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THE EVOLUTION OF LEAN CONSTRUCTION EDUCATION (PART 1 OF 2): AT US-BASED UNIVERSITIES

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ABSTRACT

Effectively transferring lean knowledge and skills to owners, architects, engineers, and constructors (OAEC) requires behavioral changes within an industry that has been legitimately criticized for entrenched practices and low productivity. Documenting how successful that knowledge transfer is taking place can be helpful to those wishing to efficiently introduce lean into their own OAEC organizations.

Lean educational efforts within academic settings have been brought to light through earlier publications. This research identifies the content of lean construction courses from five US-based universities to add to the seven previously documented. Tabulated results revealed that: (a) the content of lean curricula is evolving as grading formats, types of readings, and numbers and types of simulations have grown; and (b) lean curricula as defined by the Associated General Contractors (AGC) lean certification program is starting to permeate academic coursework. This may be a testament that AGC lean certification is providing some advantage in career placement for students.

Investigation of the evolution of lean education within academia helps us better understand a driver of change as students enter the OAEC industry following graduation. The intent of this paper is to document this moment in time, as well as to raise a question about the potential impact of curriculum standardization on future continuous improvement initiatives with respect to lean construction philosophy, methods, and tools, in the OAEC industry.

KEYWORDS

Lean construction education, lean in academia, US-based universities, lean certification

INTRODUCTION

Lean construction pioneer, consultant, and educator Hal Macomberclaims very few contractors, trade partners, architects or engineering firms are truly lean because most are

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operating from only partial experience. Like the ancient Indian parable of the five blind men touching only part of an elephant where each one erroneously comes to believe the animal has the shape and form of a snake (trunk), rope (tail), tree-trunk (leg), fan (ears), spear (tusk), or wall (side), few companies grasp the fuller picture of lean(Schmaltz 2003; Hal Macomber, *Personal Communication*, November 22, 2017).

While there are many definitions of lean, this paper defines lean as *reducing waste and adding value using continuous improvement in a culture of respect* (Rybkowski and Forbes 2016).This description suggests there are at least four critical conceptual parts to the lean "elephant" (e.g. waste, value, continuous improvement, and respect); if any one of the four components is missing, an organization arguably cannot truly be considered lean.

Understanding the full size and shape of the lean animal therefore demands that lean education be both broad and deep. Being able to exercise lean thought means not only nurturing an understanding of lean concepts and principles, but also developing an ability to generate new processes while applying existing ones. Educational specialists reference the importance of teachers engaging students at all levels of the Bloom's Taxonomy pyramid (Bloom et al. 1956; Figure 1).While remembering/recalling information is certainly foundational to the educational process, it is not sufficient; more advanced forms of learning such as applying, analyzing, and creating are also necessary.

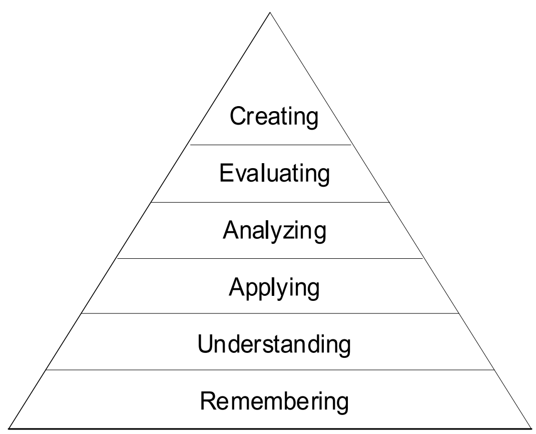

Figure 1: Bloom's taxonomy

To illustrate lean principles to students and effectively engage them at multiple levels, lean pioneer Greg Howell early on began experimenting with serious games and simulations (Tsao and Howell 2015). Serious games are distinguished from simple "gaming" in that the primary aim is educational—i.e.to *learn* through entertainment rather than to be purely entertained (Wouters et al. 2007). Serious games facilitate participant learning through trial and error without risking interference with actual practice. Organizations wishing to inculcate lean thinking use serious games and simulations to teach concepts such as lean processes, supply chain management, sustainable production, logistics, capacity planning, etc. (Pourabdollahian et al. 2012).

