortages, work congestion, or misaligned work demands (Thomas and Oloufa, 1995). And, Interruptions not only increase the time and cost of the project but also hinder overall efficiency and success.

Various studies have explored work interruptions, analyzed the types and impacts of interruptions and proposing solutions. Leite and Griego (2019) analyzed the types and impacts of interruptions through case studies, expert interviews, and surveys, emphasizing the importance of managing interruptions. Hassan and Khaled (2020) quantitatively analyzed how activity delays that disrupt the continuity of subsequent crews affect the overall workflow. Thomas and Oloufa (1995) quantified the impact of work interruptions on labor productivity in masonry, concrete formwork, and structural steel installation. Remon and Asmaa (2016) investigated the causes of delays in road construction projects through surveys, identifying various delay factors including external site factors and presenting corresponding mitigation strategies.In efforts to address work interruptions, Ayman and Khaled (2018) developed an optimization model to minimize project duration, interruptions, and associated costs. Salama and Moselhi (2019) presented a multi-objective optimization model that not only minimized project costs and duration but also minimized work interruptions, thereby shortening the project period. These approaches help field managers operate projects in an effective manner.

2.2 Interruption in PC method

PC components are typically large and heavy, requiring cranes for installation (Al-Gahtani et al., 2024). Hatomoko et al. (2019) found that PC projects typically experience delays for 22% of the total project duration. Also, Li et al. and (2018) reported that delays are likely to occur every five-story cycle in PC residential buildings.

Various studies have been conducted to identify and mitigate the primary causes of work interruptions in PC projects. Pheng and Chuan (2001) conducted surveys among main contractors to identify several key factors causing schedule delays and determine their frequency. Ji et al. (2018) used the DEMATEL-ANP method based on survey results to prioritize major delay factors in PC projects and quantify their causal relationships. Cho et al. (2021) identified delay risk factors in PC projects through expert interviews and Qualitative Comparative Analysis (QCA), investigating the effects of various factor combinations on project schedule delays. Zhao et al. (2022) proposed a model combining system dynamics and back propagation neural networks to predict and manage work delays. Al-Gahtani (2024) analyzed the main causes of work interruptions at various stages (i.e., general, predesign/initiating, design, production, transportation, construction, closing) and proposed strategies to manage and minimize them.

2.3 Knowledge Gap

While most studies have focused on the overall schedule of PC projects, this study concentrates on the individual work steps of PC component installation, analyzing detailed causes of work interruptions. This approach provides crucial insights for establishing daily installation plans and efficient project management. Additionally, this research directly observes the actual PC component installation process and quantitatively analyzes the collected data, unlike previous studies that relied on qualitative methods such as surveys and expert interviews. This approach offers a clearer understanding of potential issues during PC component installation and provides practical information to prepare for unexpected work interruptions, contributing to enhanced project efficiency.

3 METHODS

This study specifically focuses on PC components of the column type and assuming that all PC columns were neither damaged nor incorrectly produced. It also excluded from analysis any causes of work interruptions that do not clearly contribute to a direct increase in time (e.g., interference in work positioning with RC operations).

3.1 PC Columns Installation Process and Work Step

Upon arrival at the site, PC columns are first placed on-site to prevent damage and then installed. Therefore, the PC column installation process is divided into two main phases: unloading and installation. The unloading process consists of rigging for unloading, unloading in the yard, unrigging in the yard, and crane return from the yard. The installation process comprises rigging, lifting, assembly, unrigging, and crane return (Jeong et al., 2024). In this study, these nine work steps are augmented by an additional work step, 'others,' which includes activities such as crane movement, lifting line movement, aerial work platform (AWP) movement, and worker movement that occur during the day but do not fall into the other nine categories.

3.2 Case Description

The project where the researchers observed work interruptions was at a logistics facility construction site in South Korea that applied the PC method (Figure 2). The construction took place from January 2021 to April 2023, with PC components installed from November 2021 to September 2022. The project covers a total area of 133,327 m² and consists of an eight-story structure. Two mobile cranes were employed for the installation of PC components, coordinated to avoid interfering within their operational radii. The ramps and cores of the structure were built using the Reinforced Concrete (RC) method, while the remainder was constructed using the PC method. The site used various PC components, including columns, beams, and slabs. Work on the site started at 7 AM and ended at 5 PM daily, with a lunch break from noon to 1 PM. The installation workforce included one crane operator, two signalmen, two to six column installers, and one or two managers per crane.

