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TEACHING LEAN CONSTRUCTION: AN OVERVIEW OF TRENDS AND FUTURE

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ABSTRACT

Since its inception in the early 1990s, Lean Construction (LC) has had a significant impact on the Architecture, Engineering, and Construction (AEC) industry. Under this philosophy, various methods have been developed to apply Lean practices in AEC. A fundamental first step is to begin with higher education institutions that train future construction professionals. Consequently, this research aimed to identify the main current and future trends in teaching LC. Additionally, it aimed to assess how such teaching aligns with the most commonly employed didactic techniques in AEC education. To achieve this objective, a survey was conducted among professors and practitioners from different parts of the world, revealing interesting findings, including the predominance of tools such as the Last Planner System in teaching LC, and that the Case Study approach as the most utilized in the classroom from a didactic view.

KEYWORDS

Lean Construction, AEC Education, Teaching, Didactic Techniques.

INTRODUCTION

Lean Construction (LC), which applies lean manufacturing principles to the construction sector, has gained considerable popularity by prioritizing waste reduction, boosting efficiency, and fostering collaboration. With the rising demand for sustainable and efficient construction practices, education in LC has become increasingly vital for Architecture, Engineering, and Construction (AEC) students. Thus, this research addresses current trends in teaching LC, focusing on the educational frameworks, tools, and methodologies influencing the field. It also anticipates the future of LC education by discussing emerging challenges, potential prospects, and innovations that will shape the training of the next generation of construction professionals.

This research also addresses relevant aspects of the different educational paradigms and teaching strategies used to train architects, engineers, and builders, as well as how teaching LC is intertwined with these paradigms and methods. To achieve this objective, this study applied a consultative instrument (questionnaire) to LC educators and practitioners worldwide to gather plausible evidence to determine the trends and future of LC teaching.

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LEAN CONSTRUCTION

Initially, LC emerged as a new production management theory focused on minimizing waste and maximizing value, ensuring a smooth production flow with minimum intermediate inventories (Howell, 1999; Koskela, 2000), adapting to traditional project management production principles and tools from Lean Manufacturing and the Toyota Production System (Liker, 2021; Womack et al., 1991). Then, LC matured and broadened its scope to other areas such as organization theory, education, sustainability, and digitalization (González et al., 2022).

From this perspective, Lean Education has become a critical driver for disseminating LC in academia and industry. As such, researchers and practitioners have explored and developed a variety of approaches to teaching Lean in construction organizations, ranging from traditional workshops to simulation games (Liu et al., 2024). These approaches have focused on acquiring knowledge, skills, and behavioral shifts (from traditional to Lean-based production) to increase the effectiveness of LC uptake in the construction industry (Liu et al., 2024).

MAIN TECHNIQUES AND METHODS USED IN LEAN CONSTRUCTION

Different lean tools and methods have been developed to support continuous improvement. These tools align closely with lean principles, supporting reducing waste while increasing the value delivered to customers (Ballard et al., 2002). For instance, the Last Planner System (LPS) supports improving workflow reliability, while Value Stream Mapping (VSM) addresses the identification and removal of non-value-adding activities. Similarly, Takt planning ensures balanced workflows and A3 problem-solving encourages team-based problem resolution. Together, these methods provide a structured and holistic approach to achieving LC goals. An overview of some selected methods, just to mention a few examples, is provided below:

- **Last Planner System (LPS):** a collaborative planning system that enhances workflow reliability by considering stakeholders, master scheduling, phase planning, look-ahead planning, weekly work plans, and variance analysis (Ballard, 2000).
- ***Takt* Planning**: A production planning method aligning work sequences with a consistent rhythm (takt time) for balanced and predictable workflows in manufacturing (Hopp & Spearman, 2008) and applied in construction (Frandson et al., 2013).
- **Value Stream Mapping (VSM):** a visual tool for analyzing and improving material and data flow in projects. It maps current processes, identifies non-value-adding activities, and helps streamline workflows, reducing waste (Rother & Shook, 2003).
- **A3 Problem-Solving:** a method for visually identifying and solving problems. Teams use an A3 sheet to register issues, root causes, potential solutions, and actions, encouraging collaboration, continuous improvement, and value creation (Shook, 2008).
- **Pull Planning:** ensures tasks begin according to demand rather than fixed schedules, reducing overproduction, aligning with project needs, and enhancing workflow (Tommelein, 1998).

