

TOWARDS EFFICIENT OFF-SITE MANUFACTURING IN MODULAR CONSTRUCTION: DETERMINING DECISION FACTORS AND RESEARCH NEEDS

M. Elkabalawy^{1*}, M.R.I. Chowdhury¹, J.W. Ma^{1,2}, S.H. Han^{1,2}

¹ Dept of Building, Civil & Environmental Engineering, Concordia University, Montréal, QC, Canada

² Centre for Innovation in Construction and Infrastructure Engineering and Management (CICIEM), Gina Cody School of Engineering and Computer Science, Concordia University, Montréal, QC, Canada

*moaaz.elkabalawy@mail.concordia.ca

ABSTRACT: Modular offsite construction (MOC) has emerged as a key solution to address the global demand for efficient and sustainable construction methods. Despite its advantages, MOC faces challenges in factory-based manufacturing, where 70% of construction activities occur. Key challenges include inefficient facility layouts and logistics, limited visibility into process inefficiencies, and suboptimal workspace planning and ergonomics. Thus, considerable efforts have been made to overcome these challenges by considering spatial organization, production flow, and resource allocation. However, these studies are often fragmented, failing to account for the dynamic interdependencies among operational, technical, managerial, and logistical decision-making factors. Consequently, the literature lacks holistic decision-making models that capture the collective impact of these interconnected factor categories on production performance. Accordingly, this paper identifies and analyzes key decision factors in offsite manufacturing, laying the groundwork for developing future holistic decision-making models. As such, our mixed-review methodology involves: (1) conducting a systematic literature review spanning the last two decades using Scopus database and following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines; (2) performing a qualitative inductive thematic analysis to identify explicitly and implicitly incorporated factors in various decision-making tools within the literature; (3) employing a quantitative social network analysis (SNA) to identify prominent factors using the degree centrality measures, and utilizing edge weights to uncover understudied relationships among factors; and (4) identifying gaps and strengths in the literature based on the SNA results and outlining actionable future research directions. The results revealed gaps in integrating lean principles, sustainability, and logistical factors, suggesting that crucial synergies remain underexplored. Accordingly, this paper proposes future research directions for developing comprehensive decision-making models to support scholars in optimizing manufacturing processes, enhancing sustainability, and achieving improved performance.

1. INTRODUCTION

Modular offsite construction (MOC) has rapidly gained global prominence as a practical approach to mitigating chronic labor shortages, frequent schedule overruns, and sustainability challenges inherent in traditional construction (Pan and Goodier 2012). MOC entails offsite manufacturing of building components in a controlled factory environment and transporting them to the construction site for final assembly. This approach shifts a significant portion of the construction process to specialized factories, streamlining production, reducing waste, and improving quality assurance (Blismas et al. 2006). Despite these benefits, offsite manufacturing is characterized by fast-paced, nonlinear, intricate procedures with minimal standardization and is subject to cyclical demand (Arashpour et al. 2015). Existing research has attempted

to model these complex production features through various approaches, including mathematical modeling and simulation (Hussein et al. 2021). However, these studies often focus on isolated decision factor categories, including time, design, cost, and sustainability. As a result, current offsite manufacturing decision-making models do not reflect the diverse and interdependent factors that influence production performance. Identifying decision-making factors is critical in MOC as it enables stakeholders to evaluate options systematically, reduce uncertainties, and optimize project outcomes. Recently, diverse methodologies, such as multi-criteria analyses (Daget and Zhang 2019), Analytical Hierarchy Process (Attouri et al. 2022), and Social Network Analysis (SNA) (Abdul Nabi and El-adaway 2020), have been utilized to systematically identify, evaluate, and prioritize decision factors relevant to various aspects of MOC. However, these works predominantly focus on higher-level project planning and system selection, leaving offsite manufacturing decision-making largely unexplored.

SNA is a graph-based methodology that investigates networks by examining relationships among their components (Otte & Rousseau, 2002). This approach has effectively revealed research gaps and synergies in construction, including uncovering key themes in Building Information Modeling research (Hosseini et al., 2018), identifying dynamic factors that impact construction performance (Abotaleb & El-adaway, 2018), and modeling construction business failures (Assaad & El-adaway, 2020). Accordingly, this paper uses a mixed-method approach based on SNA to holistically study and map the diverse decision factors influencing offsite manufacturing. The paper aims to (1) identify a comprehensive list of factors affecting the decision-making processes in offsite manufacturing; (2) study the level of inclusion, interconnectivity, and synergy between the factors in developed decision-making models and frameworks; and (3) highlight the understudied factors synergy and develop a road map to areas that need further investigation concerning decision-making in offsite manufacturing. It is essential to note that quantifying the impact of each factor on project performance is beyond the scope of this paper. Future research should aim to conduct such studies to validate and measure the significance of these factors in real case studies.

