Sobh, D., Shehab, L., & Hamzeh, F. (2026). Workforce readiness: the need for a competency framework in off-site construction to support Lean transformation. In F. Hamzeh, M. Poshdar, N. P. Garcia-Lopez, & V. Gan (Eds.), *Proceedings of the 34th Annual Conference of the International Group for Lean Construction* (IGLC34) (pp. 1052–1063). https://doi.org/10.24928/2026/0167

WORKFORCE READINESS: THE NEED FOR A COMPETENCY FRAMEWORK IN OFF-SITE CONSTRUCTION TO SUPPORT LEAN TRANSFORMATION

Dana Sobh[1], Lynn Shehab[2], & Farook Hamzeh[3]

ABSTRACT

Off-site Construction (OSC) has shifted the work from traditional sites to more controlled production environments. However, lean implementation in OSC remains restricted because workforce readiness is often addressed through trades or stand-alone skills rather than as a combination of integrated competencies that enable lean practices and impact performance. Furthermore, existing research on OSC workforce development remains fragmented and offers limited guidance on how workforce capabilities support lean transformation. This study presents a conceptual literature review that examines how workforce competencies are currently framed within OSC, and identifies gaps in how those competencies are defined and structured. Building on this analysis, the research proposes a competency framework that positions workforce capabilities as socio-technical enablers of lean practices in OSC. The framework organizes competencies into four themes: Knowledge, Skills, Abilities, and Other Characteristics, and is embedded within the Toyota Production System (TPS). To demonstrate its applicability, the competencies are identified as primary or secondary enablers of four commonly used lean tools: 5S, Last Planner System (LPS), 5 Whys, and Value Stream Mapping (VSM). The study contributes to the understanding of workforce readiness in OSC and serves as the foundation for future empirical research on competency development and understanding its impact on performance.

KEYWORDS

Off-site construction, workforce competencies, Lean implementation, KSAO.

INTRODUCTION

Off-site construction (OSC), also known as prefabrication or construction manufacturing, represents the industrialization of the construction industry. OSC is the process in which the majority of site-based construction operations are performed in a factory (Alsakka et al., 2023; Choi et al., 2019). This shift toward industrialized production has been widely associated with a range of benefits that impact performance. OSC addresses several industry challenges, including time inefficiency, high costs, and worker safety. OSC is an effective solution to increase production speed and minimize quality issues (Ofori-Kuragu et al., 2022). A recent

[1] PhD Student, Civil and Environmental Engineering, University of Alberta, Edmonton, Canada, dsobh@ualberta.ca, orcid.org/0009-0004-2609-054X

[2] Assistant Professor, Civil and Environmental Engineering, University of Alberta, Edmonton, Canada, lshehab@ualberta.ca, orcid.org/0000-0002-2708-3550

[3] Professor, Civil and Environmental Engineering, University of Alberta, Edmonton, Canada, hamzeh@ualberta.ca, orcid.org/0000-0002-3986-9534

report by the Modular Building Institute (2025) indicates that offsite construction can reduce costs and environmental impacts, while also accelerating project timelines, improving quality oversight, and enhancing safety.

Many technological advancements have been introduced to the OSC industry with the aim of improving efficiency and quality. These technologies include Building Information Modelling (BIM), Extended Reality (XR), smart sensors, and robotics (Assaad, El-Adaway, et al., 2022; Hedayati et al., 2025). For example, BIM can improve communication and information management (Sarvari et al., 2020), AI-driven Digital Twins allow for dynamic scheduling and real-time quality control (Najafzadeh & Yeganeh, 2025), and Virtual Reality (VR) is an effective educational tool for OSC training (Joshi et al., 2021) and can also be used as a feasible tool for productivity and ergonomic assessments (Inyang et al., 2012). As a result, with the increase in adoption of these tools, new challenges are introduced to the industry, including requiring a workforce that is equipped with new and more advanced competencies.

Technological advancements are increasingly being integrated in OSC, however, questions remain regarding workforce readiness. Our current understanding of workforce capabilities remains largely rooted in traditional paradigms. OSC requires skillsets that differ from those associated with traditional onsite construction, and with the adoption of Industry 4.0 technologies in OSC, this imposes additional challenges on the workforce and increases the demand for advanced competencies. Assaad et al. (2022) administered a survey and conducted interviews to determine the impact of OSC on the workforce and found that OSC involves upskilling the workforce rather than reskilling them, with trades related to assembly, fabrication, and production being among the occupations that are most impacted by OSC. When it comes to technological change, Ginigaddara et al. (2022) identified a shift in skill requirements between onsite and offsite construction, highlighting the need to develop new skills specific to OSC. Similarly, Lattuga and Ginigaddara (2025) demonstrated that OSC shifts work away from traditional construction toward digitally driven manufacturing processes, requiring upskilling of critical trades (carpenters and joiners, electricians, plumbers, HVAC technicians, and metal workers) to accommodate technologically driven processes. Workforce skills continue to lag behind technological advancements despite playing a critical role in project outcomes.