In addition to this brief preliminary summary, the following LC methods were included in the survey asked in this study: 3P, 5S, 5 Whys, A3 Process (Method A3), Andon, Agile Planning, AWP (Advanced Work Packaging), Big Room Planning, BIM Execution Plan, CBA (Choosing by Advantages), Cell Production Units, Design Structure Matrix, Gemba Walk, Heijunka, Hoshin Kanri, Jidoka, Just-In-Time (JIT), Kaisen, Kanban, Last Planner System, Lean Daily Management, PDCA (Plan, Do, Check, Adjust), Poka-yoke, Simulation, Shop Floor Management, SMED, Takt Time, TQM, Toyota 3M model, Virtual Design and Construction (VDC), Value Stream Mapping (VSM), Visual Management, and Work Clusters.

AEC EDUCATION

The Architecture, Engineering, and Construction (AEC) education sector is undergoing significant changes to address the industry's evolving demands, particularly in terms of management challenges and technological advancements. Emerging technologies, including Robotics, Drones, Computer-aided design, Artificial Intelligence (AI), Augmented and Virtual Reality (AR/VR), Cloud Computing, and the Internet of Things (IoT), among others, are increasingly influential in AEC education. In this sense, integrating technology is essential because the AEC industry is under growing pressure to meet the demands of Industry 4.0, requiring a workforce skilled in both traditional and digital competencies (Vassigh et al., 2024).

Alongside technological integration, AEC programs are increasingly focusing on competency-based education. Research highlights the need to align educational outcomes with industry standards, especially in informatization and new technologies (Zhou & Wang, 2023). The primary aim is to prepare graduates who are proficient in technical skills and adept at managing the complexities of contemporary AEC projects.

In summary, AEC education is progressing by incorporating transdisciplinary methods, technological innovations, and competency-driven frameworks. These advancements are designed to equip students for the complex challenges of the AEC industry, ensuring they possess the knowledge and skills necessary to contribute to innovative practices. In this sense, teaching LC could play a leading role in AEC education.

EDUCATIONAL PARADIGMS AND TEACHING TECHNIQUES IN AEC EDUCATION

To study a learning or pedagogical model, one must thoroughly understand the sources, key authors, and philosophies that underpin it, revealing the origins and developments of the theories, approaches, and models it offers (Borrego et al., 2009; Patton, 2022). As a result, paradigms evolve into patterns, models, or guidelines that educators should follow. Diverse authors identify three views to understanding educational reality: positivism, constructivism, and the socio-critical paradigm (Hwang, 1996; Koetting, 1984). Another learning paradigm, called critical communicative, has gained attention in addressing educational and social inequalities (Gómez et al., 2011). These educational paradigms are summarized in Table 1.

Table 1: Educational paradigms (Adapted from (Eric Forcael et al., 2023)).

Ambits / Paradigm	Approach	Content construction method	Information gathering technique	Social Orientation
Positivism	Quantitative: experiments, observation	Deductive-inferential	Quantitative	It finds to represent and explain facts
Constructivism	Qualitative: interpretation, hermeneutics	Inductive	Qualitative	It interprets social reality
Socio-Critical	Socio-critical: dialectics	Dialectic	Quantitative and qualitative	It transforms social organizations by practice
Critical-Communicative	It encourages consensual dialogues	Dialogic	Quanti and qualitative, with a communicative orientation	It transforms society through communicative action

The educational paradigms aim to address the longstanding challenges of education, each featuring: a distinctive perspective on educational reality, a varying model of the relationship between the researcher and this reality, and a unique method of creating and getting knowledge. Didactic methodologies and techniques emerged from these educational paradigms to enhance the teaching and learning process for students (E. Forcael et al., 2019; Hus & Grmek, 2011).

Conversely, teaching techniques consist of structured and formal methods designed to plan the teaching-learning process, allowing educators to deliberately and thoughtfully reach the intended goals (Andrews, 2009; E. Forcael et al., 2018). AEC education considers various teaching-learning techniques, categorized into: a) strategies with educators as the main figures in the classroom, b) methods that foster active student engagement, and c) approaches where students and professors collaboratively lead the learning process. Moreover, these techniques can align with different educational paradigms, where the paradigms shown in Table 1 can be sorted based on whether control or autonomy is held by a) the AEC educator; b) the AEC student; or c) both collaboratively. Table 2 shows examples of teaching techniques applicable to AEC education, their connection to the educators' role, and the related educational paradigms.

