AlBalkhy, W., Rankohi, S., Lafhaj, Z., Iordanova, I., Ramirez Velasquez., J. M., Bourgault, M. & Pellerin, R. (2023). Lean and IoT integration to improve flow in construction prefabrication: a proposed framework. *Proceedings of the 31st Annual Conference of the International Group for Lean Construction (IGLC31),* 836–845. doi.org/10.24928/2023/0260

# LEAN AND IOT INTEGRATION TO IMPROVE FLOW IN CONSTRUCTION PREFABRICATION: A PROPOSED FRAMEWORK

**Wassim AlBalkhy[1], Sara Rankohi[2], Zoubeir Lafhaj[3], Ivanka Iordanova[4], Jorge Mauricio Ramirez Velasquez[5], Mario Bourgault[6], and Robert Pellerin[7]**

## ABSTRACT

Creating a stable and smooth flow is an essential principle of lean thinking. Failure to create a stable flow in the production system degrades performance and impacts value creation. In construction prefabricated systems, variability in flow between the construction site and manufacturing plant can cause an increase in time and cost of the projects. This paper aims to deal with the problem of lack of synchronization between the onsite and offsite fabrication. To achieve this aim, a framework that is based on the integration between lean and the Internet of Things (IoT) is proposed. The proposed framework integrates the planning and control work from the Last Planner System® (LPS) with IoT to improve the planning, tracking, and delivery of prefabricated components. The study sheds the light on some of the expected challenges that may face the use of the proposed framework and covers the preliminary observations after putting it in use to improve flow in the delivery of prefabricated steel components.

## KEYWORDS

Lean construction, Last Planner System® (LPS), Internet of things (IoT), lean construction 4.0, construction prefabrication, flow.

## INTRODUCTION

Construction prefabrication is the term that describes the practice of producing a certain quantity of building components partially or fully in a factory to further assembly on the construction site (Qi et al., 2021). As one of the most important examples of industrialization of construction (Cheng et al., 2023), construction prefabrication has attracted attention and is considered an effective way to improve performance in the Architecture, Engineering, and

[1] Doctoral Candidate, Centrale Lille, CNRS, UMR 9013-LaMcube, Lille, France, wassim.albalkhy@gmail.com, https://orcid.org/0000-0002-4772-8133

[2] Postdoctoral Fellow, Department of Mathematical and Industrial Engineering, Polytechnique Montreal, sara.rankohi@polymtl.ca

[3] Full Professor, Centrale Lille, CNRS, UMR 9013-LaMcube, Lille, France, zoubeir.lafhaj@centralelille.fr, https://orcid.org/0000-0003-1985-9176

[4] Professor, Department of Construction Engineering, École de Technologie Supérieure, Montréal, QC, Canada, Ivanka.Iordanova@etsmtl.ca

[5] Doctoral Candidate, École de Technologie Supérieure, Montréal, QC, Canada, jorge-mauricio.ramirez-velasquez.1@ens.etsmtl.ca

[6] Professor, Department of Mathematical and Industrial Engineering, Polytechnique Montreal, mario.bourgault@polymtl.ca

[7] Professor, Department of Mathematic and Industrial Engineering, Polytechnique Montreal, robert.pellerin@polymtl.ca

Construction (AEC) industry. This is due to the various improvements it could improve when it is compared with conventional on-site construction practices (Cheng et al., 2023; Xu et al., 2018). Examples of possible improvements include time and cost savings, reduction in greenhouse gas emissions (GHGs), safety improvement, reduction in materials consumption, and productivity gain (Arashpour et al., 2015; Mossman & Sarhan, 2021; Qi et al., 2021; Xu et al., 2018). Prefabrication is also an effective way to reduce more than half of the physical waste (Jaillon et al., 2009). While comparing fully on-site construction with prefabrication, Horman et al (2006) presented a list of economic, social, and environmental benefits of prefabrication. Some of these benefits were the establishment of long-term supply chain planning, less maintenance work and reworks due to the improved quality, fewer defects, variety in materials choices, improved de-constructability, and improved working conditions.