While technological advancements are rapidly transforming OSC processes, the effectiveness of these innovations ultimately depends on the capabilities of the workforce implementing them. The construction industry is a labor-intensive industry, and labor skills have been continuously cited as a factor that impacts productivity. A lack of skilled labor would have a negative impact on completion time, cost, and quality (Alinaitwe et al., 2007). A review by Hasan et al. (2018) on factors impacting construction productivity from 1989 to 2016 identified "skill shortage" as a highly cited factor. Similarly, Assaf et al. (2025) conducted a scoping review on the factors that affect OSC and identified 38 factors grouped into seven categories. Of relevance to this study are the vocational factors such as "training", "multiskilling", and "skillset"; social factors such as "communication", "coordination", and "collaboration"; and intellectual factors such as "learning ability." These factors reiterate the role of both hard and soft skills in enhancing productivity in OSC. In addition, Assaad et al. (2023) held panel discussions with industry experts, administered surveys, and identified "labor skills" and "proper workforce training and development" as one of the main factors affecting labor productivity. Moreover, Alsakka et al. (2023) investigated the factors that influence cycle times in OSC and categorized them into eight classes. Within the "worker" class—a human-centric class—one of the factors identified was the "learning curve." These studies emphasized the role skills play in impacting productivity.

Beyond general productivity considerations, workforce competencies are also central to the successful implementation of structured process-improvement philosophies such as lean construction. Lean is not merely a collection of tools, but a dynamic interaction between

technical methodologies and social elements. Effective implementation of lean in construction requires the adoption of lean tools aligned with specific processes. However, these tools must be supported by a culture that fosters adaptability, shared responsibility, and innovation. Research indicates that organizations with strong lean cultures, that support collaboration and continuous learning, are more successful in realizing Lean's full potential than those relying solely on isolated technical tools (Kallassy & Hamzeh, 2021; Romo et al., 2025)

Achieving a true lean transformation remains a socio-technological challenge that relies on the alignment of advanced OSC systems and workforce readiness. Lean maturity cannot be achieved through technological adoption alone; it requires a workforce equipped with specific competencies to identify waste, maintain standardized work, and accept the culture of change. Existing literature shows that these competencies are critical prerequisites for the implementation of lean construction. Gao et al. (2023) found that cognitive, social, and continuous improvement competencies influence lean maturity and safety performance. Knowledge, communication skills, critical thinking, teamwork, and having a positive attitude are human capacities that enable lean (Ranadewa et al., 2021).

Despite the recognized importance of workforce competencies for lean success, existing studies tend to examine skills in isolation, without offering an integrated perspective on how prepared the workforce is to engage with Lean principles in OSC environments. This lack of an integrated view of workforce preparedness makes it difficult to assess or develop the capabilities required for effective lean implementation. Therefore, this study addresses the following research questions: (1) What competencies enable lean implementation in OSC? (2) How are there competencies currently conceptualized in the existing literature? (3) How can these competencies be structured into a coherent framework to support workforce readiness for lean implementation in OSC? The study aims to develop a conceptual Lean Workforce Readiness Framework that is oriented toward lean implementation in OSC. The proposed framework is intended to support both researchers in advancing competency-based studies and industry practitioners in guiding the workforce development and lean implementation efforts.

METHODOLOGY

To examine workforce competencies in OSC and address workforce readiness for lean implementation, this study follows the design science research (DSR) methodology. DSR is used because the goal is to design and structure an artifact that addresses an identified practical problem (Hevner et al., 2004). Common stages in DSR include problem identification and motivation, objective definition, artifact development, demonstration, and evaluation (Peffers et al., 2007). This approach has been previously applied in OSC and lean research to develop frameworks that support implementation and decision-making (e.g., Barkokebas et al. (2021)).

Following the DSR logic, the study consists of three key steps: (1) Problem identification and needs analysis, (2) Development of a workforce readiness competency framework that supports lean implementation, and (3) Evaluation through mapping the framework to lean tools. First, a conceptual review was conducted to investigate previous studies on knowledge, skills, and abilities required for OSC within existing literature. The review utilized the Scopus database and included combinations of keywords such as "off-site construction," "prefabrication," "skills," "competencies," and "workforce." The review targeted peer-reviewed articles and conference proceedings, and studies were included based on their relevance to competencies and OSC. The screening process involved an initial review of titles and abstracts, followed by a full-text assessment of relevant papers. This analysis was conducted to examine how competencies are discussed and to identify prevalent themes, inconsistencies, and research gaps. Second, the insights from the review were synthesized to develop a human-centered framework that positions the worker at the core of lean implementation in OSC environments. To achieve this, competencies were categorized based

on their inherent nature, informed by established definitions from recognized occupational frameworks. The framework organizes capacities into themes and reflects on how workforce development is a big part of the lean philosophy. Lastly, the proposed framework was conceptually mapped to popular lean tools to examine how workforce capabilities can enable lean transformation within OSC. The mapping was conducted using deductive reasoning, where the functional requirements of specific lean tools (5S, 5 Whys, Last Planner System (LPS), and Value Stream Mapping (VSM)) were cross-referenced with identified workforce competencies.