2. METHODOLOGY

2.1 Systematic Literature Selection

This paper employs a mixed-methods approach, integrating a systematic literature review with qualitative and quantitative techniques. The authors selected literature published between 2000 and 2024 in the Scopus database. This timeframe was chosen because (i) 20 years is common in reviews of recent trends; (ii) MOC has grown significantly in the past two decades; and (iii) publication rates before 2000 were notably low, with approximately one article per year (Zaalouk et al. 2023). As demonstrated in Figure 1, the authors systematically reviewed the relevant literature using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

2.2 Qualitative Analysis

Based on the selected studies, this phase aims to identify the decision factors influencing offsite manufacturing. This examines how these factors are implicitly and explicitly incorporated into various decision-making tools within the literature. Two researchers independently examined the full texts of the included studies through an inductive thematic analysis. Subsequently, they systematically extracted key factors and analyzed how each was utilized within decision-making frameworks and operational models. To minimize subjectivity, the identified factors were recorded using a standardized Excel spreadsheet, with instances of synonymous terms consolidated under unified labels. Discrepancies between the researchers were resolved through discussion, ensuring consistency and reliability in the extraction process.

2.3 Quantitative Analysis

As previously highlighted, the authors utilized SNA to visually and quantitatively examine the level of study of the identified decision factors in the developed models and frameworks. This constitutes a micro-level analysis of the studied decision factors and their inclusion and interconnectivity in previous related studies.

In implementing SNA, the authors compiled a reference matrix by listing the decision factors in rows and source articles in columns, marking cells with one if a factor appears in an article and zero otherwise. Using Python, the reference matrix was converted into an adjacency matrix by multiplying it by its transpose and setting the diagonal values to zero. Subsequently, an undirected social network was developed using Gephi, where each node represents a decision factor, and an edge between any two nodes indicates that these factors co-occurred in at least one study. To gauge the prominence of each factor, we computed its weighted degree centrality (DC) by summing the weights of all connected edges and then normalized these values by dividing by the maximum observed degree, yielding a scale from 0 to 1. Factors with high DC are interpreted as deeply integrated in current research, while low values suggest underexplored topics. Accordingly, the edge weights of these nodes were analyzed to distinguish well-studied from under-researched relationships and identify potential research gaps. Readers interested in detailed steps for constructing such networks and computing centrality measures can refer to Abdul Nabi & El-adaway (2020).