Nevertheless, prefabrication in projects faces various challenges that may hinder the smooth flow of processes. According to Mossman and Sarhan (2021), synchronizing flow between offsite prefabrication and onsite construction is essential to ensure success when depending on prefabricated components. This synchronization has to cover all flow phases starting from the arrival of the raw materials at the factory and ending with the onsite assembly. Failure to achieve such synchronization can prohibit the delivery of materials or components and cause an increase in time and cost of the project (Kanai et al., 2021). The heavy dependence on the critical path method (CPM), delivery of materials based on pushing strategies, and lack of focus on optimizing the overall production system in the factory and site are among the most affecting factors that limit the flow synchronization (Mossman & Sarhan, 2021). The use of lean principles and tools such as the Last Planner System® (LPS), Jus-In-Time (JIT), and Kanban or pull signals can help mitigate the impact of these problems by focusing on the end-to-end process flow, collaboratively working and planning based-on what can be done rather than what should be done, and produce and deliver only what is needed and when it is needed (Kanai et al., 2021; Mossman & Sarhan, 2021).

The Internet of things (IoT) has shown effectiveness in managing the flow of information and materials in many sectors but has still not been adopted on a large scale in the construction industry. IoT can help in reducing the time between data capture and decision-making, which allows for coping with real-time changes in the production system (Ben-Daya et al., 2019). It also helps improve coordination and facilitates monitoring based on accurate information. Furthermore, it helps to identify the locations and track employees, trucks, and materials, which result in higher productivity and safer site (Gamil et al., 2020; Kumar & Shoghli, 2018; Matteo Giovanardi et al., 2021). Its interaction with lean comes from its ability to improve the visualization of processes and share it with different stakeholders to improve flow, collaboration, problem-solving, error-proofing, and achieving continuous improvement (Dave et al., 2016; Tezel et al., 2022). Therefore, there have been, recently, various efforts to support lean-IoT integration. These efforts have resulted in some lean-IoT applications and software such as Visilean®, KanBIM™, and others (Dave et al., 2016; Kanai et al., 2021; Sacks et al., 2011). Nevertheless, the focus on synchronizing flow between offsite and onsite operations and integrating LPS planning results in this synchronization is still not widely implemented. The current study proposes a lean-IoT framework to integrate LPS planning levels in the synchronization between the construction site and the prefabrication factory.

# LITERATURE REVIEW

## PROCESS DEFINITION AND TECHNOLOGY USE IN PREFABRICATED CONSTRUCTION

The literature has several definitions for the prefabrication process. For instance, Cheng et al (2023) considered that the process can be depicted in three main stages such as design, manufacturing, and onsite assembly. According to Liu et al (2020), the process comprises ordering, manufacturing, transportation, and assembly. In turn, Qi et al (2021) stated that the prefabrication process includes design and planning, production and manufacturing, delivery and store, and the assembly stages. In their study, Qi et al (2021) affirmed that challenges along all these phases can appear. The traditional approaches, which consider mainly architectural and performance requirements in the design stage can lead to a decrease the efficiency; therefore, manufacturing, delivery, and assembly aspects have to be considered. In the production stage, the lack of real-time information to monitor quality, location, and performance aspects can hinder optimal productivity. In the delivery process, errors in logistic management can affect the performance of the whole project.

Cheng et al (2023) classified technologies in offsite construction (OSC) based on data perspective technologies into data acquisition, data integration, data analysis, and decision-making technologies. For the acquisition, their study listed paper-based monitor and sensor techniques. They highlighted the use of long-range radio communication techniques (LoRA), radio frequency identification (RFID), the global positioning system (GPS), laser scanning, and photogrammetry techniques. The integration technologies connect data with web platforms. In the making decision field, most of the decisions are taken by human actors and some are taken by artificial artifacts. Liu et al (2020) found in their review, advances in the management and implementation levels for OSC. In the management process, strategic research, overall design, and supply chain integration and management are key. At the technological level, supply chain process design and optimization and application of advanced technology.

## TECHNOLOGICAL GAPS AND CHALLENGES IN PREFABRICATED CONSTRUCTION

According to Xu et al (2018), despite the numerous expected benefits when presenting technological solutions to construction prefabrication companies, these companies face various challenges. Among these challenges, is the reliance on traditional methods and the resistance to adopting new technologies, which results in inaccurate and inefficient practices. The second problem is the low level of coordination and collaboration, which prohibits the dissemination and sharing of information with the prefabricated companies; as a result, causes late and misplaced delivery. The third problem is related to the nature of the prefabricated companies as most of these companies are small and medium-sized companies (SMEs). It is widely conceived that this type of company faces several challenges when trying to adopt technology such as the lack of financial capabilities, lack of managerial flexibility, resistance to change, lack of skilled employees, and lack of knowledge (Agostini & Nosella, 2020; Albalkhy et al., 2021; Albalkhy & Sweis, 2021; Elhusseiny & Crispim, 2022; Kolla et al., 2019). The fourth problem is that most of the provided technology-based practices do not fully address the nature of the prefabricated construction and the link between the onsite and offsite production in construction. As a result, these solutions cannot be directly applied in prefabricated companies (Xu et al., 2018). Additionally, in their review, Qi et al (2021) classified the technologies that are currently applied in prefabricated construction into business digitalization, computer-integrated design, data acquisition, optimization, predictive analytics, and robotics and automation. According to their analysis, most technological applications to improve prefabrication processes have been done in a research context.