Table 2: Examples of teaching techniques, the role of an AEC educator, and educational paradigms (adapted from Forcael et al. (2023)).

Teaching techniques	Positivism	Constructivism	Socio-critic.	Critical Comm.
a) Strategies where AEC educators are the protagonists in the classroom				
Symposium or presentation	•		•	
Traditional lecture	•			
Teacher tutoring	•	•		
Classroom demonstration	•			
b) Techniques that encourage the active participation of AEC students				
Roleplay		•	•	•
Flipped classroom		•	•	
Brainstorming		•	•	
Conceptual and mind map		•		
Student debate			•	•
Portfolio		•		
c) Approaches where AEC students and AEC professors collaboratively lead the learning process				
Cooperative learning		•		•
Case-based and Challenge based-learning (CBL)		•	•	•
Problem-based learning and Project-oriented learning		•	•	•
Round tables and seminars		•	•	•
Service-learning		•		•
Competition-based learning		•		•

Thus, Table 2 allows AEC educators to act as protagonists or facilitators. They can explain and control, interpret and understand, or promote equal dialogue for social transformation. AEC educators must recognize the prevailing paradigms that influence their methods, align them with their educational philosophy, and implement strategies that reflect the paradigms they wish to advance, as well as how these paradigms can be considered in teaching Lean.

LEAN CONSTRUCTION AND AEC EDUCATION

Lean Education emphasizes the integration of Lean principles and tools into educational practices to enhance learning efficiency and outcomes. It focuses on minimizing waste and maximizing value in educational processes, aligning with Lean's broader philosophy of continuous improvement. Implementing Lean in teaching requires innovative methods, such as active learning and collaborative projects, which empower students to engage deeply with the material and foster critical thinking (Anandh et al., 2018; Nofera et al., 2015).

Teaching LC, a subset of Lean Education, involves equipping students with the principles and practices of Lean specific to the construction industry. Courses often employ practical simulations to provide hands-on learning experiences. Examples include the "Parade of Trades" game, which illustrates the impacts of variability and workflow reliability; the "Last Planner System simulation," designed to teach production planning and control; and the "Light Fixture Game," which explores workflow and balancing processes. Other tools, such as the "LEGO Airplane Game," focus on material management and pull systems, while the "Silent Squares simulation" demonstrates the optimization of the entire system over individual components (Biotto et al., 2021; Rybkowski et al., 2018).

Additionally, instructors incorporate virtual adaptations of these simulations, such as the Virtual Parade Game, which became particularly useful during the COVID-19 pandemic for remote teaching environments (Biotto et al., 2021). Integrating real-world case studies and fieldwork complements these activities, bridging theoretical knowledge with practical applications (Nofera et al., 2015; Rybkowski et al., 2018).

Despite its importance, LC education faces challenges, such as limited curricular inclusion and varying levels of awareness among educators and industry practitioners. Collaborative efforts between academia and industry are crucial for overcoming these barriers, ensuring that graduates are prepared to lead Lean transformations in the construction sector (Anandh et al., 2018; Power & Taylor, 2019). In this sense, educators and practitioners continually incorporate strategies for teaching the integration of Lean methods in construction management courses to engineering students (Brioso et al., 2017; Sánchez et al., 2023).

METHODOLOGY

STUDY DESIGN

This study employs a descriptive and exploratory approach to gain a global perspective on teaching practices in LC education. A structured survey is the primary data collection instrument, targeting educators from various institutional types and geographic regions. The survey incorporates quantitative and qualitative components, enabling an in-depth analysis of teaching methodologies, resources, challenges, and perceived outcomes (Xiong, 2022). To visually represent the methodological framework and the survey's structure, Figure 1 illustrates the key components of the study, including the purpose, survey sections, and their connections to the subsequent analytical phases.