Psychologist Csikszentmihalyi described *flow* as the state in which an individual is deeply immersed in an activity, resulting in sense of contentment with little awareness of the passage of time (Csikszentmihalyi 2002). Like scientific experiments, serious games often include a control group, and sequentially modify a single variable that leads to measureable improvements—all while engaging participants in an enjoyable state of play. The most successful simulations immerse players in a state of flow while imparting the lessons intended to be conveyed.

Academics, consultants, and industry practitioners use serious games and simulations, but they are not a panacea. Like all scientific experiments, they must be validated. *Internal validation* means an experiment measures that which researchers believe it is measuring, and *external validation* means the behavioral outcomes predicted by experimental results are applicable to conditions external to that experiment (Jackson 2012).

In addition to internal and external validation, participants must be able to make a cognitive connection between the lean principles illustrated and ways those principles can be applied to actual construction projects. Neeraj et al. (2016) attempted to forge a connection between lean simulations and their onsite manifestations by linking the principles the simulations illustrate to published project case studies.

While serious games are regarded as a hallmark of lean education, no known course on lean consists solely of simulations. Instead serious games are typically embedded into a *structured framework*, offering a deep dive into specific concepts at strategic moments.

Some examples of lean course frameworks include:

- *Factory Physics* and its application to construction (Hopp and Spearman 2001);
- Eleven (11) principles from *Technical Report #72*(Koskela 1992);
- Fourteen (14) principles from *The Toyota Way*(Liker 2003; Figure 2);
- *Lean history and theory* from manufacturing to construction(Taylor 1947; Spriegel & Myers 1953; Gilbreth & Gilbreth 1963; Ohno 1988; Deming [Dawson-Pick 2004]; Liker 2003; Koskela 1992; Ballard 2000; etc.
- *Modern Construction* text (Forbes and Ahmed 2011); and
- Course modules from the Associated General Contractors (AGC 2017).

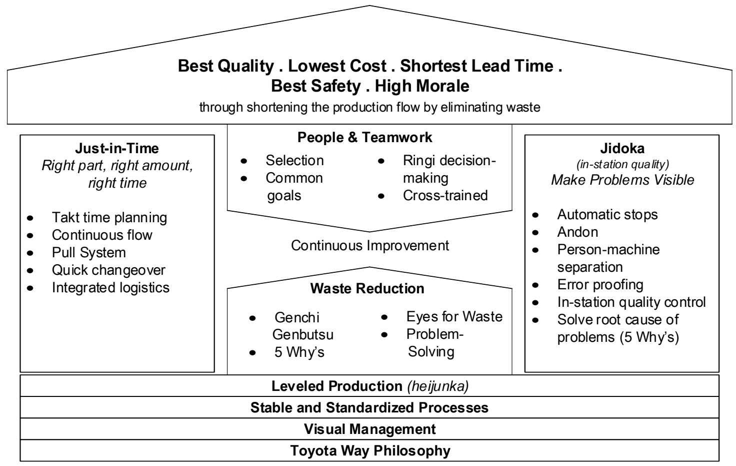

Figure 2: The Toyota Production System as represented in Liker (2003), Figure 3-3, p. 33

THE NEED FOR LEAN: SETTING THE STAGE

One challenge unique to teaching lean at universities that is not shared by those presenting the material to industry representatives and practitioners, is the importance of first establishing the *need* for lean. To students who have yet to work on an actual construction site, lean principles often represent obvious common sense. When one of the co-authors of this paper started teaching lean to a mixed group of undergraduates and graduate students, various methods were used to heighten awareness of the challenges typically faced during project delivery. For example, teams of students were assigned to interview fourteen representative stakeholders about specific challenges the stakeholders faced during their workday. Stakeholders included building owners, architects, structural engineers, mechanical engineers, contractors, specialty contractors, permitting agents, inspectors, vendors, financiers, insurers, attorneys, bonding agencies, and union hall representatives. Students typically expressed surprise about difficulties the practitioners shared during their conversations. These practitioner "deltas" would eventually form the basis for development of the students' final projects—the invention, testing, and reporting of unique and innovative lean simulations designed to address specific challenges mentioned during the stakeholder interviews (Bhaidani et al. 2016; Bhatt et al. 2016; Rybkowski and Kahler 2014; Rybkowski et al. 2011; Rybkowski et al. 2012; Rybkowski et al. 2016).