Based on the above-mentioned challenges, more practical and scalable technologically supported solutions should be proposed and put into use. However, these technologies should fit with the nature of work in the prefabricated construction sector. They also should ensure high levels of collaboration between different stakeholders in the project and synchronization of practices and flow on the site and at the factory. This means that the proposed frameworks should be based on linking the three pillars of production systems, which are technology, process, and people. Linking these pillars is essential in lean thinking (Sacks et al., 2010).

# THE PROPOSED FRAMEWORK

The current study is based on linking planning and control deliverables of the construction processes with the manufacturing processes in the prefabricated companies to ensure the synchronization of flow processes between the two production systems. To do so, the proposed framework tries to cover deliverables from the planning and control tool (LPS), application of JIT and pull signals, and development of IoT architecture to continuously track, monitor, and localize prefabricated components. The proposed framework was based on studying different cases in offsite and onsite construction (Chen et al., 2020; Dave et al., 2016; Kanai et al., 2021; Li et al., 2018; Von Heyl & Teizer, 2017; Xu et al., 2018) and based on studying a process map in a prefabrication company in Canada.

## LAST PLANNER SYSTEM® (LPS)

LPS is one of the most important tools that support the adoption of lean theory in the construction sector (Albalkhy & Sweis, 2022). LPS can be understood as a short-term planning tool that is based on integrating collaborative planning with all possible stakeholders especially the last planner (people who do the work) (Ballard, 2000; Mossman & Sarhan, 2021). As shown in Figure 1, LPS has generally different levels of planning and control and incorporates the pull concept and plan based on what "CAN" be done instead of the push mechanism that is based only on what "SHOULD" be done. This planning structure identifies constraints to be removed, develops performance measures such as Planned-Percent-Completed (PPC), and integrates the learning process based on the principles of continuous improvement and non-compliance to plan analysis (Porwal et al., 2010). The main planning and control levels in LPS are (LCI Congress, 2016):

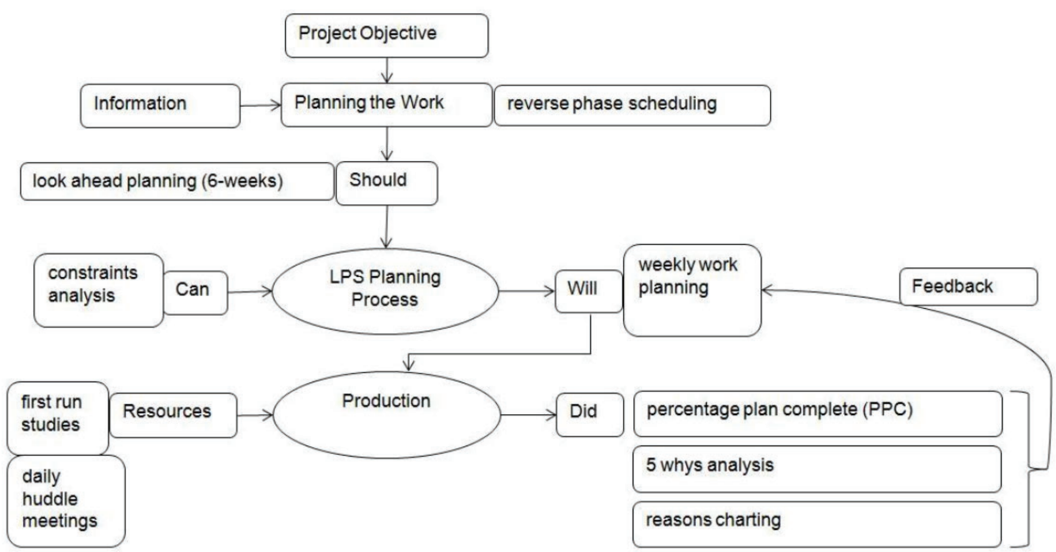


Figure 1: LPS planning process (Porwal et al., 2010).