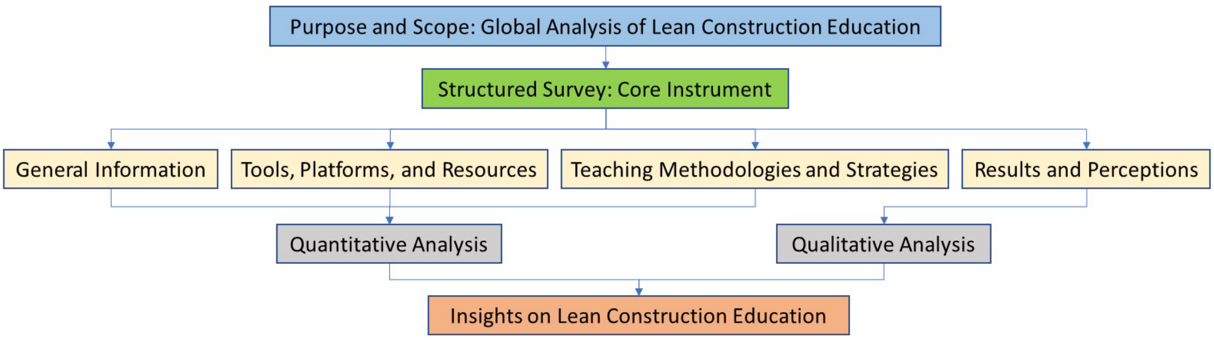

Figure 1: Study design diagram

KEY ASPECTS OF THE STUDY DESIGN

Objective and Scope

The study aims to identify and analyze the teaching methodologies, resources, and challenges employed in LC education. Regarding the scope, the survey targeted educators from public and private universities, technical institutes, and corporate training organizations. Participants varied in their teaching experience and student academic levels, including undergraduate, graduate, and continuing education students. The survey was distributed internationally to ensure diverse perspectives and insights into teaching practices across different regions.

Participants

This study included 57 educators from diverse educational and professional contexts, ensuring representation across regions, institutions, and experience levels (Rikala et al., 2024).

Participants came from public universities, private universities, technical institutes, and corporate training organizations, allowing for the analysis of commonalities and differences in teaching practices (Sincer et al., 2019). Geographic diversity provided insights into how cultural, economic, and institutional contexts influence LC education. Participants represented both developed and developing countries, ensuring international diversity in the data.

Participants' teaching experience ranged from less than one year to over six years, enabling the identification of trends in pedagogical approaches and challenges over time (Dolmans et al., 2005). Educators reported teaching at undergraduate, graduate, and continuing education levels, incorporating insights from diverse student populations. Class sizes varied from fewer than 15 to over 50 students, while teaching modalities included on-site, online, and hybrid formats, offering a comprehensive view of LC education delivery.

Data Collection Instrument

The survey comprises four key sections that focus on Lean Construction education. It combines closed-ended (e.g., multiple-choice, Likert) and open-ended questions for respondents to share their experiences. Besides collecting demographic data, it examines the integration of Lean techniques in teaching and the use of resources. Expert feedback and a pilot test refined its validity and clarity. The survey was divided into four sections:

1. **General Information:** Focused on participants' professional backgrounds, institutional affiliations, teaching experience, and geographic diversity. It also included details on academic programs, class sizes, and teaching modalities (on-site, online, or hybrid).
2. **Tools, Platforms, and Resources:** Explored various teaching materials, including textbooks, case studies, digital tools, and simulation software. Challenges such as software compatibility and connectivity issues were also addressed.
3. **Teaching Methodologies:** Examined various pedagogical strategies, ranging from lecture-based instruction to interactive approaches such as project-based and collaborative learning. Specific Lean techniques, such as the Last Planner System and Value Stream Mapping, were highlighted for their practical applications.
4. **Results and Perceptions:** Examined assessment methods, including exams, case studies, and feedback mechanisms such as peer reviews. Investigated barriers such as limited curriculum time and resources through open-ended questions to gather educators' experiences and suggestions.

Procedures

The gathering information process was structured into four key stages: survey development, participant recruitment, survey administration, and data analysis

1. **Survey Development:** The survey instrument was reviewed and validated by LC education experts, incorporating feedback from a pilot test to ensure clarity, structure, and alignment with study objectives.
2. **Participant Recruitment:** Educators were invited through a global LC network via email, ensuring broad geographic and institutional representation. Invitations detailed the study's purpose and emphasized voluntary participation.
3. **Survey Administration:** The survey was distributed online through a secure platform, providing participants with a two-week deadline. Periodic reminders were sent to maximize response rates, with measures ensuring confidentiality and anonymity.
4. **Data Analysis:** Responses were stored in a secure database for analysis and processing. Quantitative data were processed using Python libraries (Pandas, NumPy, Matplotlib) for statistics and visualizations. Qualitative data were thematically analyzed with NLTK and KMeans and visualized through word clouds and bubble charts.