LITERATURE SYNTHESIS AND PROBLEM IDENTIFICATION

To transition from a fragmented landscape of 'skills' and 'trades' toward a socio-technical framework, relevant literature was synthesized. Through a qualitative analysis of the literature, three observations became clear: (1) there is no clear terminology regarding competencies and skills, (2) there is limited research on workforce capabilities in OSC, and (3) existing competency models reveal recurring themes and competency dimensions that can be adapted into a coherent structure for OSC. The combination of these observations formed the basis of the proposed Lean Workforce Readiness Framework that was later developed.

FRAGMENTED TERMINOLOGY

As observed in the literature review, the majority of studies mention the term 'skills' without a clear outline of what that means. 'Skills' are defined differently across the literature. The Occupational Information Network (O*NET) – a comprehensive database of occupations – defines 'skills' as "*...developed capacities that facilitate learning or the more rapid acquisition of knowledge*" (O*NET Resource Center, n.d.). In contrast, the Organization for Economic Co-operation and Development (OECD) – an international organization that aims to establish international standards – defines 'skills' as "*...the ability and capacity to carry out processes and to be able to use one's knowledge in a responsible way to achieve a goal"*(OECD, 2019).

When it comes to studies within OSC, this ambiguity persists. Some papers consider skills as a broad set of hard and soft capabilities (e.g., Siriwardhana and Moehler (2023)) ,while others conflate specific occupations with the skills themselves, treating roles such as "assembler" or "operator" as functional skill sets, as seen in Ginigaddara et al. (2022). Moreover, the majority of the OSC literature lumps distinct abilities and personal attributes under a generic "skills" umbrella. For example, Alhloul and Kiss (2022) classified "creativity" as a methodological skill, whereas according to O*NET it is classified as a "cognitive ability." Similarly, the authors categorized "flexibility" and "motivation to learn" as personal skills, when these are more accurately classified as characteristics since they are related to personality traits and work styles.

There is no universal definition that is utilized by all, and this creates an issue across the literature. Thus, the need for a more consistent competency framework becomes more appealing.

SCARCITY OF HUMAN-CENTERED RESEARCH

Despite the important role of competencies, there are limited studies that empirically examine specific workforce requirements in OSC. In many cases, these requirements are implied rather than being explicitly stated and defined. For example, certain researchers empirically derived the skills through observations and unstructured interviews, such as the studies conducted by Jørsfeldt et al. (2024) and Adepoju and Aigbavboa (2021). In contrast, other researchers indirectly inferred them, as seen in the work of Mohsen et al. (2019), where the main objective of their study was to determine the factors that may contribute to enhancing skilled worker requirements in Industrialized Building System. Moreover, a common occurrence across the literature is that studies mention 'skills' in a general sense, but do not delve deep into the specifics regarding which particular skills are relevant or critical for a specific trade.

WORKFORCE COMPETENCY MODELS

There have been multiple competency models generated across diverse disciplines to identify workforce capabilities, with each model emphasizing different aspects of performance. A review of these models reveals an alignment around a common set of competency dimensions. For example, the KSAO model defines competency based on four components: Knowledge, Skills, Abilities, and Other Characteristics that impact performance on a job (Mirabile, 1997). Similarly, the Iceberg Model (Spencer & Spencer, 1993), categorizes competencies into visible ones which include knowledge and skills, as well as hidden ones such as traits, motives, and self-concepts. On the other hand, Bartram (2005) developed The Great Eight, a model that focuses on general job performance and has a behaviorally oriented approach.

Although these models were developed across different fields, there is a consistent underlying structure in how workforce competencies are conceptualized. These models group capabilities into distinct dimensions, including knowledge, applied skills, social skills, cognitive abilities, physical abilities, and personal traits. However, none of these models have been explicitly adapted and developed within OSC environments or linked to lean tools.

LEAN WORKFORCE READINESS FRAMEWORK

The proposed Lean Workforce Readiness Framework organizes workforce competencies using the KSAO structure. These categories were used to systematically organize competencies identified in the literature into a coherent and structured framework, informed by established definitions from O*NET. The KSAO wheel provides a structure for organizing competencies into four groups. **Knowledge** refers to domain-specific information. It includes understanding procedures, processes, quality requirements, safety standards, and lean principles. **Skills** are trainable capacities and the application of knowledge. These learned proficiencies can be practiced and trained. Skills can also be technical, such as assembly, material handling, or using digital tools, but can also be cognitive skills, such as problem solving, or even social skills, such as collaboration. **Abilities** are innate attributes that can be cognitive, such as deductive reasoning, or physical, such as dexterity. **Other Characteristics** include preferences and work styles, such as motivation, adaptability, and willingness to learn.