1- Master planning or milestone planning: which defines the overall road and the main milestones of the projects (identifying what should be done).
2- Phase planning or pull planning: collaborative planning of phases to achieve the milestones (identifying what should be done).
3- Lookahead planning: uses phase planning to make work ready. In this phase, the focus is on identifying constraints-free tasks (identifying what can be done).
4- Weekly work plan (WWP): a detailed weekly plan that includes commitments and promises to deliver the tasks (identifying what will be done).

5- Daily huddle meetings and learning: to identify what will be completed and what was completed, what needs to be re-planned, and how to prevent deviations from the plan (identifying what will be done and what was done).

According to Mossman and Sarhan (2021), the short-term collaborative planning approach in LPS facilitates the synchronization of flow between onsite and offsite fabrication and creates the conditions for JIT delivery, which aims to reduce the volume in inventory and ensure the delivery of materials to the right place at the right time. With a technological application such as Building Information Modeling (BIM) and IoT, LPS planning can integrate real-time information that can create reliable flow, improve visibility, and reduce variability (Dave et al., 2016; Mossman & Sarhan, 2021; Sacks et al., 2010).

## IOT-BASED ARCHITECTURE FOR THE PROPOSED FRAMEWORK

According to the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) (ISO/IEC, 2014), IoT is “an infrastructure of interconnected entities, people, systems and information resources together with services which process and react to information from the physical world and from the virtual world”.

Figure 2 shows the various layers of the IoT architecture in the proposed framework inspired from (Karmaoui et al., 2022; Rankohi et al., 2023). The developed architecture is based on using barcode tags, RFID antennas, and readers for collecting data. The data transmission is done by WiFi to databases that are accessible to the plant operators and project managers to conduct analysis and make decisions. As shown, the proposed architecture consists of three main layers: perception, network, and application layers.

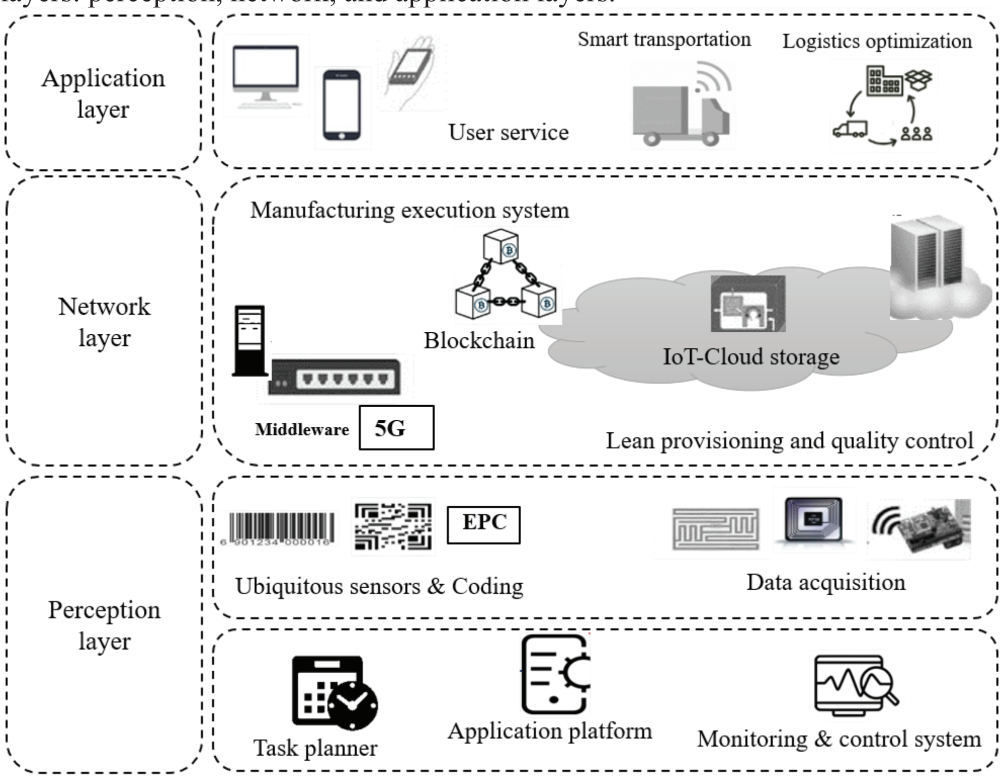


Figure 2: IoT-based architecture for the proposed framework.