Similarly, early in a course, students need to be convinced that lean philosophy, methods, and tools offer the potential to solve an organization's problems. Two exercises that help set the stage include: (1) Deming's Red Bead Experiment (Lean Simulations 2017a), and the (2) Repairman Exercise (Mossman 2013; Seddon 2017). In the former, a facilitator assumes the role of a manager who demands her "employees" (audience volunteers) randomly dip a dimpled paddle into a bin of red and white beads while avoiding red beads, where red beads represent an organization's problems. Proverbial sticks and carrots are offered to motivate employees, including threats of firing (the former) and imaginary trips to Hawaii (the latter). Despite their best efforts, players are unable to satisfy their manager's demands because there are significantly more red than white beads in the bin. The purpose of Deming's exercise is to illustrate that the problem of poor performance often rests not with employees, but with a system that makes it impossible for even the most diligent to succeed.

Similarly, during the Repairman Exercise, a facilitator invites her audience to brainstorm all the reasons a house-call repairman may be unable to meet his manager's target average of eight calls per day. The facilitator captures these on a displayed flip chart or computer projection, and, after listing at least ten to twenty possibilities (e.g. traffic, homeowner not in, tools not on truck, bad weather, etc.), s/he invites participants to successively revisit each item on the list and ask: "Is this the fault of the individual repairman or the system?" Inevitably 80 to 90% of the fault lies with the system; yet the repairman is the one who is most often blamed. Blaming the worker for a problem not of his or her own making is not only a recipe for poor morale, it also does not solve the problem. In other words, the intent of both Deming's Red Bead Experiment and the Repairman Game is to set the stage for what is to follow. Once they engage in stakeholder interviews and play either or both of these games, participants tend to become more receptive to learning lean philosophy, methods, and tools.

UNIVERSITY-BASED LEAN EDUCATION

In 2013, Tsao et al. published an inventory of academic lean construction syllabi at seven universities, including an overview of course characteristics, grading metrics, readings assigned (both required and optional) and simulations played. Tsao's articles describe the strategies used by various faculty members, as well as instructions for a number of the most popular simulations (Tsao and Howell 2015; Tsao et al. 2012; Tsao et al. 2013; Tsao et al. 2014). In Table 1, Tsao et al.'s (2013) inventory has been extended to include the lean construction course content of five additional universities. To prepare the expanded table, the co-authors of this paper contacted US-based faculty members they knew were teaching lean, and requested referrals to find additional faculty members they had not previously known. The faculty were invited to fill in a spreadsheet with existing categories and add to these categories as needed.

It is clear from Table 1 that of the 12 universities surveyed, the most frequently played simulations include the Parade of Trades (all 12); the Lego® Airplane Game (or its lower cost variants—the Cup Game, Light Fixture Game, or Make-A-Card) (all 12); and Silent Squares (7 out of 12). From Table 1 it is also clear that of the 12 universities surveyed, the standard required reading diet of most lean construction courses in academia include IGLC papers (9 out of 12), journal papers (7 out of 12), Koskela (1992; 6 out of 12), and Liker (2003; 6 out of 12). The two most commonly played simulations indicate that faculty consider the following concepts critical to Lean thought: reduction of variability (illustrated by Parade of Trades); and materials management, pull, one-piece flow, and balancing workflow (demonstrated by Lego® Airplane Game and/or its variants). Silent Squares is the third most commonly played simulation. This may be due to the fact that it is an easier simulation to set up and faculty regard the demonstration of optimizing the whole over the parts as a critical Lean principle to cover with students. The observation that a majority of Lean faculty require students to read IGLC articles and journal papers, and half of the Lean faculty assign Koskela (1992) and Liker (2003) suggests that they consider these works to be seminal to the understanding of Lean thought. Also of note is that additional material has been added to Table 1 with respect to "Grading," "Readings," and "Simulations," reflecting the continuous improvement of lean construction thought and lean teaching.

