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Teaching Lean Construction Principles and Methods Across the Construction Curriculum

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Lean Construction (LC) has been taught in academic and professional settings over the past 30 years. However, it is still not considered a mainstream topic in Construction-related programs. This paper reports on a collaborative initiative where academics are incorporating LC across the construction curriculum offered through their institutions using a structured method in different courses. Specific examples show how different construction courses have used serious games (simulations) to explain and anchor LC concepts into activities students can relate to. Such examples also demonstrate the integration of LC in multiple construction engineering and management courses at SDSU. It is envisioned that by sharing these examples, the construction education community is informed about the different mechanisms associated with embedding LC education as part of mainstream construction degree programs.

Keywords: Lean Construction, Teaching, Serious Games, Student Learning Outcomes

Introduction

Lean Construction (LC) was originally defined as philosophy to improve processes to deliver projects which provide value to their clients, with activities flowing between different parties without wasteful elements (Koskela, 1992). Following the publication of Koskela's (1992) report, which coined the term Lean Construction, after industry counterparts coined the Lean Production (Womack et al., 1991), LC started being taught in industry settings and universities strongly relying on serious games or simulations to convey the concepts associated with it. The development of LC teaching and learning has been mostly documented in the proceedings of the International Group of Lean Construction (IGLC), available at iglc.net, and discussed later in this paper.

Despite being taught for over 30 years, LC as a philosophy still has much to advance in terms of where and how it is taught. Most recently, survey results indicate that 61% of a representative sample from the construction industry is aware of LC, but only 6% of respondents reported that they are engaged with the use of LC practices in their projects (Dodge Construction Network, 2025). A previous study reported that even companies that were members of the Lean Construction Institute (LCI) in the United States did not require LC-based knowledge in their job positions (Alves et al., 2016). Considering that LC-related tools and skills are not required by industry organizations, academic institutions might lag in teaching LC and, consequently, this might have hindered progress regarding making LC concepts, principles and tools more mainstream when compared to longstanding practices taught in Construction-related degrees.

To address this gap related to teaching LC in Construction-related programs, this paper presents examples to illustrate how LC can be taught across the curriculum using the method developed by Bhawani et al. (2024). The approach described in this paper relies particularly on using serious games (simulations) as a mechanism to illustrate the importance of communication and transparency in the construction industry.

Using Serious Games (Simulations) to Teach LC in Construction Programs

The teaching of LC has usually been paired with the use of serious games or simulations to illustrate the differences between traditional ways and new ways of managing production systems in construction (Tsao et al., 2012; Tsao et al., 2013; Rybkowski et al., 2020). Most of this progress was made in the initial stages when LC was starting to take form as a sub-domain within the construction body of knowledge and limited to only graduate-level research and education.

The importance of using simulations to teach Lean concepts applied to construction resides in the ability instructors have to make a series of changes to illustrate LC concepts and principles in action using simulations with multiple rounds of play with different set ups. These simulations are an effective way to help students compare and contrast results obtained when different elements of LC are incorporated to address a process or problem starting from business as usual and moving towards an environment where Lean is implemented. A comprehensive list of simulations to teach Lean can be found in the work of Rybkowski et al. (2020), which show a compilation of simulations used by academics and practitioners to illustrate the impact of LC in a broad range of processes from design to preconstruction to construction to operations.

Over the years, faculty and practitioners have engaged in loosely formed communities to share their experiences in teaching and learning about LC. Most notably, the Administering and Playing Lean Simulations Online (APLSO) is an active international community, started during the COVID-19 pandemic when researchers moved their courses online and that created a need to adapt the teaching of LC using simulations to a virtual environment (Rybkowski et al., 2021).

Incorporating Lean Construction Across the Construction Curriculum

Previously, educators have focused on either module or course-level integration of LC, which provided the foundation for progressive teaching and learning. However, for sustained inclusion of LC as a mainstream topic in construction curricula, it is essential to align it with program-level integration. Considering this gap in terms of teaching LC to a broader audience of students in construction programs, the authors are currently leading a group of academics who have volunteered to participate in a structured process to identify courses where LC can be incorporated. The process initially described in Bhawani et al. (2024) builds on existing courses already taught by the faculty recruited to be part of the teaching LC group and uses outcomes already covered in the courses which can be supported with the use of LC practices to enhance student learning in construction programs.