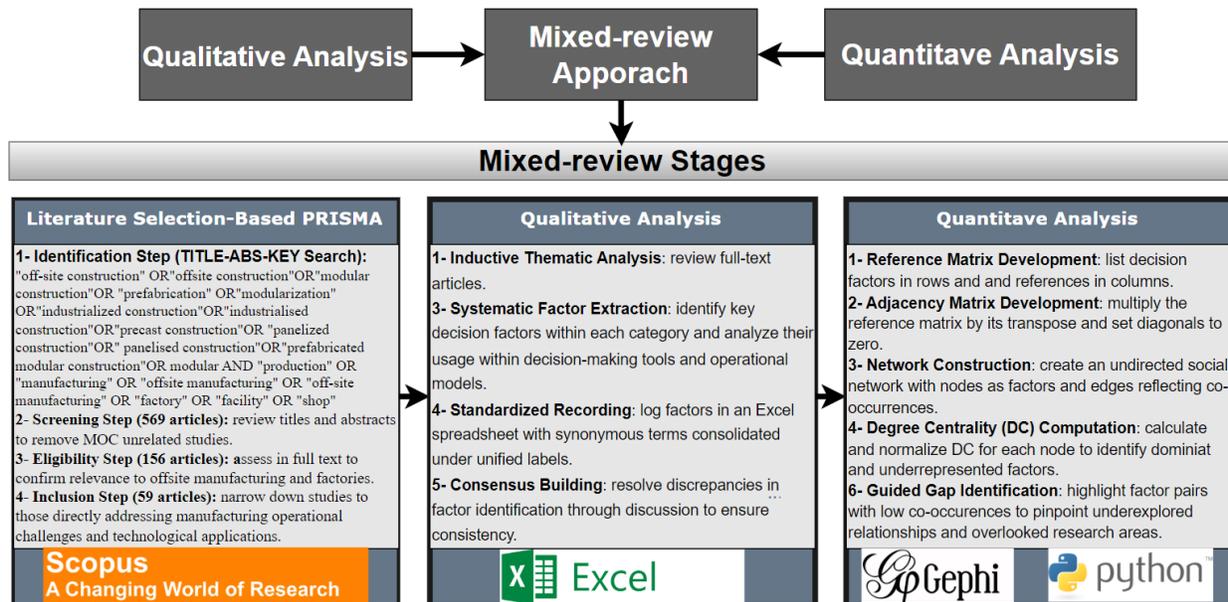


Figure 1 Overview of the research methodology

3. RESULTS AND ANALYSIS

3.1 Systematic Literature Review Results

Based on insights from the literature, the selected articles were first classified into three primary categories: production logistics, planning, and management (see Table 1). This categorization captures the distinct yet interrelated stages of offsite production operations, serving as a structural framework for our subsequent network analysis and gap identification. Production logistics defines long-term production strategies required to achieve business objectives. Its scope includes operation-related decisions, such as structuring factory zones, resource flow, and coordinating high-level supply chain requirements. The goal is to establish a harmonized environment where physical space, resource usage, and external logistics interact cohesively. The production logistics category has two reported thematic groups: facility layout design (FLD) and supply chain coordination. The FLD problem is centered on devising the most effective arrangement and optimal sizes of production zones, storage areas, material handling paths, and ancillary services within a factory setting (Yang and Lu 2023). The production planning category translates strategic decisions into tangible scheduling and resource allocation frameworks that guide day-to-day operations. It encompasses production line design, scheduling, and resource planning. Production line design is typically the first step, defining workstation layouts and spatial arrangements. It aims to configure line geometries (e.g., I, L, U shapes) and rearrange workstations to streamline the flow of materials, labor, and information. Once the line configuration is set, scheduling determines the optimal module production sequence, and resource

allocation ensures that workstations receive the required labor, equipment, and materials. The third category, Production Management, involves ongoing supervision and refinement, mainly focusing on short-term planning. The literature identifies four central themes within this category that facilitate short-term monitoring: process optimization, manufacturability analysis, ergonomic analysis, and energy management.

Table 1 Selected studies in the literature categories

Category	Article
Logistics	(Ahn et al. 2022; Assaf et al. 2024; Chen et al. 2019; Cheung et al. 2002; Du et al. 2019; Hsu et al. 2018, 2019; Salari et al. 2022; Tavares et al. 2019; Wei et al. 2024; Yang and Lu 2023; Zhang et al. 2023)
Planning	(Abu Hammad et al. 2008; Al-Bazi and Dawood 2010; Banerjee et al. 2006; Benjaoran et al. 2005; Bhatia et al. 2022; Cao et al. 2022b; Gartner et al. 2024; Hyun et al. 2021; Kim et al. 2020; Ko and Wang 2011; Lee et al. 2017; Li et al. 2018; Liu et al. 2021b; Mehrotra et al. 2005; Nam et al. 2019; Nasirian et al. 2019; Wang et al. 2018b; Wang and Hu 2017, 2018; Xie et al. 2023)
Management	(Afifi et al. 2022; Ayinla et al. 2022; Barkokebas et al. 2023; Han et al. 2012; Lachance et al. 2023; Malik et al. 2021; Martinez et al. 2020a; b; Nasereddin et al. 2007; Orłowski 2019; Tao et al. 2018; Xu et al. 2023, 2024; Yin et al. 2009) (Cao et al. 2022a; Khalili and Chua 2013; Liang et al. 2024; Liu et al. 2021a; Malik et al. 2019; Wang et al. 2018a) (Li et al. 2019; Nam et al. 2020; Wang et al. 2021, 2023) (Chippagiri et al. 2023; Xu et al. 2019)

A comprehensive set of 39 decision factors that influenced offsite manufacturing was identified throughout these categories. Figure 2 illustrates how these factors appear across the selected articles, which were organized into seven groups:

- Cost-related factors (F1–F9) including direct resource costs, resource transportation costs, overheads, equipment investment, unitary production cost, delay/tardiness, overtime, changeover costs, and electricity/fuel expenses.
- Time-related factors (F10–F16) encompassing task sequencing, processing times, disruptions/delays, transportation schedules, production demand, onsite schedules, and factory operational schedules.
- Design and engineering factors (F17–F19) covering module weight/size, module specifications, and product mix.
- Logistical factors (F20–F30) addressing shop capacity, storage capacity, material inventory/handling, workstation design, material requirement, production line design, factory layout, and resource characteristics, competence, productivity, and requirement.
- Environmental and energy factors (F31–F33) tracking material and resource emission factors and energy consumption.
- Lean manufacturing-related factors (F34–F37) focusing on lean layout & flow optimization, lean scheduling, lean resource planning, and performance measurement.
- Quality-related factors (F38–F39) encompassing the quality of prefabricated modules and quality control implementation.

3.2 Quantitative Analysis Results

3.2.1 Production logistics

The network analysis indicates that dominant factors such as F20 (Shop Capacity) and F19 (Product Mix) have yielded high normalized values of 1.00 and 0.76, respectively. These findings suggest that existing literature adequately addresses crucial elements in determining a facility's maximum output and managing product variety. As illustrated in Figure 3(I), there is a strong synergy among F20 (Shop Capacity), F13 (Transportation Schedule), and F21 (Storage Capacity). This alignment is supported by supply chain coordination studies that align shop production capacity with every stage of the supply chain, which enables timely delivery and minimizes backlog (Ahn et al. 2022; Hsu et al. 2018; Salari et al. 2022; Zhang et al. 2023). In contrast, facility layout design (FLD) literature has integrated F2 (Resource Transportation Cost) and F30 (Resource Requirement), as evidenced by their moderate DC values of 0.43 and 0.51, respectively. For instance, Yang and Lu (2023) demonstrated how these variables impact facility layouts