Figure 2: Site photo taken by authors

3.3 Data Collection

Data were collected on 34 columns over three days in May 2022 through site observation and video recording. For each of the 10 work steps, the researchers recorded the start and end times and whether the work was interrupted. In cases of work interruption, they additionally recorded the timing of the interruption (before or during work), its causes, and the start and end times of the work interruption. A total of 332 cases were collected.

3.4 Data Analysis

According to Nelly and Martin (2024) and Koskela (1999), construction flows are essential inputs that need to be managed efficiently for activity execution. These flows are classified into seven types: labor, equipment, workspace, materials, precedence, information, and external (Table 1). The researchers further classified the causes of work interruptions into these seven flows, adding an 'others' flow for a total of eight. The researcher analyzed the frequency and duration (minimum, average, and maximum) of work interruptions for each flow, depending on their occurrence. The frequency of work interruptions was counted by overlaps (e.g., if a crane malfunctioned and a worker had to fetch tools during the assembly of a PC column, it counted as one interruption under equipment flow and another under materials flow). The duration of each interruption was calculated by subtracting the start time from the end time. Finally, the probability of work interruption occurring in each work step was calculated based on the number of work interruptions for each flow divided by the number of times that work step was performed.

Table 1: Definitions and examples of flow

Flow	Definition (Nelly 2017; Aalami 1998; Echeverry et al. 1991; Ballard 2000)	Definition in this study	Examples of flow
Labor	Labor refers to the human workforce involved in construction activities.	Interruptions due to reasons associated with labor.	Workers absent from their posts, workers moving, waiting for workers to vacate a location, or waiting for workers to clear from the trailer.
Equipment	Equipment refers to all machinery and tools used in construction processes.	Interruptions caused by equipment issues, including cranes, AWP, and transits.	Crane malfunctions, crane movement, AWP lifting, changing lifting heads, and transit adjustments.
Workspace	Workspace refers to the physical area where construction activities take place.	Interruptions related to the workspace.	Interference between different trades and adjusting the position of components.
Materials	Materials refers to the movement of raw materials and work-in-progress items from one construction	Interruptions caused by materials-related issues involving PC components, mortar, water, tools (e.g.,	Waiting for a trailer loaded with PC components, moving to fetch tools or backfill, lifting materials

	activity to another.	hammers), and backfill.	other than PC components (e.g., water or mortar), absence of PC components, and processing of components.
Precedence	Precedence refers to the necessary sequence of construction activities based on physical or process constraints.	Interruptions due to necessary preparatory work for PC component installation.	Failure to prepare, connecting lifting lines to the crane, attaching ring clutches, and not pre-attached ring clutches.
Information	Information refers to the directives, design specifications, requests for information, and change orders that are communicated among stakeholders.	Interruptions caused by issues in communication with managers and PC manufacturing plants, due to poor quality or incorrectly installed components, or scheduling adjustments.	communication issues, requests for information, and change orders.
External	External refers to inputs that are external to the construction project but necessary for the activities to begin, such as permits and inspections.	Interruptions related to external necessities required to start work.	Inspections and permits.
Others	-	Interruptions for reasons not falling under the aforementioned seven flows.	Unknown reasons, missing a component during a work step, tangling lines, missing lines, rework, rainfall, break times, and rotating components.

3.5 Mitigation Strategies

The authors proposed strategies to avoid work interruptions based on documentation related to PC component installation (e.g., contractor's construction plans, architectural guidelines), observations of the PC column unloading and installation processes, and interviews with five field managers of PC projects (average PC project experience of 12.2 years, average participation in 3.8 PC projects).

4 RESULTS

4.1 Causes and Frequency of Work Interruptions

Over three days, a total of 259 work interruptions occurred during the unloading and installation of 34 PC columns. These involved 160 pre-installation and 99 during-installation interruptions.

4.1.1 Pre-Installation Interruptions

The major flows of causes for pre-installation interruptions were labor flow (47.77%), materials flow (20.38%), and precedence flow (19.11%). The duration of work interruptions varied by flow, with labor flow ranging from 2 to 1,379 seconds, materials flow from 7 to 142 seconds, and precedence flow from 7 to 62 seconds (Table 2).

Major causes of interruptions by each flow include:

- Labor: waiting for workers to moving from the component or trailer, to climb onto the trailer, or to climb onto the component, and worker movement.

- Materials: waiting for trailers to depart, trailers to arrive, and lifting other materials (e.g., water and mortar).

- Precedence: not pre-attached ring clutches, and adjusting ring clutches.