The process applies the revised structure of Bloom's Taxonomy to scaffold learning in multiple stages of the curriculum (University of Arkansas, 2022). Considering the definitions of the six levels addressing learning and mastery of the content, the structure proposed by the authors addressed the use of LC to support learning from developing knowledge and being able to **remember**, moving to the ability to **understand** how the concepts and tools discussed might support addressing problems in the construction industry. The next level supports the student's ability to **apply** LC in problem settings and later **analyze** potential results to be achieved. The final two levels address the ability to

evaluate different solutions and elements discussed and, finally, at the higher level to be able to **create** new ways to use LC to address the problems and situations at hand.

Examples of Module and Course-level LC Integrations

Table 1 presents recommended examples of how LC can be adopted in a module within a course. This approach is appropriate to introduce students to LC at any given time during the course while making the link with the course contents of the module. Table 2 recommends alternatives to incorporate LC within a course on multiple occasions by using multiple approaches and simulations to link how LC can be used to support addressing problems in the construction industry.

Table 1. Incorporating Lean Construction in a module within a course

Levels	Lean Topics	Lecture/Assignments - Module within a Course (items below can be applied to a single lecture/module within the course)
Remember/ Understand	Basic Lean concepts: Value, Waste, Transparency	<ul style="list-style-type: none"> • Presentation • Q&A: How/where is value generated in Construction? What types of waste can they see in construction? • Exercise: share their favorite (sport, restaurant, hobby, etc.) and what makes that special (valued)? Discuss what students see as the value provided by what they shared versus elements that they do not care about (waste). • Simulation: <ul style="list-style-type: none"> - Draw a house (see description below), share comments with class
Apply/Analyze	5S	<ul style="list-style-type: none"> • Simulations - play, debrief, make improvements, and discuss changes over time. <ul style="list-style-type: none"> - Numbers Game/Inspection Game (Superteams n.d.)/Alves et al., 2016) - Puzzle Game (similar in nature to numbers game) (Obulam & Rybkowski 2021) - House of Cards Game (Pollesch et al., 2017) and discussion about what changes in each scenario. Visual details (YouTube video) available at Lean Team (2016).
Evaluate	Continuous Improvement (Kaizen)	<ul style="list-style-type: none"> • In each round of the simulations, ask students about changes that could be made in each round to improve the scenario, and document them during a review of lessons learned during each round. • Next, lead students into writing an A3 to resolve some of the problems identified as the previous games were played.

Table 2. Incorporating Lean Construction in a course

Level	Lean Topics	Lecture/Assignments - Multiple modules within a Course
Remember/ Understand	Basic Lean concepts:	<ul style="list-style-type: none"> • Presentation about LC including a discussion on basic tenets including: value, flow, waste.

	Value Collaboration Lean in Design Sustainability	<ul style="list-style-type: none"> • Q&A: How/where is value generated in Construction? What types of waste can they see in construction? • Exercise: share their favorite (sport, restaurant, hobby, etc.) and what makes that special (valued)? Discuss what students see as the value provided by what they shared versus elements that they do not care about (waste).
Apply/Analyze/Evaluate	Basic Lean concepts: Value Collaboration Lean in Design Sustainability	<ul style="list-style-type: none"> • Use multiple simulations during the course to reinforce concepts related to collaboration and teamwork, learning to identify value during client interactions, choosing alternatives based on LC principles. • For each simulation used, tie discussion with the topics being discussed within a certain week of the course. • Simulations - play, debrief, make improvements, and discuss changes over time. <ul style="list-style-type: none"> - Design: Architectural Programing simulation (Solhjol Khah et al. 2019) - Design/Collaboration: The Silo Game (Alves 2022) - Collaboration: Silent Squares/Broken Squares (Bavelas 1973). Example available at the Center for Leadership & Educational Equity (nd). - Production planning and control: The Airplane Game (Rybkowski et al. 2008, Visionary Products 2026)

Using LC to Achieve Student Learning Outcomes at SDSU

This section presents examples of how LC has been implemented in courses delivered at different levels at San Diego State University to achieve student learning outcomes. The outcomes addressed in each course are indicated alongside the simulations and other approaches used to support student learning.