(Production Line Configuration) demonstrated moderate values in scheduling, indicating the significance of accounting for required buffer and clearance space for efficient production (Ko & Wang, 2011). Conversely, the literature reveals a significant limitation in collaborative scheduling, which often fails to consider the impact of various supply chain-related factors necessary for creating a practical schedule. For instance, there is infrequent integration of F13 (Transportation Schedules) with scheduling-based factors such as F10 and F11. The network analysis also uncovers a notable gap between F11 and F33 (Resource Energy Consumption), as existing scheduling trade-off optimization models rarely consider energy aspects. Furthermore, resource planning is conducted at a macro level without considering individual workstation needs. This disconnect is illustrated by the relationship between F30 (Resource Requirement) and F23 (Workstation Design). For example, while Al-Bazi and Dawood (2010) and Gartner et al. (2024) effectively developed methods to allocate resources to overall production lines, they didn't adequately address essential issues such as workstation space congestion and workspace clearance requirements.

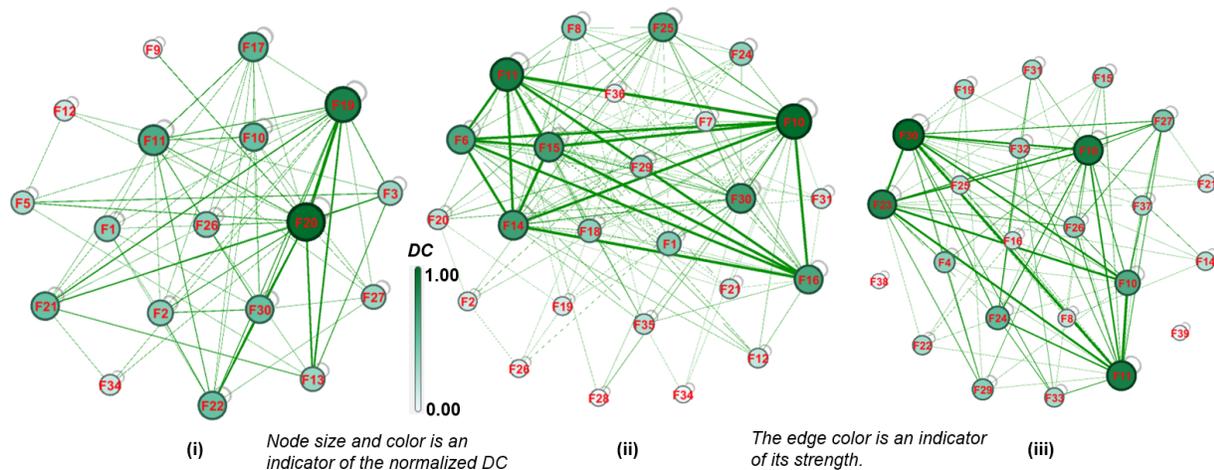


Figure 3 SNA results for (i) production logistics, (ii) production planning, and (iii) production management

3.2.3 Production management

The quantitative analysis reveals that F30 (Resource Requirement) is the most critical factor in production management, with a normalized weighted DC of 1.00. This finding emphasizes the literature's strong focus on efficiently allocating labor and equipment in managing production operations. Additionally, F23 (Workstation Design and Capacity), F18 (Module Specifications), F10 (Activity Sequencing), and F11 (Processing Time) also demonstrated high DC scores, ranging from 0.67 to 0.90 (see Figure 3(iii)). F10 and F11 are heavily utilized in all production simulation and analysis applications related to process optimization. Regarding manufacturability analysis, research has highlighted the interconnection between F23 and F18 (Khalili and Chua 2013), suggesting that a workstation's capacity should directly influence module design. Similarly, Cao et al. (2022a) developed a method that assesses a proposed module design based on immediate production efficiency. However, F18 (Module Specifications) and F23 (Material Emission) have not been incorporated into the theme of the manufacturability analysis. This reflects a significant gap in current approaches (Liu et al. 2021a), which often overlook sustainability factors such as circular economy considerations regarding recyclability and design for disassembly. Current approaches in the energy management theme have not integrated F22 (Material Handling) and F33 (Resource Energy Consumption). Although the literature has focused on quantifying resource energy consumption and emissions during production, it has largely overlooked the effects of resource transportation (Tao et al. 2018; Xu et al. 2023, 2024). This oversight fails to account for emissions and fuel consumption from moving materials, machinery, or personnel between stations and storage areas. Finally, existing ergonomic assessments typically model tasks as static instances, failing to account for their repetitive cycles within production schedules. This limitation is particularly evident in applications that lack synergy between F14 (Production Demand) and schedule factors (Wang et al., 2023). This disconnect can reduce the accuracy of ergonomic risk assessments and lead to underestimating the cumulative physical strain imposed on workers during a working shift.