The classification of workforce competencies is dynamic and flexible. It is not intended to represent a fixed or exhaustive set of competencies, but rather a flexible structure that can be further updated and refined through future empirical research for specific OSC trades.

Figure 1: KSAO-based representation of workforce readiness

While the KSAO structure provides a way to organize workforce competencies, understanding their role in lean implementation requires situating them within an established lean system. As such, the proposed framework integrates KSAO within the Toyota Production System (TPS). This provides an organizing structure for applying lean principles.

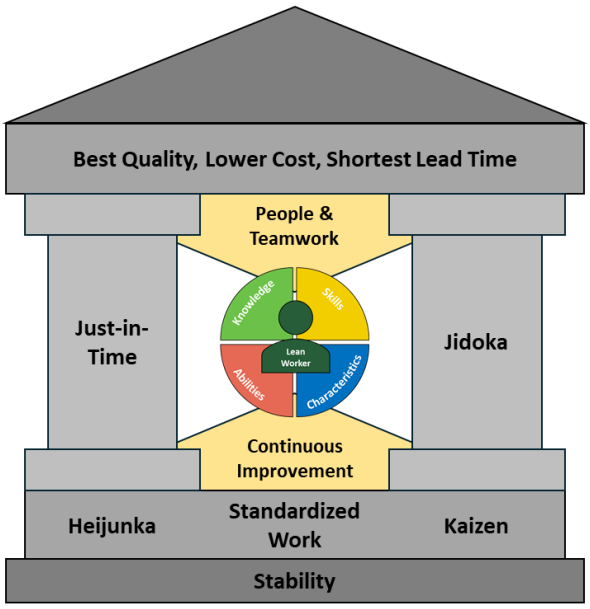

Figure 2: Positioning workforce readiness within the Toyota Production System

Lean philosophy emphasizes 'respect for people' by empowering the workforce, involving front-line workers, developing capabilities, and enabling continuous improvement. Within the TPS house, 'People and Teamwork' are at the center of the system, which emphasizes the role of human capabilities in sustaining lean practices. Building on this principle, workforce readiness in OSC is conceptualized in this study as an enabler of lean implementation.

MAPPING COMPETENCIES TO LEAN TOOLS

This study focuses on four commonly used lean tools to demonstrate how workforce competencies can play an effective role in the adoption of lean philosophy and support lean implementation. The classification of competencies as primary or supporting enablers is based on their relative emphasis in the literature. Within this analysis, a competency is considered to be a primary enabler if it is essential for the effective and sustainable implementation of a given lean tool. On the other hand, it is considered a supporting enabler if it strengthens the implementation of the lean tool, but is not strictly required for it to effectively function. The relationships between the lean tools and the workforce competencies are conceptually derived from the literature through qualitative synthesis.

Table 1: Competency-Lean map

Lean Tools	Competencies			
	Knowledge	Skills	Abilities	Other Characteristics
5S	●	●	○	●
LPS	●	●	●	●
5 Whys	○	●	○	●
VSM	●	●	●	○

● = Primary enabler ○ = Supporting enabler

5S

The 5S tool is an organization method that consists of 5 elements (Sort, Set in Order, Shine, Standardize, and Sustain), with the goal of improving efficiency and quality (Sui-PPheng &

Danielle Khoo, 2001). The 5S involves decluttering the workspace, having a dedicated place for everything, regular cleaning and inspection, maintaining consistency to sustain improvements, and building discipline and culture through habit.

Within the proposed framework, knowledge, skills, and other characteristics are considered primary enablers of 5S. Knowledge of lean principles, operating procedures, and quality criteria ensures that employees understand 5S principles and procedures and can implement them. This enables correct sorting, organizing, cleaning, and standardizing of workspaces, materials, and tools, and sustains workplace improvements. Skills related to task execution and tool operation are essential for standardizing work and ensuring the worker's ability to use tools and maintain consistency in daily activities. Furthermore, other characteristics such as discipline and responsibility are essential for sustaining 5S activities over time and embedding them into daily routines (Fardhosseini et al., 2021). 5S primarily depends on adherence to standards and consistent behavior rather than high levels of cognitive or physical exertion.

LAST PLANNER SYSTEM (LPS)

LPS is a production planning and control approach that reduces variation in workflow, improves planning reliability, and minimizes uncertainty in construction operations (Hamzeh et al., 2012). LPS achieves this by developing a plan that progresses in detail as execution approaches while also emphasizing task readiness and reliable handoffs (Agrawal et al., 2024).