Labor flow was the most frequent cause of pre-installation interruption, with having the longest maximum interruption time, showing high variability. Materials flow interruptions occurred less frequently but had a longer average duration. Interruptions related to materials flow and precedence flow occurred relatively frequently but typically had shorter durations. Others, though less frequent, showed significant variability in duration.

Table 2: Frequency and duration of pre-installation interruptions by each flow

Flow	Frequency	Minimum (sec)	Average (sec)	Maximum (sec)	SD (sec)
Labor	75	2	47	1,379	212
Equipment	15	5	171	625	303
Workspace	-	-	-	-	-
Materials	32	7	25	142	28
Precedence	30	7	32	62	23
Information	-	-	-	-	-
External	-	-	-	-	-
Others	5	10	291	1,344	589

4.1.2 During-Installation Interruptions

During-installation interruptions were predominantly caused by others (65.69%), equipment (13.73%), and workspace (9.80%). The duration of work interruptions ranged from 3 to 153 seconds for others flow, 7 to 818 seconds for equipment flow, and 2 to 34 seconds for workspace flow (Table 3).

Major causes of interruptions by each flow include:

- Others: tangling lines, missing lines, rotation of components, and interference with lower reinforcement.

- Equipment: crane movement, and disassembly or reattachment of ring clutches.

- Workspace: adjustment of component position.

Others flow was the most frequent cause of during-installation interruptions, generally with short durations. Equipment flow had the longest maximum duration. Labor flow was rare during work but had long durations and high variability.

Table 3: Frequency and duration of during-installation interruptions by each flow

Flow	Frequency	Minimum (sec)	Average (sec)	Maximum (sec)	SD (sec)
Labor	3	27	274	738	402
Equipment	14	7	138	818	267
Workspace	10	2	13	34	11
Materials	8	12	37	82	28
Precedence	-	-	-	-	-
Information	-	-	-	-	-
External	-	-	-	-	-
Others	67	3	15	153	25

4.2 Probability and Duration of Work Interruptions

4.2.1 Pre-Installation Interruptions

Table 4 presents the probability and duration of pre-installation interruptions. The work steps with the most frequent pre-installation interruptions were unloading in the yard (38.22%), crane return from the yard (25.48%), and rigging (16.56%).

During unloading in the yard, work interruptions due to labor occurred up to 2 times per column installation, exceeding 100%.

Lifting had the longest average duration of labor flow, as it involves worker movement from ground to installation floor level.

Crane return from the yard had the highest probability of labor flow due to the need for labor to climb onto the trailer and columns for rigging for unloading.

Table 4: Probability and duration of pre-installation interruptions by each work step

Work step	Flow	probability of interruption occurrence	Average interruption time (sec)
Rigging for unloading	-	-	-
Unloading in the yard	Labor	1.32	6 (SD: 4)
	Materials	0.44	13 (SD: 8)
	Others	0.03	10 (SD: 0)
Unrigging in the yard	Labor	0.09	9 (SD: 4)
Crane return from the yard	Equipment	0.03	5 (SD: 0)
	Labor	0.71	75 (SD: 245)
	materials	0.32	41 (SD: 37)
	Precedence	0.12	30 (SD: 25)
Rigging	Precedence	0.76	43 (SD: 0)
Lifting	Labor	0.03	1379 (SD: 0)
	Others	0.12	361 (SD: 655)
Assembly	-	-	-
unrigging	-	-	-
Crane return	Materials	0.03	625 (SD: 0)
Others	Equipment	0.38	26 (SD: 12)
	Labor	0.06	-
	Materials	0.18	-

4.2.2 During-Installation Interruptions

Table 5 presents the probability and duration of during-installation interruptions. The work steps with the most frequent during-installation interruptions were unloading in the yard (26.47%), rigging for unloading (24.51%), and assembly (24.51%).

For rigging for unloading, unloading in the yard, and assembly, the probability of interruptions occurring from others was over 0.50, but the average duration was short.

Rigging for unloading had the highest probability of interruptions from others, primarily due to tangling and missing lines during the movement of the lifting lines.