4. FUTURE RESEARCH NEEDS

Building on the insights from our literature review and the results of our network analysis, several key research gaps emerge across the identified literature categories. Table 2 summarizes these gaps, outlines the future needs for addressing them, and proposes corresponding research actions to guide future studies in offsite manufacturing.

Table 2 Mapping research gaps to future needs

	Research Gaps	Future Needs	Research Actions
Production Logistics	Lack of holistic integration of raw material, resource, and information flows (e.g., shop drawings) to optimize facility layout design.	Integrated Flow Facility Design	Develop coordinated layout models synchronizing material supply, resource allocation, and information exchange.
	Inflexible layouts fail to account for congestion, collisions, or dynamic interactions of resources.	Adaptive Spatial Modeling	Use 3D simulation to incorporate spatial constraints and resource maneuverability to reduce collisions and bottlenecks.
	Traditional layouts often omit lean principles, resulting in labor and material handling inefficiencies.	Lean Facility Design	Identify and remove non-value-added tasks (e.g., excessive movement) using lean methods to streamline workflows.
	Limited environmental metrics (energy/emissions) integrated into facility design decisions.	Sustainable Design Integration	Embed eco-performance indicators (e.g., energy usage, emissions) into layout planning to foster environmentally sound operations.
Production Planning	Fragmented scheduling that fails to align internal production tasks with broader logistics, including transportation and on-site assembly.	Collaborative Scheduling Systems	Develop integrated scheduling frameworks linking factory tasks, transport schedules, and onsite demands.
	Ignoring energy usage trade-offs in scheduling, missing opportunities for cost and environmental gains.	Energy-Conscious Scheduling	Design models that balance throughput with off-peak energy usage, reducing costs and carbon footprints.
	Macro-level resource planning that overlooks workstation-level spatial constraints, causing inefficiencies and mismatched allocations	Granular Resource Allocation	Develop planning models incorporating station-specific design constraints, factoring equipment configuration, workforce competence, and varying resource demands for more accurate allocations.
Production Management	Overlooking circular economy concepts, such as recyclability and design for disassembly, in design.	Circular Production Strategies	Integrate lifecycle thinking into manufacturability, evaluating reuse and recycling to extend sustainability beyond near-term efficiency.
	Energy management often overlooks the comprehensive scope of material movement, equipment cycles, and worker logistics.	Comprehensive Energy Management Frameworks	Expand models to capture all energy factors (transport paths, equipment usage, workforce logistics) for a holistic environmental assessment.
	Treating tasks as static underestimates the risk of repetitive strain and the impact of shifting workflows, thereby undermining ergonomic evaluations.	Dynamic Ergonomic Assessment	Create real-time posture/fatigue monitoring tools to adapt workstations, reducing strain while preserving productivity.

5. CONCLUSIONS

This paper aimed to identify key decision-making factors and outline future research directions for offsite manufacturing. A systematic literature review, conducted according to PRISMA guidelines, analyzed 57 peer-reviewed articles published between 2000 and 2024 to identify operational manufacturing challenges. An inductive thematic analysis identified a comprehensive set of 39 decision factors, organizing them into seven groups: cost, time, design, logistical, environmental, lean manufacturing, and quality-related factors. Subsequent SNA mapping and quantification revealed the interrelationships among these factors, highlighting both well-studied domains and critical gaps. The analysis highlighted the under-exploration of

lean principles, sustainability, and logistical factors. Future research directions highlight guidelines for integrating these factors into MOC holistic decision-support frameworks to enhance production efficiency, reduce operational costs, and promote sustainability.