Competencies, such as knowledge, skills, abilities, and other characteristics, are essential for implementing the LPS. The lack of LPS Knowledge can hinder implementation (Murguia, 2019). When it comes to trade workers in OSC, it is important that they understand task requirements, task sequencing, and process constraints. Soft skills such as communication and collaboration are vital among team members and are key factors that influence LPS (AlSehaimi et al., 2014; Murguia, 2019). Sharing information efficiently and accurately is important for the success of the Weekly Work Plan (WWP) (AlSehaimi et al., 2014). When it comes to cognitive abilities, problem sensitivity and reasoning play a role in enabling workers to anticipate constraints, assess readiness, and understand how things are interrelated. Personal Attributes such as accountability, commitment, and openness to change are critical attributes when it comes to honoring commitments, maintaining trust, and having the willingness to adopt LPS practices. Overall, these competencies collectively enhance coordination, planning accuracy, and productivity in construction projects using LPS.

5 WHYS

Repeating "Why" five times is a root-cause problem analysis tool that was developed by Ohno to uncover root problems and resolve them (Ohno, 1988). The 5 Whys is a simple yet powerful tool that eliminates waste and improves quality (Ohno, 1988).

Within the proposed framework, soft skills, cognitive skills, and personal attributes are identified as primary enablers of the 5 Whys. Soft skills such as communication and teamwork are essential to facilitate the iterative questioning process and improve collaboration across stakeholders. Cognitive skills such as critical thinking and systems thinking enable individuals to identify the root cause of a problem rather than focus on surface-level symptoms and subsequently reach premature conclusions. Personal attributes such as persistence and openness to feedback support a thorough understanding of the problem without jumping to conclusions. Being knowledgeable and having technical expertise play a supporting role in the implementation of the 5 Whys. Domain knowledge can inform the development of countermeasures. Thus, effective application of 5 Whys depends on reasoning ability, problem-solving skills, and interpersonal skills.

VALUE STREAM MAPPING (VSM)

Value Stream Mapping (VSM) is a lean tool that is used to visualize and understand the flow of material and information as a product or service makes its way across all the activities required for completion (Rother & Shook, 1999). The main goal of the VSM is to identify and eliminate waste from a process.

Within the proposed framework, knowledge, skills, and abilities are identified as primary enablers of VSM. Knowledge of production processes, task sequencing, and flow concepts is essential to develop the current-state map. Insufficient knowledge could result in a misleading or incomplete representation of the value stream. As for skills, communication and collaboration are relevant for the effective implementation of the VSM. In order for the VSM to reflect the current-map, it relies on the involvement of multiple stakeholders and effective information exchange. Moreover, cognitive abilities related to pattern recognition and inductive reasoning are essential for identifying sources of waste, differentiating value-adding from non-value-adding activities, and understanding cause-and-effect relationships. VSM is supported by personality traits such as willingness to learn and ability to change when it comes to achieving the future-state map. These characteristics strengthen the implementation of the VSM, but are not strictly required to perform the mapping itself.

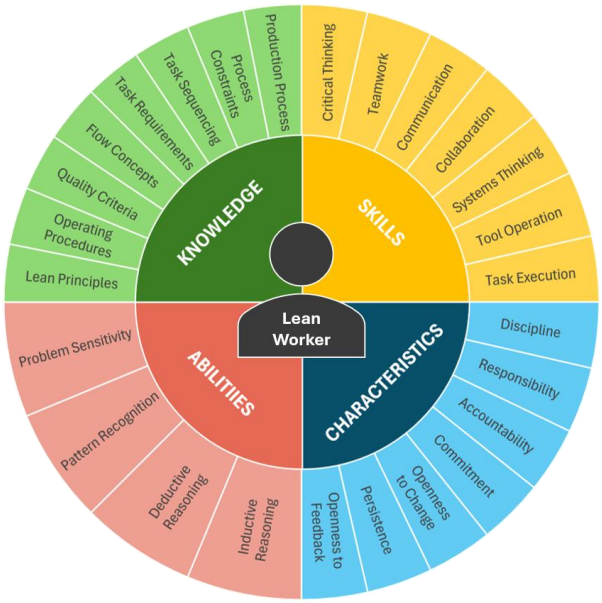

Figure 3: Preliminary Lean worker competencies for Lean implementation

DISCUSSION

The proposed Lean Workforce Readiness Framework responds to a practical challenge observed across OSC and lean implementation. Organizations may invest in advanced systems and lean tools, yet still struggle to achieve sustained performance and improvements if workforce capability is taken for granted rather than explicitly defined and developed. This study reinforces that lean implementation in OSC is not solely a technical or procedural effort, but a socio-technical process in which workforce readiness plays a central role.

Taylor (2016) highlights that OSC offers favorable conditions for workforce development compared to on-site work. However, in the absence of a clear competency framework, this raises fundamental questions for workforce development in OSC: *what specific competencies should be developed for a given role? What framework would be adopted? How should training efforts be structured to support lean implementation?* Without a structured approach to defining workforce competencies, training initiatives risk remaining misaligned with lean objectives.