Table 5: Probability and duration of during-installation interruptions by each work step

Work step	Flow	probability of interruption occurrence	Interruption time (sec)
Rigging for unloading	Others	0.74	9 (SD: 6)
Unloading in the yard	Workspace	0.29	13 (SD: 11)
	Others	0.50	13 (SD: 11)
Unrigging in the yard	-	-	-
Crane return from the yard	Equipment	0.09	32 (SD: 9)
	Others	0.06	4 (SD: 0)
Rigging	Equipment	0.12	138 (SD: 239)
	Others	0.15	6 (SD: 3)
Lifting	Labor	0.03	738 (SD: 0)
Assembly	Materials	0.24	37 (SD: 28)
	Others	0.50	30 (SD: 40)
unrigging	Equipment	0.06	18 (SD: 4)
	Labor	0.06	43 (SD: 22)
Crane return	Equipment	0.06	818 (SD: 0)
Others	Equipment	0.09	22 (SD: 6)
	Others	0.03	14 (SD: 0)

4.3 Mitigation Strategies

Strategies to mitigate work interruptions before and during PC component installation include increasing the number of workers, preparing equipment and materials at the work location before starting, performing pre-checks and maintenance on cranes, and training on equipment usage. To prevent work interruptions due to "no component", field managers should accurately predict the time needed for PC component installation and prepare transportation request forms accordingly. Additionally, setting up trailer waiting areas on-site can prevent arrival delays due to traffic conditions. Pre-attaching spare ring clutches to subsequent components can streamline the process when rigging for unloading or rigging work step is completed. Painting lifting lines for intuitive identification and quick resolution of tangles can reduce downtime caused by such work interruptions. Although not observed during data collection, interference with other trades can cause work interruptions, which can be mitigated by coordinating with subcontractor managers in advance. Lifting water, mortar, and other materials before all PC columns arrive or after their installation can prevent disruptions during installation. These measures can enhance work efficiency and improve project time management.

5 CONCLUSION

This study aims to observe and quantitatively analyze the causes, frequency, and duration of work interruptions during the installation process of precast concrete (PC) columns in a logistics facility center construction project in Korea. The researchers distinguish work interruptions into pre-installation interruptions and during-installation interruptions. They categorize the causes of interruptions into eight flows and calculates the probability of interruptions occurring for each work step, providing mitigation strategies.

The results indicate that work interruptions are primarily related to the flows of labor, materials, and precedence, with work interruptions of labor flow occurring most frequently. During-installation interruptions are mainly caused by other flow such as equipment movement, adjustments of the position of components, and lines tangling. Managing these interruptions effectively is crucial as work interruptions impact the overall time and cost of the project.

The study suggests several strategies to reduce work interruptions, including increasing the number of workers, preparing equipment and materials in advance, conducting pre-checks and maintenance on cranes, and providing training on equipment usage. Additional measures include pre-preparing work tools to enhance work efficiency.

This research provides important baseline data for improving schedule management and efficiency in PC projects and can serve as a reference for similar projects in the future, potentially reducing time and costs and contributing to overall project success.

Significantly, this study quantitatively investigates the causes, frequency, and duration of work interruptions based on actual data collected at the construction site. This represents a shift from previous studies that mainly used qualitative methods such as surveys or expert interviews. The quantitative confirmation of work interruptions and the calculation of their probabilities per work step offer valuable information for field managers planning PC component installations and preparing transportation requests using a probabilistic approach.

Furthermore, this research lays the groundwork for analyzing the probability and duration of work interruptions based on various variables such as the conditions of PC components (e.g., weight, size, and type), positional conditions (e.g., crane and installation spot), and weather conditions (e.g., temperature and wind speed), and the number of workers. This foundation allows for more sophisticated installation planning and efficient resource management.

However, the study is limited by its analysis based on data collected from a single site over a short period. Future research should involve data collection and analysis over longer periods across various sites. It should also include different component types, such as beams, slabs, and walls, to more accurately calculate the probabilities of work interruptions in PC component installation. Expanding the scope of the study could be integrated into a PC component installation planning estimation model to more accurately predict daily work times. Additionally, a simulation for daily PC component installation could be developed, proposed to assist field managers in reviewing the appropriateness of installation plans and identifying potential issues beforehand.

Moreover, while increasing the number of workers as a mitigation strategy can reduce some work interruptions, it may also lead to increased labor costs and site complexity. Therefore, further studies are needed to identify the optimal relationship between the number of workers, costs, and productivity.

Acknowledgements

This work is supported by the Korea Agency for Infrastructure Technology Advancement (KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant No. RS-2020-KA158109).

References

Aalami, F. B. 1998. Using construction method models to generate four-dimensional production models. Doctoral dissertation, Stanford University.

Al-Gahtani, K. S., Aldokhi, M. I., Alsanabani, N. M., Alotaibi, H. F., and Bin Mahmoud, A. A. 2024. The Impact of Dynamic Risk Interdependencies on the Saudi Precast Concrete Industry. Buildings, 14(4): 875.

Altuwaim, A., and El-Rayes, K. 2018. Optimizing the scheduling of repetitive construction to minimize interruption cost. Journal of Construction Engineering and Management, 144(7): 04018051.