REFERENCES

- Abdul Nabi, M., and I. H. El-adaway. 2020. "Modular Construction: Determining Decision-Making Factors and Future Research Needs." *J. Manag. Eng.*, 36 (6): 04020085.
- Abotaleb, I. S., and I. H. El-adaway. 2018. "Managing Construction Projects through Dynamic Modeling: Reviewing the Existing Body of Knowledge and Deriving Future Research Directions." *J. Manag. Eng.*, 34 (6): 04018033.
- Abu Hammad, A., O. Salem, M. Hastak, and M. Syal. 2008. "Decision Support System for Manufactured Housing Facility Layout." *J. Archit. Eng.*, 14 (2): 36–46.
- Afifi, M., A. Fotouh, M. Al-Hussein, and S. Abourizk. 2022. "Integrated lean concepts and continuous/discrete-event simulation to examine productivity improvement in door assembly-line for residential buildings." *Int. J. Constr. Manag.*, 22 (13): 2423–2434.
- Ahmed, M. O., I. H. El-adaway, and A. Caldwell. 2024. "Comprehensive Understanding of Factors Impacting Competitive Construction Bidding." *J. Constr. Eng. Manag.*, 150 (4): 04024017.
- Ahn, S. J., S. Han, M. S. Altaf, and M. Al-Hussein. 2022. "Integrating off-site and on-site panelized construction schedules using fleet dispatching." *Autom. Constr.*, 137: 104201.
- Al-Bazi, A., and N. Dawood. 2010. "Developing Crew Allocation System for the Precast Industry Using Genetic Algorithms." *Comput.-Aided Civ. Infrastruct. Eng.*, 25 (8): 581–595.
- Arashpour, M., R. Wakefield, N. Blismas, and T. Maqsood. 2015. "Autonomous production tracking for augmenting output in off-site construction." *Autom. Constr.*, 53: 13–21.
- Assaad, R., and I. H. El-adaway. 2020. "Enhancing the Knowledge of Construction Business Failure: A Social Network Analysis Approach." *J. Constr. Eng. Manag.*, 146 (6): 04020052.
- Assaf, S., F. Alsakka, M. Darwish, and M. Al-Hussein. 2024. "Simulation-Based Analysis of a Precast Factory Layout to Reduce Labor Travel Time and Production Time." 1087–1096.
- Attouri, E., Z. Lafhaj, L. Ducoulombier, and B. Linéatte. 2022. "Development of decision-making tool for construction method selection: choosing and optimizing offsite construction." *Modul. Offsite Constr. MOC Summit Proc.*, 25–33.
- Ayinla, K., F. Cheung, and M. Skitmore. 2022. "Process Waste Analysis for Offsite Production Methods for House Construction: A Case Study of Factory Wall Panel Production." *J. Constr. Eng. Manag.*, 148 (1): 05021011.
- Banerjee, D., M. Syal, and M. Hastak. 2006. "Material Flow-Based Facility Layout Analysis of a Manufactured Housing Production Plant." *J. Archit. Eng.*, 12 (4): 196–206.
- Barkokebas, B., P. Martinez, A. Bouferguene, F. Hamzeh, and M. Al-Hussein. 2023. "Digitalization-based process improvement and decision-making in offsite construction." *Autom. Constr.*, 155: 105052.
- Benjaoran, V., N. Dawood, and B. Hobbs. 2005. "Flowshop scheduling model for bespoke precast concrete production planning." *Constr. Manag. Econ.*, 23 (1): 93–105.
- Bhatia, A. P. S., S. Han, and O. Moselhi. 2022. "A simulation-based statistical method for planning modular construction manufacturing." *J. Inf. Technol. Constr.*, 27: 130–144.
- Blismas, N., C. Pasquire, and A. Gibb. 2006. "Benefit evaluation for off-site production in construction." *Constr. Manag. Econ.*, 24 (2): 121–130.
- Cao, J., E. Vakaj, R. K. Soman, and D. M. Hall. 2022a. "Ontology-based manufacturability analysis automation for industrialized construction." *Autom. Constr.*, 139: 104277.
- Cao, J., P. Zhao, and G. Liu. 2022b. "Optimizing the production process of modular construction using an assembly line-integrated supermarket." *Autom. Constr.*, 142: 104495.
- Chen, C., D. Tran Huy, L. K. Tiong, I.-M. Chen, and Y. Cai. 2019. "Optimal facility layout planning for AGV-based modular prefabricated manufacturing system." *Autom. Constr.*, 98: 310–321.
- Cheung, S.-O., T. K.-L. Tong, and C.-M. Tam. 2002. "Site pre-cast yard layout arrangement through genetic algorithms." *Autom. Constr.*, 11 (1): 35–46.
- Chippagiri, R., D. Biswal, S. Mandavgane, A. Bras, and R. Ralegaonkar. 2023. "Life Cycle Assessment of a Sustainable Prefabricated Housing System: A Cradle-to-Site Approach Based on a Small-Scale Experimental Model." *Buildings*, 13 (4): 964.