The proposed framework organizes workforce readiness using the KSAO structure and links these competencies to lean tools. What differentiates this framework is that it moves away from a narrow focus on trades or technical skills and instead emphasizes a broader competency profile that encompasses social skills, abilities, and characteristics. While knowledge and technical skills are important and may be acquired through traditional education, many soft skills and abilities related to lean implementation can be developed through targeted training. Emerging empirical research supports the importance of such abilities in construction contexts. For example, Shehab et al. (2026) demonstrated the influence of four cognitive abilities on performance, and Eltahan et al. (2025) established the impact of task complexity on cognitive load. Thus, identifying which competencies matter for specific jobs is essential for designing effective workforce development strategies in OSC.

The findings also highlight a gap in lean implementation. When lean tools are put in place as procedures without adequate workforce readiness, organizations risk superficial adoption and stagnant performance. Building on that, workforce competencies can be viewed as a mediating factor between lean tools and implementation outcomes. Without appropriate competencies in place, lean tools may fail to deliver their intended benefits. This aligns with prior studies that have demonstrated the importance of competencies in enabling lean implementation (Ranadewa et al., 2021) and impacting project performance (Gao et al., 2023).

While this study conceptualizes competencies as enablers of lean implementation, the relationship is arguably bidirectional. Lean tools and practices inherently contribute to workforce development over time. For example, lean environments often utilize “multi-skilling” or cross-training to create a more flexible workforce. Furthermore, the lean philosophy prioritizes worker empowerment such as allowing them to stop the line, suggest improvements to a process, and involves them directly in collaborative planning through systems like the Last Planner System. While specific competencies can be considered as prerequisites for successful lean adoption, the rigorous application of lean principles can simultaneously serve as a catalyst for ongoing workforce development. However, these mechanisms are contingent on the presence of supportive leadership and an empowering organizational culture; without them, the impact of both competencies and lean practices may be significantly constrained.

This study also contributes to the ongoing discussion on competency modelling in construction. Given the different models and fragmented terminology, there is a need for a competency framework tailored to trade workers in OSC. The proposed framework provides a foundation for competency-based training, assessment, and future research in OSC.

CONCLUSION

This paper develops a conceptual Lean Workforce Readiness Framework for OSC by synthesizing relevant literature on workforce competency and organizing capabilities using the KSAO structure. The framework is embedded within a TPS-oriented view of lean implementation and is analytically mapped to four common lean tools (5S, LPS, 5 Whys, and VSM) to illustrate how each tool relies on distinct competency profiles. The main contribution of this study is the integration of workforce competencies as structured, socio-enablers of lean implementation in OSC, moving beyond fragmented skill-based perspectives toward an operationally relevant competency framework. The study suggests that workforce readiness in OSC extends beyond technical skills and encompasses a wide range of social, cognitive, and individual traits and work styles. This study is conceptual in nature and has a number of limitations. The literature synthesis was not exhaustive, and the proposed competency structure was not validated. Therefore, the framework is meant as a starting point and foundation to guide future work. Future work should expand on this study through a scoping review and thematic analysis to more comprehensively identify competencies discussed across OSC literature. Subsequent work should validate the competency sets with industry experts through interviews

or case studies. It should also further develop the framework by linking competencies to measurable performance indicators (e.g. quality and safety) and incorporating role-specific competencies and proficiency levels across different OSC trades. These steps can later support the development of targeted training initiatives and examine how specific competencies impact performance and therefore influence lean implementation.

REFERENCES

Adepoju, O. O., & Aigbavboa, C. O. (2021). Assessing knowledge and skills gap for construction 4.0 in a developing economy. *Journal of Public Affairs*, *21*(3), e2264. https://doi.org/10.1002/pa.2264

Agrawal, A. K., Zou, Y., Chen, L., Abdelmegid, M. A., & González, V. A. (2024). Moving toward lean construction through automation of planning and control in last planner system: A systematic literature review. *Developments in the Built Environment*, *18*, 100419. https://doi.org/10.1016/j.dibe.2024.100419

Alhloul, A., & Kiss, E. (2022). Industry 4.0 as a Challenge for the Skills and Competencies of the Labor Force: A Bibliometric Review and a Survey. *Sci*, *4*(3), 34. https://doi.org/10.3390/sci4030034

Alinaitwe, H. M., Mwakali, J. A., & Hansson, B. (2007). Factors Affecting the Productivity of Building Craftsmen—Studies of Uganda. *Journal of Civil Engineering and Management*, *13*(3), 169–176. https://doi.org/10.3846/13923730.2007.9636434

Alsakka, F., Yu, H., Hamzeh, F., & Al-Hussein, M. (2023). Factors Influencing Cycle Times in Offsite Construction. *Proceedings of the 31st Annual Conference of the International Group for Lean Construction (IGLC 31)*, 723–734. https://doi.org/10.24928/2023/0123

AlSehaimi, A. O., Tzortzopoulos Fazenda, P., & Koskela, L. (2014). Improving construction management practice with the Last Planner System: A case study. *Engineering, Construction and Architectural Management*, *21*(1), 51–64. https://doi.org/10.1108/ECAM-03-2012-0032