CONM 102 - Fundamentals of Construction Management (First year seminar, 1 unit, example of lecture on LC principles)

CONM 102 is a first year 1-unit seminar offered for Construction Management (CONM) majors. While the course covers the fundamentals of construction management to help students get familiar with the type of work and professions they will find in the industry, it also serves to get students acquainted with the J.R. Filanc Construction Engineering and Management Program at SDSU and how to succeed in the CONM major. The course uses a combination of guest speakers, traditional lectures with the use of the TopHat in-class response system for questions, and a simulation to teach students about the importance of site organization.

The simulation used is the House of Cards (Pollesch et al. 2017) which comprises five rounds of play addressing concepts related to the 5S organization method comprising stages of sorting, setting in order, shining, standardizing, and sustaining. By using the 5S method with groups of 3-5 students, they go through the simulation using a deck of cards with three suits representing specialty trades building a structure from ace through king, and the spades representing waste. Several concepts are mimicked during the simulation including ways to reduce waste and improve flow by continuously improving the system, and collaborative work. The simulation starts with a pile of cards in loose format where the students in charge of each suit/trade take their cards to start building sequentially from ace to king. A student on the team is charged with keeping track of the time spent to build. For details about this simulation please refer to Pollesch et al. (2017) and, for more visual information about the play, please refer to the video available at the same reference and at Lean Team (2016).

After each round of play students are asked about how much time they took to build the structure, what they noticed in that round, and what could be done to improve the system. Some of their suggestions are accepted for the next round, based on the original design of the simulation, whereas others are pushed to rounds later in the game. The first rounds are not just disorganized and full of waste, but also communication is not allowed during play and that makes it hard for the players to address mistakes. The entire simulation and discussion takes about 50 minutes.

The main outcome addressed by the simulation used is this course ABET/EAC Outcome 5: “An ability to function effectively on a team whose members together provide leadership, create a collaborative environment, establish goals, plan tasks, and meet objectives” (ABET 2025). Considering that time is kept for each round, teams start competing with one another and the classroom becomes louder after each round. Once students see the rules for the following round, they try to strategize to build faster considering the limitations given to them. After the game, students have a week to add a comment and respond to a post in a discussion board on Canvas (learning management system). Over the past five years, when this simulation has been played, entries show that students clearly connect the concepts mimicked in the simulation and how that impacts site organization, the flow and speed of construction, safety, and reinforces the importance of organization, planning, and communication.

CONE 301 - Construction Ethics, Law, and Contracts (Junior, 3 units, example of lecture on LC principles)

CONE 301 is a third-year course where students learn about construction contracts and construction law, as well as codes of ethics which are used in cases and examples discussed throughout the semester. The course is taught using a combination of traditional lectures, guest speakers, case discussions, and short questions using TopHat to gauge students’ understanding of course content. In the first day of classes, an activity is introduced to illustrate the importance of clear communication and interpretation of requests. Students are given a simple instruction to “draw a house”. No additional information or instructions are given and students are given 45 seconds to draw their house. After 45 seconds, 5-7 students are asked to come to the front of the class with their drawings and show them to the class. It is very evident from the drawings presented that students draw houses with different characteristics, which include different sizes and types of windows and doors, roofs, garages, and number of floors represented. Then, the instructor proceeds with questions about what students noticed in the drawings presented, next, students are asked to share what they observed in this exercise. The entire exercise takes about 10-15 minutes, and it also serves as an ice-breaker on the first day of classes.

Comments provided by students include topics related to the importance of giving and receiving clear instructions, transparency, understanding clients' requirements and what is important to them, and having enough time to properly develop their drawings. All comments point to the importance of construction contracts in construction and the relevance of Outcome 3 (ABET/EAC): "An ability to communicate effectively with a range of audiences".

CONE 520 - Environmentally Conscious Construction (Elective, 3 units, multiple examples of lectures presented throughout the course)

CONE 520 is a senior-level elective course, which can also be taken by graduate students. The course covers principles and solutions related to environmentally conscious construction projects. Contents include the use of the LEED rating system to develop a group project, and a combination of lectures, simulations, and guest speakers throughout the semester.