- Daget, Y. T., and H. Zhang. 2019. "Decision-making model for the evaluation of industrialized housing systems in Ethiopia." *Eng. Constr. Archit. Manag.*, 27 (1): 296–320.
- Du, Q., T. Bao, Y. Li, Y. Huang, and L. Shao. 2019. "Impact of prefabrication technology on the cradle-to-site CO2 emissions of residential buildings." *Clean Technol. Environ. Policy*, 21 (7): 1499–1514.
- Gartner, M. A., W. Grenzfurtner, B. Zauner, and M. Gronalt. 2024. "Job and product rotation for maximising the production output on multi mixed-model assembly lines for element prefabrication in industrialised housebuilding." *Comput. Ind. Eng.*, 190: 110041.
- Han, S. H., M. Al-Hussein, S. Al-Jibouri, and H. Yu. 2012. "Automated post-simulation visualization of modular building production assembly line." *Autom. Constr.*, 21: 229–236.
- Hosseini, M. R., M. Maghrebi, A. Akbarnezhad, I. Martek, and M. Arashpour. 2018. "Analysis of Citation Networks in Building Information Modeling Research." *J. Constr. Eng. Manag.*, 144 (8): 04018064.
- Hsu, P.-Y., P. Angeloudis, and M. Aurisicchio. 2018. "Optimal logistics planning for modular construction using two-stage stochastic programming." *Autom. Constr.*, 94: 47–61.
- Hsu, P.-Y., M. Aurisicchio, and P. Angeloudis. 2019. "Risk-averse supply chain for modular construction projects." *Autom. Constr.*, 106: 102898.
- Hussein, M., A. E. E. Eltoukhy, A. Karam, I. A. Shaban, and T. Zayed. 2021. "Modelling in off-site construction supply chain management: A review and future directions for sustainable modular integrated construction." *J. Clean. Prod.*, 310: 127503.
- Hyun, H., I. Yoon, H.-S. Lee, M. Park, and J. Lee. 2021. "Multiobjective optimization for modular unit production lines focusing on crew allocation and production performance." *Autom. Constr.*, 125.
- Khalili, A., and D. K. H. Chua. 2013. "IFC-Based Framework to Move beyond Individual Building Elements toward Configuring a Higher Level of Prefabrication." *J. Comput. Civ. Eng.*, 27 (3): 243–253.
- Kim, T., Y. Kim, and H. Cho. 2020. "Dynamic production scheduling model under due date uncertainty in precast concrete construction." *J. Clean. Prod.*, 257: 120527.
- Ko, C.-H., and S.-F. Wang. 2011. "Precast production scheduling using multi-objective genetic algorithms." *Expert Syst. Appl.*, 38 (7): 8293–8302.
- Lachance, E., N. Lehoux, and P. Blanchet. 2023. "A Simulation Model to Analyze Different Automation Scenarios in a Mixed-Assembly Manufacturing Line: Timber-Frame Prefabrication Industry." *J. Constr. Eng. Manag.*, 149 (10): 04023091.
- Lee, J., M. Park, H.-S. Lee, T. Kim, S. Kim, and H. Hyun. 2017. "Workflow dependency approach for modular building construction manufacturing process using Dependency Structure Matrix (DSM)." *KSCE J. Civ. Eng.*, 21 (5): 1525–1535.
- Li, X., S. Han, M. Gül, and M. Al-Hussein. 2019. "Automated post-3D visualization ergonomic analysis system for rapid workplace design in modular construction." *Autom. Constr.*, 98: 160–174.
- Li, X., Z. Li, and G. Wu. 2018. "Lean Precast Production System based on the CONWIP Method." *KSCE J. Civ. Eng.*, 22 (7): 2167–2177. <https://doi.org/10.1007/s12205-017-2009-4>.
- Liang, J., Z. Cao, Q. Zu, H. Huang, and S. Guo. 2024. "Production Sequencing and Layout Optimization of Precast Concrete Components under Mold Resource Constraints." *Buildings*, 14 (10): 3173. Multidisciplinary Digital Publishing Institute. <https://doi.org/10.3390/buildings14103173>.
- Liu, H., Y. Zhang, Z. Lei, H. X. Li, and S. Han. 2021a. "Design for Manufacturing and Assembly: A BIM-Enabled Generative Framework for Building Panelization Design." *Adv. Civ. Eng.*, 2021: e5554551.
- Liu, Z., Z. Liu, M. Liu, and J. Wang. 2021b. "Optimization of Flow Shop Scheduling in Precast Concrete Component Production via Mixed-Integer Linear Programming." *Adv. Civ. Eng.*, 2021: e6637248.
- Malik, N., R. Ahmad, and M. Al-Hussein. 2019. "Generation of safe tool-paths for automatic manufacturing of light gauge steel panels in residential construction." *Autom. Constr.*, 98: 46–60.
- Malik, N., R. Ahmad, Y. Chen, M. S. Altaf, and M. Al-Hussein. 2021. "Minimizing joist cutting waste through dynamic waste allocation in panelized floor manufacturing." *Int. J. Constr. Manag.*, 21 (10): 1011–1023.
- Martinez, P., M. Al-Hussein, and R. Ahmad. 2020a. "Intelligent vision-based online inspection system of screw-fastening operations in light-gauge steel frame manufacturing." *Int. J. Adv. Manuf. Technol.*, 109 (3): 645–657.
- Martinez, P., M. Livojevic, P. Jajal, D. R. Aldrich, M. Al-Hussein, and R. Ahmad. 2020b. "Simulation-Driven Design of Wood Framing Support Systems for Off-Site Construction Machinery." *J. Constr. Eng. Manag.*, 146 (7): 04020075.
- Mehrotra, N., M. Syal, and M. Hastak. 2005. "Manufactured Housing Production Layout Design." *J. Archit. Eng.*, 11 (1): 25–34.