Limitations

This study offers valuable insights into LC education, but it also has limitations. The sample of 57 participants, although diverse, may not fully represent global perspectives, as some regions or institutions may have been underrepresented due to the reliance on an existing network of LC educators. This approach may have introduced selection bias, excluding those outside this network or in less connected contexts. The cross-sectional nature of the survey offers a snapshot of current practices but does not capture their evolution over time.

ANALYSIS OF RESULTS

The survey results provide a comprehensive overview of LC education, identifying its strengths, challenges, and potential areas for growth. Educators' experience, class characteristics, and methodologies align with industry demands while highlighting opportunities for innovation and enhanced teaching practices.

QUANTITATIVE ANALYSIS

First, a chi-square test was used to examine whether Lean-specific techniques differ by institution type. The null hypothesis (H_0) posits that the frequency of Lean usage (high or low) is independent of institution type (public, private, or technical/corporate). The alternative hypothesis (H_1) suggests a relationship between the use of the technique and the type of institution. Participants were grouped by their institution and reported usage of four or more techniques (high) or three or fewer (low). This data led to a contingency table: $\chi^2(2, N = 57) = 5.11$, $p = 0.078$. The p-value exceeds 0.05, meaning the null hypothesis cannot be rejected. Thus, no significant relationship exists between the type of institution and the use of Lean techniques in this sample. Notably, the higher usage among public university educators indicates potential trends for future study with larger samples.

Educators reported an average of 5.06 years of teaching experience, indicating a relatively high level of experience. Class sizes varied widely, with an average of 30.84 students, reflecting diverse teaching environments. Public universities were the primary educational setting, accounting for 45.6%, followed by private universities at 28.1% and technical or corporate institutions at 26.3%. Most teaching occurred on-site (71.9%), with hybrid (17.5%) and online (10.6%) formats representing emerging trends toward flexible delivery methods.

Teaching resources included traditional and digital tools, with textbooks (61.4%), audiovisual materials (64.9%), and case studies (78.9%) being most common, followed by software tools (52.6%) and simulation tools (54.4%). This mix highlights the integration of foundational knowledge and innovative technologies for effective teaching. Lean techniques, such as the Last Planner System (78.9%) and Value Stream Mapping (70.2%), were most frequently used, along with Pull Planning (61.4%) and Kanban Systems (52.6%). These tools demonstrate a strong connection between educational practices and industry needs, with a focus on workflow planning and process optimization. Lean techniques are shown in Figure 2. Pedagogical methods revealed key trends, including case studies (78.9%) and collaborative learning (96.5%), followed by problem-based learning (78.9%) and traditional education (87.7%), summarized in Figure 3. These insights highlight the interplay between instructional strategies and the tools educators use.

Both figures demonstrate a relationship between the methodologies used and the Lean techniques emphasized in classrooms. For instance, the frequent use of collaborative learning aligns closely with tools such as the Last Planner System and Value Stream Mapping, which inherently support teamwork and problem-solving.