Interestingly, Joe Levens' course at Pittsburg State University in Pittsburg, KS, represents a significant departure from previous university courses on Lean Construction because it follows the standard Associated General Contractors' (AGC's) textbook on lean construction and—with the exception of the optional web-based audio book by Paul Akers (2014)—the course is not supplemented with additional required readings. One primary aim of the course is to prepare students to sit for the AGC certificate examination after completing the course, if they so choose. Enrolled Pittsburg State University students and industry representatives alike take the course together in the same university classroom. The site of the course is fluid as well; Pittsburg State students are equally permitted to earn university credit by sitting in the AGC course when offered in Wichita, KS, especially when Levens is serving as local AGC lean course instructor (Joe Levens, *Personal Communication*, November 21, 2017).

ACADEMIC COURSE FRAMEWORKS

Several university faculty commented via e-mail on the conceptual frameworks they employed. The following was communicated by Tariq Adelhamid of Michigan State University: "The conceptual framework I use for the course has always been structured around the premise that Lean Construction is a set of principles and methods that significantly and continuously change what and how we build. I am very keen on emphasizing that Lean Construction has been incorrectly assumed to be related only to the construction phase of a project, while Lean Construction is really Lean in the construction industry, with all of the industry's different providers (owners, architects, engineers, constructors, suppliers, regulators, etc.) considered benefactors of what it has to offer" (Tariq Abdelhamid, *Personal Communication*, January 5, 2018). This comment vividly reflects many of the challenges associated with teaching a university course of Lean—i.e. (1) the reality that the discipline is constantly evolving, as evidenced by the ever-expanding Table 1, and (2) the fact that to maximize success, a culture of lean must permeate not only that of the contractor, but also that of the associated stakeholders as well. The need to "spread lean" to all players has posed to be a significant challenge, and understanding this helps explain the reason why the Associated General Contractors chose to start to develop and standardize an otherwise ever-changing, continuously improving, body of knowledge. This also helps explain why pioneering legal attorneys such as Will Lichtig, took it upon themselves to investigate and write some of the earliest relational contracts for construction, such as the IFOA (Integrated Form of Agreement), and participate in the drafting of Integrated Projected Delivery contracts for the AIA, and Consensus Docs for the AGC. It also explains why Tariq Abdelhamid introduces students to relational contracts as part of his Lean Construction course at Michigan State University. It can be argued that, because the force of law sides with written contracts and many lean projects are now operating under Lean-IPD contracts (or similar), the prognosis for survival of lean construction is greater than earlier, voluntary (i.e. not legally enforceable) collaborative OAEC efforts such as "partnering."

CONCLUSION

Lean construction education—both at universities and in practice—is arguably rooted in lean production theories. The aim of this paper has been to capture a snapshot, through sampling, of university course material that is evolving to include additional readings and simulations. A number of industry practices have been influenced by lean theory developed by academics, as is explored in Part II—a companion article to this paper. An inventory of university curricula suggest there is observable growth with respect to grading, assigned readings, and simulations played. Also, at the time of publication of the Tsao et al. (2013) paper, the Associated General Contractors Lean certification course was still under development. Four years later, not only is the AGC course well-developed and offered to practitioners throughout the US, we are observing its first emergence as a bonafide offering at universities. We observe that graduating students seeking to enhance their credentials in a competitive job market through recognized certifications are increasingly requesting coursework that can do this. Although development of the AGC course and its offering at universities can be viewed as a positive sign that lean construction is "going mainstream" (it is now possible to rapidly grow a workforce of multiple stakeholders who understand lean),a very real concern also arises: i.e. How might standardization of curricula affect the *continuous improvement* process in lean thought itself, which is so fundamental to lean?