- Nam, S., D. Lee, B. Cho, and K. Kim. 2019. "Integrated Management Software for Factory Production of Modular Buildings." *Adv. Civ. Eng.*, 2019: e7693459.
- Nam, S., J. Yoon, K. Kim, and B. Choi. 2020. "Optimization of Prefabricated Components in Housing Modular Construction." *Sustainability*, 12 (24): 10269.
- Nasereddin, M., M. A. Mullens, and D. Cope. 2007. "Automated simulator development: A strategy for modeling modular housing production." *Autom. Constr.*, 16 (2): 212–223.
- Nasirian, A., M. Arashpour, B. Abbasi, and A. Akbarnezhad. 2019. "Optimal Work Assignment to Multiskilled Resources in Prefabricated Construction." *J. Constr. Eng. Manag.*, 145 (4): 04019011.
- Orlowski, K. 2019. "Assessment of Manufacturing Processes for Automated Timber-Based Panelised Prefabrication." *Buildings*, 9 (5): 125.
- Otte, E., and R. Rousseau. 2002. "Social network analysis: a powerful strategy, also for the information sciences." *J. Inf. Sci.*, 28 (6): 441–453.
- Pan, W., and C. Goodier. 2012. "House-Building Business Models and Off-Site Construction Take-Up." *J. Archit. Eng.*, 18 (2): 84–93.
- Salari, S. A.-S., H. Mahmoudi, A. Aghsami, F. Jolai, S. Jolai, and M. Yazdani. 2022. "Off-Site Construction Three-Echelon Supply Chain Management with Stochastic Constraints: A Modelling Approach." *Buildings*, 12 (2): 119.
- Tao, X., C. Mao, F. Xie, G. Liu, and P. Xu. 2018. "Greenhouse gas emission monitoring system for manufacturing prefabricated components." *Autom. Constr.*, 93: 361–374.
- Tavares, V., N. Lacerda, and F. Freire. 2019. "Embodied energy and greenhouse gas emissions analysis of a prefabricated modular house: The 'Moby' case study." *J. Clean. Prod.*, 212: 1044–1053.
- Wang, D., G. Liu, K. Li, T. Wang, A. Shrestha, I. Martek, and X. Tao. 2018a. "Layout Optimization Model for the Production Planning of Precast Concrete Building Components." *Sustainability*, 10 (6): 1807.
- Wang, J., S. Han, and X. Li. 2021. "3D fuzzy ergonomic analysis for rapid workplace design and modification in construction." *Autom. Constr.*, 123: 103521.
- Wang, J., Y. Mohamed, S. Han, X. Li, and M. Al-Hussein. 2023. "3D ergonomics-based motion-level productivity analysis for intelligent manufacturing in industrialized construction." *Can. J. Civ. Eng.*, 50 (3): 197–209.
- Wang, Z., and H. Hu. 2017. "Improved Precast Production–Scheduling Model Considering the Whole Supply Chain." *J. Comput. Civ. Eng.*, 31 (4): 04017013.
- Wang, Z., and H. Hu. 2018. "Dynamic response to demand variability for precast production rescheduling with multiple lines." *Int. J. Prod. Res.*, 56 (16): 5386–5401.
- Wang, Z., H. Hu, J. Gong, and X. Ma. 2018b. "Synchronizing production scheduling with resources allocation for precast components in a multi-agent system environment." *J. Manuf. Syst.*, 49.
- Wei, Y., Z. Lei, and M. S. Altaf. 2024. "Simulation-based comparison of push- and pull-based planning in panelized construction." *Autom. Constr.*, 158: 105228.
- Xie, Y., H. Wang, G. Liu, and H. Lu. 2023. "Just-in-Time Precast Production Scheduling Using Dominance Rule-Based Genetic Algorithm." *IEEE Trans. Neural Netw. Learn. Syst.*, 34 (9): 5283–5297.
- Xu, A., Y. Zhu, and Z. Wang. 2024. "Carbon emission evaluation of eight different prefabricated components during the materialization stage." *J. Build. Eng.*, 89: 109262.
- Xu, A., Y. Zhu, Z. Wang, and Y. Zhao. 2023. "Carbon emission calculation of prefabricated concrete composite slabs during the production and construction stages." *J. Build. Eng.*, 80: 107936.
- Xu, Z., S. Wang, and E. Wang. 2019. "Integration of BIM and Energy Consumption Modelling for Manufacturing Prefabricated Components: A Case Study in China." *Adv. Civ. Eng.*, 2019.
- Yang, Z., and W. Lu. 2023. "Facility layout design for modular construction manufacturing: A comparison based on simulation and optimization." *Autom. Constr.*, 147: 104713.
- Yin, S. Y. L., H. P. Tserng, J. C. Wang, and S. C. Tsai. 2009. "Developing a precast production management system using RFID technology." *Autom. Constr.*, 18 (5): 677–691.
- Zaalouk, A., S. Moon, and S. Han. 2023. "Operations planning and scheduling in off-site construction supply chain management: Scope definition and future directions." *Autom. Constr.*, 153: 104952.
- Zhang, W., C. Yu, and R. Y. Zhong. 2023. "Stability measure for prefab balancing in prefabrication construction supply chain management." *Comput. Ind. Eng.*, 183: 109518.