The perception layer represents platforms for planning the tasks, using the application, and monitoring and controlling systems. It also represents units that are responsible for coding, information extracting, data processing, controlling, and monitoring. In the coding phase, an ID number is assigned to each prefabricated component. The component can be recognized in the whole cycle of the IoT. Then, the obtained information will be transmitted from the collection phase in the perception layer to the lean analyzing phase in the network layer. The network layer is a network platform based on IPV6. It consists of an intelligent network, which connects all the resources in the network. In this layer, data is collected and objects are identified via RFID tags. Then the information is integrated into the cloud, to manage and control the collected data in real-time. In this layer, the data is reorganized, filtered, shared, and transformed into the content service in the Service-oriented architecture (SOA).

Finally, the application layer integrates the service capabilities and provides the application service to the clients. Users can use different applications to access their required information, such as smart transportation, smart material tracking, and logistics optimization. For instance, barcodes are installed on prefabricated components. The users can use a smart material tracking application to scan these barcodes with their smartphones, which directs them to any used storage (e.g. company's database or website). This application can be equipped with mobile tag reader technologies, which are used by the clients to make sure they have collected all received steel bars in returning racks. In addition, clients can use this application to send automated alerts to project managers to inform them that prefabricated components or pallets are ready for pick-up.

**PROCESS**

Figure 3 shows the process in the proposed framework. The proposed framework covers the different phases of the prefabrication process and the onsite and offsite fabrication. It also integrates different LPS levels with the IoT tracking system for the delivery and installation of prefabricated components. The framework is integrating the pull concept, buffering, and JIT during the production and manufacturing and delivery, and storage phases. It is also linked with nD BIM models to improve the tracking of the process flow.

More specifically, the process starts with the development of the master planning, which is the first level of LPS planning. At this level, the main milestones of the project are identified and the development of the BIM models starts. The next phase is the phase or pull planning, in which the supplier of the prefabricated elements should participate and define the estimated lead times to deliver the orders. Using the results from the pull planning, the requirements and orders can be estimated and the look-ahead plans can be developed.

Estimates of the orders and requirements are useful to identify the production schedule and initiate the production process of the elements to be stored in warehouses. Simultaneously, the work on site focuses on the identification and removal of all possible constraints that may hinder the installation of the prefabricated elements onsite using logs from the look-ahead plans. Following the identification and removal of constraints, onsite demands and transportation plans are created to deliver the elements on time to the site. Based on the transportation plan, elements can be pulled from warehouses to be tagged and identified in the IoT system. The trucks can be tagged and linked to the IoT system as well.

The IoT system is responsible for delivering real-time updates about the delivery process including tracking, localizing, and counting the delivered elements and reporting any problem that may happen. Once the elements arrive at the site, they can be directly integrated with the weekly work plans, then installed, and then integrated into the daily huddle meetings and learning sessions.

Despite the potentials of the proposed framework, it is worth mentioning that there are different points to consider when integrating lean construction and IoT. Examples of these points include the security of data, availability of skills and knowledge when implementing the proposed framework, availability of policies and guidelines for implementation, connectivity, in addition to acceptability and readiness to make a change in the traditional practices (Albalkhy & Sweis, 2021; Khurshid et al., 2023).