Assaad, R. H., El-adaway, I. H., Hastak, M., & LaScola Needy, K. (2022). Quantification of the State of Practice of Offsite Construction and Related Technologies: Current Trends and Future Prospects. *Journal of Construction Engineering and Management*, *148*(7), 04022055. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002302

Assaad, R. H., El-adaway, I. H., Hastak, M., & LaScola Needy, K. (2023). Key Factors Affecting Labor Productivity in Offsite Construction Projects. *Journal of Construction Engineering and Management*, *149*(1), 04022158. https://doi.org/10.1061/JCEMD4.COENG-12654

Assaad, R. H., El-Adaway, I. H., Hastak, M., & Needy, K. L. (2022). Smart and Emerging Technologies: Shaping the Future of the Industry and Offsite Construction. *Computing in Civil Engineering 2021*, 787–794. https://doi.org/10.1061/9780784483893.097

Assaf, S., Anyaco, D., Bouferguene, A., & Al-Hussein, M. (2025, July 31). Prevalent Factors Affecting Workers in Industrialized Construction: Towards Human-Centric Construction Manufacturing. *Proceedings of the CSCE Construction Specialty Conference and ASCE Construction Research Congress (CSCE/CRC 2025)*. https://doi.org/10.22260/CRC-CSCE-2025/0085

Barkokebas, B., Khalife, S., Al-Hussein, M., & Hamzeh, F. (2021). A BIM-lean framework for digitalisation of premanufacturing phases in offsite construction. *Engineering, Construction and Architectural Management*, *28*(8), 2155–2175. https://doi.org/10.1108/ECAM-11-2020-0986

Bartram, D. (2005). The Great Eight Competencies: A Criterion-Centric Approach to Validation. *Journal of Applied Psychology*, *90*(6), 1185–1203. https://doi.org/10.1037/0021-9010.90.6.1185

Choi, J. O., Chen, X. B., & Kim, T. W. (2019). Opportunities and Challenges of Modular Methods in Dense Urban Environment. *International Journal of Construction Management*, *19*(2), 93–105. https://doi.org/10.1080/15623599.2017.1382093

Eltahan, A., Lee, G., & Hamzeh, F. (2025). A human-centered framework for assessing task complexity in construction: A cognitive load perspective. *Engineering, Construction and Architectural Management*, 1–22. https://doi.org/10.1108/ECAM-04-2025-0585

Fardhosseini, M. S., Soltaninejad, M., Karji, A., Ghorbani, Z., & Ghanadiof, O. (2021). Qualitative Evaluation of 5S Application Considering the Experience of Electrical Construction Experts. *American Journal of Applied Sciences*, *18*(1), 51–60. https://doi.org/10.3844/ajassp.2021.51.60

Gao, M., Wu, X., & Fang, Y. (2023). How Employees' Lean Construction Competence Affects Construction Safety Performance. *International Journal of Occupational Safety and Ergonomics*, *29*(3), 1147–1159. https://doi.org/10.1080/10803548.2022.2112848

Ginigaddara, B., Perera, S., Feng, Y., & Rahnamayiezekavat, P. (2022). Offsite Construction Skills Evolution: An Australian Case Study. *Construction Innovation*, *22*(1), 41–56. https://doi.org/10.1108/CI-10-2019-0109

Hamzeh, F., Ballard, G., & Tommelein, I. D. (2012). Rethinking Lookahead Planning to Optimize Construction Workflow. *Lean Construction Journal*, 15–34.

Hasan, A., Baroudi, B., Elmualim, A., & Rameezdeen, R. (2018). Factors Affecting Construction Productivity: A 30 Year Systematic Review. *Engineering, Construction and Architectural Management*, *25*(7), 916–937. https://doi.org/10.1108/ecam-02-2017-0035

Hedayati, E., Zabihi Kolaei, A., Khanzadi, M., & Ghodrati Amiri, G. (2025). Implementation of Hardware Technologies in Offsite Construction (2014–2023). *Automation in Construction*, *170*, 105948. https://doi.org/10.1016/j.autcon.2024.105948

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, *28*(1), 75–106. https://doi.org/10.2307/25148625

Inyang, N., Han, S., Al-Hussein, M., & El-Rich, M. (2012). A VR Model of Ergonomics and Productivity Assessment in Panelized Construction Production Line. *Construction Research Congress 2012*, 1084–1093. https://doi.org/10.1061/9780784412329.109

Jørsfeldt, L., Klitgaard, A., Selman, A., & Jeppesen, R. (2024). Towards Industry 5.0 Skills—Off-site Construction Settings in Denmark. *IOP Conference Series: Earth and Environmental Science*, *1389*(1), 012017. https://doi.org/10.1088/1755-1315/1389/1/012017

Joshi, S., Hamilton, M., Warren, R., Faucett, D., Tian, W., Wang, Y., & Ma, J. (2021). Implementing Virtual Reality technology for safety training in the precast/ prestressed concrete industry. *Applied Ergonomics*, *90*, 103286. https://doi.org/10.1016/j.apergo.2020.103286