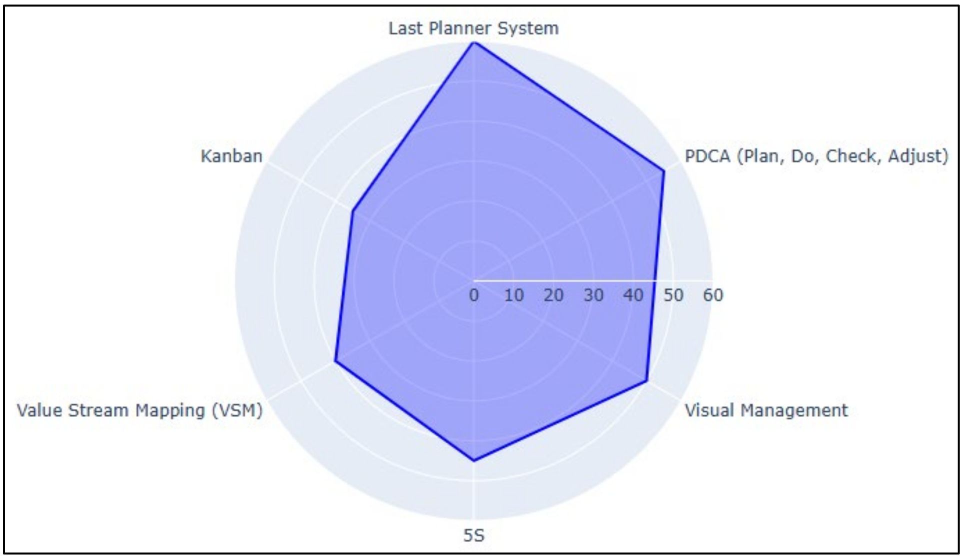

Figure 2: Prevalence of Lean-Specific Techniques in Teaching

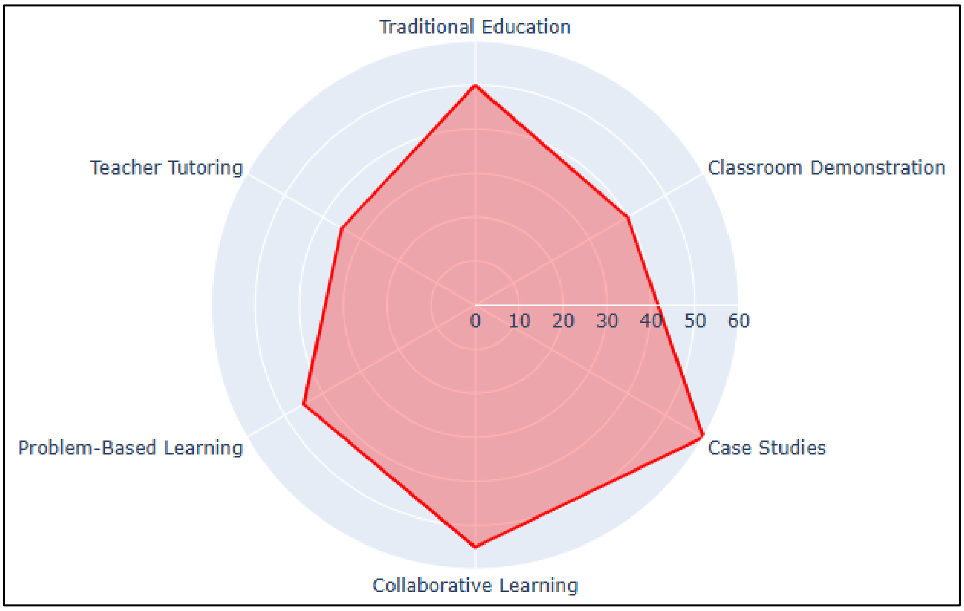

Figure 3: Prevalence of Pedagogical Techniques in Teaching

The survey sheds light on challenges faced by educators and outcomes achieved in LC education. Limited curriculum time (87.7%) and resource constraints (78.9%) were the most frequently cited challenges, reflecting systemic limitations. Other significant issues included difficulties in finding practical examples (70.2%) and engaging students effectively (52.6%). Despite these barriers, the methodologies and tools employed by educators resulted in positive student outcomes, with over 85% of respondents reporting pass rates exceeding 70%.

QUALITATIVE ANALYSIS

The analysis of open-ended responses revealed various innovative practices in LC education. A word cloud visually represented key terms and themes (Figure 4). Over one-third of participants mentioned collaborative learning, while technology-driven learning and gamification were cited by about 25% to 30%. This highlights the importance of strategies such as simulation exercises, project-based learning, and collaborative learning in enhancing student engagement and fostering a deeper understanding.

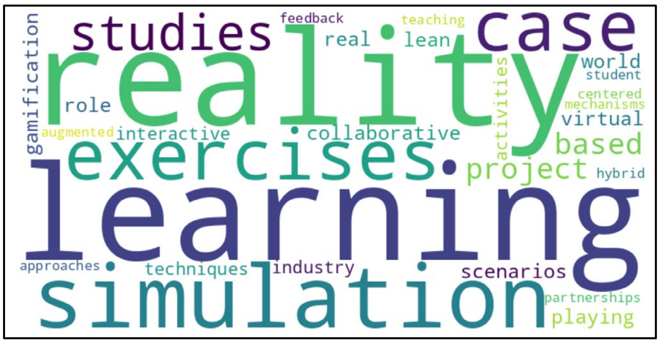

Figure 4: Innovative Practices in LC Education

Key practices include real-world scenarios and case studies that link theory with practical applications in industry. Emerging methods, such as gamification, virtual reality, and augmented reality, demonstrate a growing interest in utilizing advanced technologies to enhance learning. Feedback mechanisms, hybrid teaching, and interactive activities underscore educators' focus on student-centered teaching.