On the first day of classes, students are put in pairs to get to know each other and play the Architectural Programming (AP) simulation (Solhjol Khah et al. 2019). The AP simulation is played in pairs with one student being the architect and another who is the owner. Students are given "(t)wo 11" X 17" landscape format photocopies with 144 apartment layouts (...) provided for each pair with five variables including: Number of bedrooms, Ability/Disability, Solar Orientation, Open vs. Closed Kitchen, and Quality of Finishes" (Solhjol Khah et al. 2019, 518). The simulation is played in two rounds with the goal of having the architect figure out which floor plan is the one preferred by the owner. In the first round, architects can ask owners two yes/no questions and try to guess what floor plan was selected by the client out of the 144 presented. In the second round, owners are given a scenario, with information about the owners' living style and preferences, which is slowly read to the architect. There is a debrief after each round and students are faced with the differences in communication between the two rounds and how that hinders/facilitates the communication and the architect's task of understanding the owner's wishes (values) as represented by a specific floor plan and avoiding waste time on a wrong design.

Midway through the semester, during the module addressing the design of high-performance buildings, collaborative delivery methods are discussed to emphasize their role in the development of environmentally conscious projects. Before collaborative delivery methods are discussed, students are put into teams of 4-5 to play the Silo Game simulation (Alves 2022), which illustrates the importance of collaboration to achieve environmentally conscious projects. The instructor shares the goal of an owner who wants an environmentally conscious project but also states constraints related to the design. Students are put in teams of 4 where each student takes one of the four roles: architect, civil engineer, mechanical engineer, electrical engineer. The simulation is played in two rounds and takes about 45-50 minutes to complete including the play and discussions after each round. The first-round mimics a siloed design with professionals from different groups talking to one another (e.g., architects from all groups only talking to peer architects) but not with their counterparts in different roles, whereas the second round has students placed in teams containing all roles for their groups and taking advantage of synergies between solutions. At the end of the simulation students recognize the importance of leveraging the knowledge of an interdisciplinary team and exploring solutions that contain a synergistic effect in terms of performance for the project and cost for the owner.

Finally, towards the end of the semester during a module on the importance of construction operations in environmentally conscious projects, students play the Airplane Game (Rybkowski et al., 2008), which is one of the most popular simulations played in the LC community. The simulation uses Lego® bricks to produce an airplane using a production line that moves from the first round using a traditional batching system with no communication, which results in copious amounts waste, to a

collaborative line having parts efficiently flowing towards completion. In this course, the Airplane Game is played in three rounds including the collection of data after each set, a debrief, suggestions for improvement, and predictions for each round played. Throughout the simulation, students develop an understanding of elements related to the effective design of a production system (i.e., batch size vs. one-piece flows, cycle time, lead time, flow, work-in-progress, throughput) and learn to identify and propose solutions to eliminate waste and produce planes in a more efficient fashion. These elements are linked to the importance of designing systems to operate efficiently and sustainably during the construction phase.

Collectively, these simulations and the presentation about each topic support the following student learning outcomes in this course:

- Outcome 1 (after ABET/EAC outcome 1): Identify, formulate, and solve complex civil, construction, and environmental engineering problems by applying principles of engineering, science, and mathematics to development of an environmentally conscious building.
- Outcome 2 (after ABET/EAC outcome 2): Apply engineering design to produce solutions for an environmentally conscious building that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
- Outcome 4 (after ABET/EAC outcome 2): Recognize ethical and professional responsibilities in engineering situations associated with environmentally conscious buildings and projects and make informed judgments, which must consider the impact of civil, construction, and environmental engineering solutions in global, economic, environmental, and societal contexts.
- Outcome 5 (after ABET/EAC outcome 5): Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives related to the design, construction, and operation of an environmentally conscious building.

Final Remarks

This paper presented examples of simulations and approaches to teach Lean Construction to undergraduate students. Student learning outcomes proposed by accreditation boards, and/or adapted for different courses, can be achieved through the incorporation of LC concepts and tools to help students develop a mindset that incorporates Lean in the design, management, and operation of projects. By seamlessly incorporating LC to support the teaching in construction-related programs, the authors expect to support a broader dissemination of LC to improve the delivery of projects. The authors also look forward to expanding this conversation within the Associated Schools of Construction community.

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