REFERENCES

Akers, P. A. (2014). *2-Second Lean: How to grow people and build a lean culture*, 3rd edition, <https://www.youtube.com/watch?v=zbL4LwmWAy0> November 27, 2017.

Associated General Contractors (AGC). (2017). "Lean Construction Education Program," <https://www.agc.org/learn/education-training/lean-construction-education-program>Nov 26.

Ballard, H.G. (2000), *"Last Planner System of Production Control,"* thesis, presented to U. of Birmingham, UK, in partial fulfillment of requirements for Ph.D. degree.

Bhaidani, N., Rybkowski, Z., Smith, J., Choudhury, I., Hill, R. (2016). "Percent Planned Complete: Development and Testing of a Simulation to Increase Reliability in Scheduling." *IGLC-24Proceedings,* Boston, MA.

Bhatt, Y., Rybkowski, Z. K., Kalantar, N., and Fernandez-Solis, J. L. (2016). "Trainathon lean simulation game: Determining perceptions of the value of training among construction stakeholders." *Proceedings of the 24st annual conference of the International Group for Lean Construction*; July 20-22, 2016: Boston, MA, p. 53-62.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., &Krathwohl, D. R. (1956). *Taxonomy of educational objectives*. Handbook 1: Cognitive domain, Longman, NY.

College of Saint Benedict and Saint John's University (2012). "The Red/Black Game."<http://www.cs.csbsju.edu/~lziegler/redblack.html> April 1.

Csikszentmihalyi, M. (2002). *Flow: The psychology of happiness*, Random House: London

Dawson-Pick, D., producer (2004). *W. Edwards Deming: Prophet Unheard* (film), BBC Education & Training, Films for the Humanities, Princeton, N.J., 30 min.

Discovery Village. (2017). “Helium Stick,” <https://www.discoveryvillage.in/activity/helium-stick/> Nov 27, 2017.

Forbes, L. H. and Ahmed, S. M. (2011). *Modern Construction: Lean Project Delivery and Integrated Practices*, CRC Press / Taylor & Francis Group, Boca Raton, 490 pp.

Gilbreth F. B., Jr. and Gilbreth Carey, E. (1963). *Cheaper by the Dozen.* Thomas Y. Crowell Co., New York.

Gloger, B. (2012). “Ball Point Game: Feel the Scrum Flow” (PowerPoint), <https://borisgloger.com/> November 27, 2017.

Goldratt, E.M., and Cox, J. (1986). *The Goal: A Process of Ongoing Improvement.* The North River Press, Croton-on-Hudson, NY.

Hopp, W. J. and Spearman, M. L. (2001). *Factory Physics: Foundations of Manufacturing Management*, Irwin/McGraw-Hill.

Jackson, C. (2012). “Internal and external validity in experimental games: A social reality check,” *European Journal of Development Research*, 24(1), 71-88.

King, J. (2011). “Pull Planning Blocks Simulation.” *DPR Construction*, Oct 21, 2 pp. Konchar, M., and Manshum, A. (2017). *LCI 2017Update*, Apresentation delivered to the 19th LCI Congress, Anaheim, CA, Oct19, 2017.

Koskela, L. (1992). *Application of the New Production Philosophy to Construction*, Technical Report #72, CIFE, Dept. of Civil Engineering, Stanford University.

Lean Construction Institute (LCIa). (2017a). <https://www.leanconstruction.org/about-us/what-is-lean-design-construction/history/>Nov 26, 2017.

Lean Construction Institute (LCI). (2017b). *Make-a-Card Simulation*, <https://www.leanconstruction.org/learning/game-simulations/make-a-card-simulation/> Nov 26.

Lean Construction Institute (LCI). (2017c). *Parade-of-Trades Simulation*, <https://www.leanconstruction.org/learning/game-simulations/parade-of-trades-simulation/>Nov 26.