Thematic Clustering of Responses

The clustering analysis revealed four distinct themes based on the qualitative responses:

1. **Cluster 0 – Collaborative Learning:** This cluster emphasizes collaborative approaches to enhance teamwork and problem-solving skills. Respondents reported using group projects and peer learning to foster collaboration.
2. **Cluster 1 – Student Engagement:** This cluster highlights gamification and role-playing as key strategies to engage students, making learning more interactive and enjoyable, especially for theoretical or technical subjects.
3. **Cluster 2 – Technology-Driven Learning:** This group integrates tools such as simulation exercises, virtual reality, and augmented reality to replicate real-world scenarios, providing hands-on, immersive learning experiences.
4. **Cluster 3 – Practical Application:** This cluster emphasizes project-based learning, allowing students to apply theory in real contexts. Respondents highlighted the importance of iterative project reviews and feedback in enhancing understanding.

While the bubble chart displays thematic clusters (Figure 4), where the size of the bubbles indicates the number of responses, each cluster's label highlights the top terms from the responses, summarizing its focus, as illustrated in Figure 5.

Figure 5: Thematic Clustering of Responses

The survey highlighted a series of challenges faced by educators in teaching LC. The most frequently mentioned issues include limited curriculum time, resource shortages, and difficulty in finding relevant practical examples. Also, institutional policies, regional differences, and adapting technology to specific contexts emerged as significant obstacles. Continuous feedback, iterative reviews, and peer assessments were particularly prominent. Real-time feedback and formative evaluation were emphasized, given their crucial role in fostering student engagement and deepening understanding. These findings align with a student-centered teaching approach, keeping students engaged by providing them with timely and constructive support.

Regarding opportunities for improving LC education, educators highlighted key areas for improvement, including increasing collaboration with industry, developing additional educational resources, enhancing access to tools, and improving the integration of technology. Other priorities include offering specialized training for educators, establishing regional partnerships, and expanding the curriculum to incorporate emerging topics and techniques.

CONCLUSIONS

This research aimed to identify the main practices, provide an overview of current trends and potential future developments in teaching LC, and evaluate how such teaching aligns with the most commonly used didactic techniques in AEC education.

The analysis of LC education reveals key findings related to teaching practices, challenges, and areas for improvement. While there was no significant correlation between the type of educational institution and the use of Lean techniques, educators reported an average of 5 years of teaching experience, with most institutions being public universities. Collaborative learning, case studies, and industry-relevant Lean tools such as Value Stream Mapping and the Last Planner System were the most commonly used, aligning well with industry demands. However, educators faced challenges such as limited curriculum time, resource constraints, and difficulty engaging students. Despite these issues, positive student outcomes emerged, with over 85% of respondents achieving pass rates over 70%. Lean educators emphasized promising practices, including gamification and technology-driven learning, as well as traditional teaching methods such as project-based learning. Improvement opportunities centered on enhancing collaboration with industry, increasing technology integration, and offering specialized training for educators.

In other words, the results show that the Last Planner System is the most frequently used Lean-specific technique in LC education, while case studies are the most commonly used didactic teaching technique. This finding suggests that educators prioritize structured planning tools and practical, real-world examples to enhance student learning and align with industry practices. The prominence of specific methods, such as the Last Planner System, likely reflects their demonstrated effectiveness in practice and their incorporation into existing industry workflows, making them more accessible and relevant for academic instruction.

Regarding limitations, the limited sample size, although diverse, may not fully represent global perspectives, as the cross-sectional nature of the present study provides only an exploratory view of current practices and does not capture their evolution over time. Future research should consider conducting longitudinal studies that provide deeper insights into trends and the adoption of methodologies, such as in-depth interviews or case studies, which may offer a richer contextual understanding of the nuances of LC education.

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