Kallassy, J., & Hamzeh, F. (2021). Developing a Lean Culture Index in Construction. *Proceedings of the 29th Annual Conference of the International Group for Lean Construction (IGLC29)*, 504–513. https://doi.org/10.24928/2021/0192

Lattuga, E., & Ginigaddara, B. (2025). Investigating the implications of Industry 4.0 technology integration on critical trade roles in offsite construction. *CIB Conferences*, *1*(1). https://doi.org/10.7771/3067-4883.1947

Mirabile, R. J. (1997). Everything You Wanted to Know About Competency Modeling. *Training & Development*, *51*(8), 73–78.

Modular Building Institute. (2025). *2025 Canadian Permanent Modular Construction Industry*. https://members.modular.org/form/Fill/p8MmWhEP

Mohsen, A., Yunus, R., Handan, R., Kasim, N., & Hussain, K. (2019). Determining Factors for Enhanced Skilled Worker Requirements in IBS Construction Projects in Malaysia. *IOP*

Conference Series: Earth and Environmental Science, *220*, 012048. https://doi.org/10.1088/1755-1315/220/1/012048

Murguia, D. (2019). Factors Influencing the Use of Last Planner System Methods: An Empirical Study in Peru. *27th Annual Conference of the International Group for Lean Construction (IGLC27)*, 1457–1468. https://doi.org/10.24928/2019/0224

Najafzadeh, M., & Yeganeh, A. (2025). AI-Driven Digital Twins in Industrialized Offsite Construction: A Systematic Review. *Buildings*, *15*(17), 2997. https://doi.org/10.3390/buildings15172997

OECD. (2019). *Skills for 2030*. Organisation for Economic Co-operation and Development. https://www.oecd.org/content/dam/oecd/en/about/projects/edu/education-2040/concept-notes/Skills_for_2030_concept_note.pdf

Ofori-Kuragu, J. K., Osei-Kyei, R., & Wanigarathna, N. (2022). Offsite Construction Methods—What We Learned from the UK Housing Sector. *Infrastructures*, *7*(12), 164. https://doi.org/10.3390/infrastructures7120164

Ohno, T. (1988). *Toyota Production System: Beyond Large-Scale Production*. Productivity Press.

O*NET Resource Center. (n.d.). *Basic Skills*. U.S. Department of Labor. O*NET OnLine. Retrieved January 19, 2026, from https://www.onetonline.org/find/descriptor/browse/2.A

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems*, *24*(3), 45–77. https://doi.org/10.2753/MIS0742-1222240302

Ranadewa, K. A. T. O., Y.G. Sandanayake, Y. G. S., & Siriwardena, M. (2021). Enabling Lean through Human Capacity Building: An Investigation of Small and Medium Contractors. *Built Environment Project and Asset Management*, *11*(4), 594–610. https://doi.org/10.1108/BEPAM-03-2020-0045

Romo, R., Orozco, F., Moreno, F., Francesconi, C., Valdebenito, R., & Forcael, E. (2025). Lean Construction Barriers From the Organizational Culture Lens. *33rd Annual Conference of the International Group for Lean Construction (IGLC33)*, 1321–1332. https://doi.org/10.24928/2025/0284

Rother, M., & Shook, J. (1999). *Learning to See: Value-Stream Mapping to Create Value and Eliminate Muda*. The Lean Enterprise Institute.

Sarvari, H., Chan, D. W. M., Rakhshanifar, M., Banaitiene, N., & Banaitis, A. (2020). Evaluating the Impact of Building Information Modeling (BIM) on Mass House Building Projects. *Buildings*, *10*(2), 35. https://doi.org/10.3390/buildings10020035

Shehab, L., Lee, G., & Hamzeh, F. (2026). Minds at Work: A Design for an Experimental Approach to Assessing Cognitive Abilities in Construction. *Journal of Construction Engineering and Management*, *152*(1), 04025221. https://doi.org/10.1061/JCEMD4.COENG-16638

Siriwardhana, S., & Moehler, R. C. (2023). Enabling Productivity Goals Through Construction 4.0 Skills: Theories, Debates, Definitions. *Journal of Cleaner Production*, *425*, 139011. https://doi.org/10.1016/j.jclepro.2023.139011

Spencer, L. M., & Spencer, S. M. (1993). *Competence at Work: Models for Superior Performance*. Wiley.

Sui-PPheng, L., & Danielle Khoo, S. (2001). Team Performance Management: Enhancement through Japanese 5-S Principles. *Team Performance Management: An International Journal*, *7*(7/8), 105–111. https://doi.org/10.1108/13527590110411000

Taylor, E. (2016). Investigating the Perception of Stakeholders on Soft Skills Development of Students: Evidence from South Africa. *Interdisciplinary Journal of E-Skills and Life Long Learning*, *12*, 1–18.