Lean Construction Institute (LCI). (2017d). Silent Squares Simulation, <https://www.leanconstruction.org/learning/game-simulations/silent-squares-simulation/>Nov 26.

Lean Construction Journal (LCJ). (2017). <https://www.leanconstruction.org/about-us/publications/lean-construction-journal/>Nov 26.

Lean Simulations. (2017a). “Red Bead Experiment,” <http://www.leansimulations.org/2010/09/red-bead-experiment.html>Nov 27.

Lean Simulations. (2017b). “The Lean cups game—What’s a summer without a few cold ones?” <LCI> November 27, 2017.

Liker, J. (2003). *The Toyota Way*, McGraw-Hill, New York, 330 pp.

Martinez, J.C. (1996). "STROBOSCOPE—State and Resource-based Simulation of Construction Processes," *PhD Dissertation*, U. of Michigan, Ann Arbor, Michigan.

Mossman, A. (2013). “The Repairman Game,” PowerPoint slides, The Change Business Ltd. (unpublished work).

Neeraj, A., Rybkowski, Z., Fernandez-Solis, J.L., Hill, R., Tsao, C., Seed, B. and Heinemeier, D. (2016). “Framework Linking Lean Simulation Principles to their Application on Construction Projects.” *IGLC-24 Proceedings.* Boston, MA.

Oglesby, C. H., Parker, H. W., and Howell, G. A. (1989). Productivity Improvement in Construction, McGraw-Hill, New York.

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

Pourabdollahian, B., Taisch, M., and Kerga, E. (2012). “Serious games in manufacturing education.” *Procedia Computer Science*, 15, 256-265.

Rybkowski, Z. K. and Forbes, L. (2016). “Chapter 8: Lean Construction,” in *Handbook of Construction Management: Scope, Schedule, and Cost Control*, edited by A. RazzakRumane, CRC Press Taylor & Francis Group, Florida.

Rybkowski, Z. K. and Kahler, D. (2014). “Collective kaizen and standardization: the development and testing of a new lean simulation,” *IGLC-22 Proc.,*Oslo, Norway.

Rybkowski, Z. K., Munankami, M., Shepley, M. M., and Fernández-Solis, J. L. (2016). “Development and testing of a lean simulation to illustrate key principles of Target Value Design: A first run study.” *IGLC-24 Proceedings,*Boston, MA.

Rybkowski, Z. K., Munankami, M., Smith, J., and Kulkarni, A. (2012). “Survey instrument to facilitate continuous improvement of lean teaching materials: a first-run study," *IGLC-20 Proceedings,*San Diego, CA.

Rybkowski, Z. K., Munankami, M., Gottipati, U., Lavy, S., and Fernández-Solis, J. (2011). “Impact of cost constraints on aesthetic ranking following Target Value Design exercises,” *IGLC-19 Proceedings*, Lima, Peru.

Sacks, R. (2007). Technion LEAPCON Game (Tecnion Lean Apartment Construction Game), 2nd edition, 60 pp.

Sacks, R., Esquenazi, A., and Goldin, M. (2007). "LEAPCON: Simulation of Lean Construction of High-Rise Apartment Buildings." *JCEM*, ASCE, 133(7), 529-539.

Schmaltz, D. A. (2003). *The blind men and the elephant: mastering project work,*Berrett-Koehler Publishers, Inc., San Francisco, CA.

Seddon, J. (2017). “The washing machine repairman,” <www.vanguard-method.com> November 28, 2017.

Smith, J. P. and Rybkowski, Z. K. (2013). “The Maroon and White Game: A simulation of trust and long-term gains and losses," *IGLC-21 Proceedings,*Fortaleza, Brazil.

Spriegel, W.R. and Myers, C.E., eds. (1953). *The Writings of the Gilbreths.* Richard D. Irwin, Inc., Homewood, Ill.