Aziz, R. F., and Abdel-Hakam, A. A. 2016. Exploring delay causes of road construction projects in Egypt. Alexandria Engineering Journal, 55(2): 1515-1539.

Ballard, H. G. 2000. The last planner system of production control. Doctoral dissertation, University of Birmingham.

Cho, K., Ahn, S., Park, K., and Kim, T. W. 2021. Schedule delay leading indicators in precast concrete construction projects: Qualitative comparative analysis of Korean cases. Journal of Management in Engineering, 37(4): 04021024.

Echeverry, D., Ibbs, C. W., and Kim, S. 1991. Sequencing knowledge for construction scheduling. Journal of Construction Engineering and Management, 117(1): 118-130.

El-Razek, M. E. A., Bassioni, H. A., and Mobarak, A. M. 2008. Causes of Delay in Building Construction Projects in Egypt.

Garcia-Lopez, N. P. 2017. An activity and flow-based construction model for managing on-site work. Doctoral dissertation, Stanford University.

Garcia-Lopez, N. P., and Fischer, M. 2024. Managing On-Site Production Using an Activity and Flow–Based Construction Model. Journal of Construction Engineering and Management, 150(1), 04023144.

Hassan, A., and El-Rayes, K. 2020. Quantifying the interruption impact of activity delays in non-serial repetitive construction projects. Construction Management and Economics, 38(6): 515-533.

Hatmoko, J. U. D., Wibowo, M. A., Astuty, M. D., Arthaningtyas, D. R., and Sholeh, M. N. 2019. Managing risks of precast concrete supply chain: a case study. In MATEC Web of Conferences, Bandung, Indonesia, Vol. 270, pp. 05004.

Jang, J. Y., Ahn, S., and Kim, T. W. 2023. Cloud-based information system for automated precast concrete transportation planning. Automation in Construction, 152: 104942.

Jeong, E., Jang, J., Lee, S., Ahn, S., and Kim, T. W. 2024. Quantitative Analysis of the Factors Influencing Field Installation Time for Precast Concrete Building Components: An Empirical Study. Journal of Management in Engineering, 40(3): 04024010.

Ji, Y., Qi, L., Liu, Y., Liu, X., Li, H. X., and Li, Y. 2018. Assessing and prioritising delay factors of prefabricated concrete building projects in China. Applied sciences, 8(11): 2324.

Koskela, L. 2000. An exploration towards a production theory and its application to construction. VTT Technical Research Centre of Finland, Espoo, Finland.

Lee, G. H., Kim, J. I., Koo, C., and Kim, T. W. 2022. Automated generation of precast concrete slab stacks for transportation in offsite construction projects. Journal of Construction Engineering and Management, 148(8): 04022072.

Leite, F. L., and Griego, R. 2019. Premature start impact analysis tool: Preventing unintended construction interruptions and associated impacts. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 11(2): 04519005.

Li, C. Z., Xu, X., Shen, G. Q., Fan, C., Li, X., and Hong, J. 2018. A model for simulating schedule risks in prefabrication housing production: A case study of six-day cycle assembly activities in Hong Kong. Journal of cleaner production, 185: 366-381.

Liu, D., Li, X., Chen, J., and Jin, R. 2020. Real-time optimization of precast concrete component transportation and storage. Advances in civil engineering, 2020: 1-18.

Safapour, E., and Kermanshachi, S. 2019. Identifying early indicators of manageable rework causes and selecting mitigating best practices for construction. Journal of management in Engineering, 35(2): 04018060.

Salama, T., and Moselhi, O. 2019. Multi-objective optimization for repetitive scheduling under uncertainty. Engineering, Construction and Architectural Management, 26(7): 1294-1320.

Thomas, H. R., and Oloufa, A. A. 1995. Labor productivity, disruptions, and the ripple effect. Cost Engineering, 37(12): 49.

Toor, S. U. R., and Ogunlana, S. O. 2008. Problems causing delays in major construction projects in Thailand. Construction management and economics, 26(4): 395-408.

Wu, P., Low, S. P., and Jin, X. 2013. Identification of non-value adding (NVA) activities in precast concrete installation sites to achieve low-carbon installation. Resources, Conservation and Recycling, 81: 60-70.

Zhao, Y., Chen, W., Arashpour, M., Yang, Z., Shao, C., and Li, C. 2022. Predicting delays in prefabricated projects: SD-BP neural network to define effects of risk disruption. Engineering, Construction and Architectural Management, 29(4): 1753-1776.