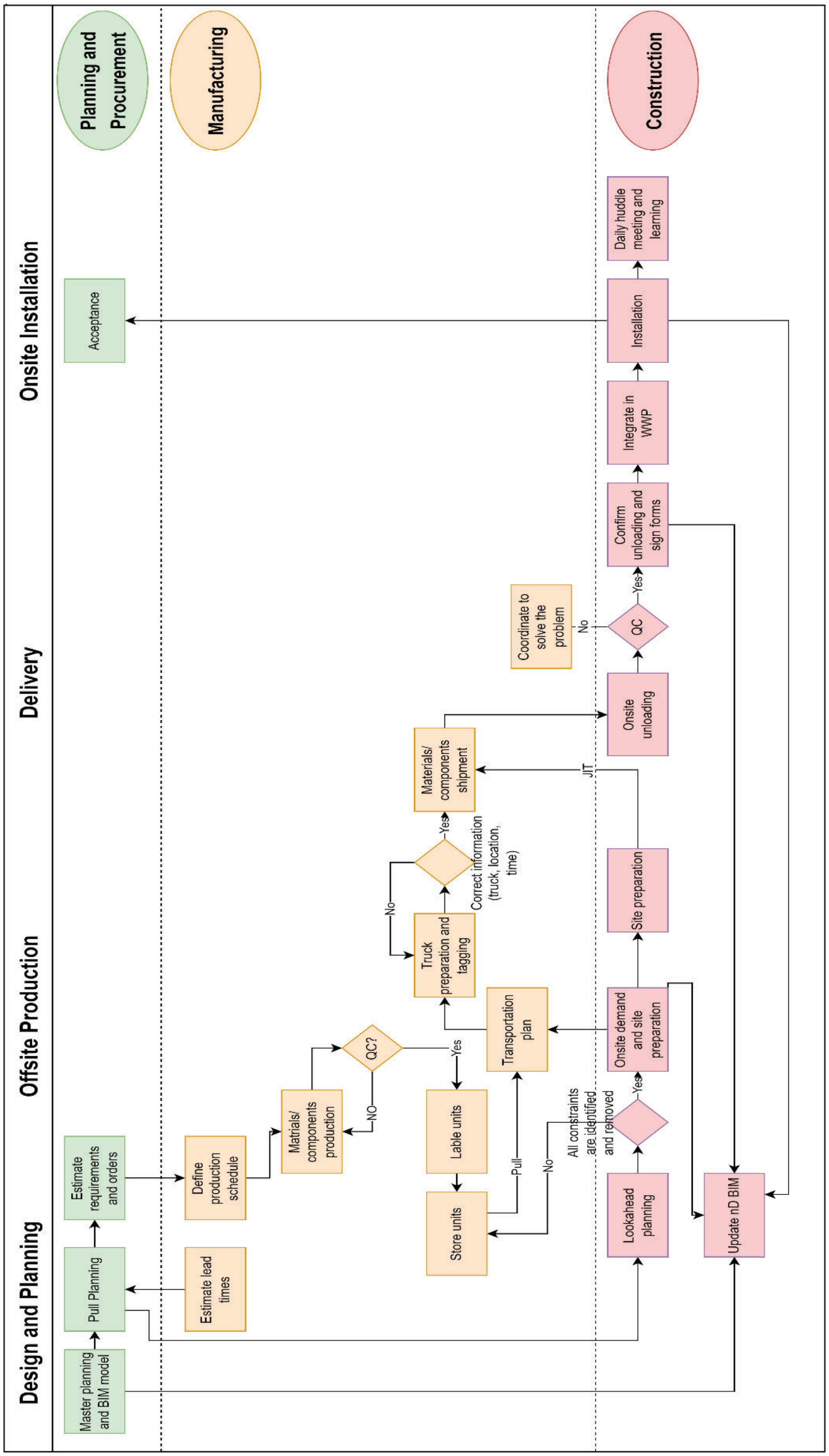


Figure 3: The proposed framework.

## CONCLUSIONS AND FUTURE DIRECTIONS

The proposed framework was presented to improve the flow of prefabricated components and avoid the problems of lack of synchronization between the onsite and offsite fabrication. Integrating the plans from LPS and IoT in the proposed framework can help to improve the efficiency of prefabricated delivery. This is due to improving the traceability, localization, and identification of these components, enhancing the communication between the plant and the site, and avoiding errors resulting from the low levels of coordination. The proposed framework can be effective in linking the supplier schedule and the production plan of the project, which is very helpful to achieve improvement along the whole process rather than achieving fragmented changes that might not result in time reduction, cost saving, or quality improvement. Moreover, the proposed framework aims to reduce flow variability, cope with complexity, increase flexibility, and improve the decision-making process in prefabricated construction.

The proposed framework is to be tested to deliver construction prefabricated steel components in a Canadian company. The preliminary experiments utilizing the proposed IoT-based platform show initial promising results concerning the ability to track the delivery and installation of steel components. Nevertheless, despite starting the implementation of the framework, its results are not yet evaluated and validated. Therefore, further extensive experimental studies on-site and in manufacturing plant environments are required to validate the proposed framework. In addition to conducting more cases, future work can be conducted to identify possibilities of framework improvement using, for instance, digital twin technology to improve on-time tracking and monitoring and artificial intelligence (AI) to predict delivery dates. Further research can also focus on studying different performance indicators for the proposed framework or different barriers to adopting it.

The current study aims to contribute to the existing efforts to link lean construction and construction 4.0 practices (known as lean construction 4.0). It also serves as a good example to integrate both concepts to improve the performance in offsite and modular construction.

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