Superteams. (2016). *The 5S Numbers Game*<http://www.superteams.com/new-site/wp-content/uploads/2016/04/SuperTeams5SGameHandout.pdf> November 26, 2017.

TED. (2012) “Tom Wujec: Build a tower, build a team.”<http://www.youtube.com/watch?v=H0_yKBitO8M> April 1, 2012.

Taylor, F.W. (1947). *The Principles of Scientific Management.* W. W. Norton, NY.

Tsao, C. C. Y. and Howell, G. A. (2015). “A history of the use of simulations, the parade of trades, and the pull planning technique in lean construction learning and development,” White Paper, March 03.

Tsao, C. C. Y. and Alves, T. da C. L., and Mitropoulos, P. (2012). “Different perspectives on teaching lean construction,” *IGLC-20 Proceedings*, San Diego, CA.

Tsao, C., Azambuja, M., Hamzeh, F., Menches, C. and Rybkowski, Z. K. (2013). “Teaching lean construction: perspectives on theory and practice," *IGLC-21 Proceedings*, Fortaleza, Brazil.

Tsao, C. C. Y., Draper, J., and Howell, G. A. (2014). “An overview, analysis, and facilitation tips for simulations that support and simulate pull planning,” *IGLC-22 Proceedings*, Oslo, Norway.

Tommelein, I. D., Riley, D.R., and Howell, G.A. (1999). "Parade Game: Impact of Work Flow Variability on Trade Performance." *JCEM*, ASCE, 125(5), 304-310.

Villego® Last Planner® Simulation. (2017). <https://www.villego.com/> (Nov 26, 2017).

Visionary Products Inc. (2008). "Lean Zone Production Methodologies: A Cellular Manufacturing Simulation for 6 to 8 Participants." <http://www.visionaryproducts.biz/index.cfm?action=view&pdfid=232.> (Feb 28, 2008).

Womack, J. P., Jones, D. T., and Roos, D. (1990). *The Machine That Changed the World: The Story of Lean Production*, Free Press, New York.

Wouters, P., Tabbers. H. K., and Paas, F. (2007). “Interactivity in video-based models,” *Educational Psychology Review*, p. 327-342.

Zettel, G. (2014). “Block Tower A-B-C.pptx” Turner Construction PowerPoint slidesfor amending the DPR Pull Planning Game, Anaheim, CA, January.

Table 1: Overview of five introductory university-level courses on Lean Construction. Extension is to seven courses published in the original table by Tsao et al. (2013; grey portion, left). Note "Additional" horizontal sections: "Grading," "Readings," and "Simulations."

OVERVIEW	**U. Cincinnati**	**Arizona State**	**San Diego St.**	**S. Illinois U.**	**Amer. U. Beir.**	**Ill. Inst. Tech.**	**Texas A&M**	**N Carolina St**	**Virginia Tech**	**Colorado St**	**Michigan St**	**Pittsburg St**
Instructor	Tsao	Mitropoulos	Alves	Azambuja	Hamzeh	Menches	Rybkowski	Liu	Muir	Senior	Abdelhamid	Levens
Undergrad/Grad	Both	Graduate	Graduate	Undergrad	Both	Grad	Both	Grad	Undergrad	Grad	Grad	Both
Required/Elective	Both	Required	Required	Elective	Elective	Required	Elective	Elective	Elective	Elective	Elective	Elective
Enrollment	10-26	8 to 24	8 to 23	10 to 25	20 to 22	40	10 to 25	20 to 30	10 to 25	8	10	10 to 15
Semester/Quarter	Quarter	Semester	Semester	Semester	Semester	Semester	Semester	Semester	Semester	Semester	Semester	Semester
Weeks	10 of 10	8 of 16	15 of 15	16 of 16	16 of 16	16 of 16	16 of 16	15	15	16	15	16 of 16
Started	2005	2004	2009	2010	2011	2012	2011	2008	2018 (antic.)	1999	2001	2016
Ended	2008	2010	Continuing	Continuing	Continuing	Continuing	Continuing	Continuing	New	Continuing	Continuing	Continuing
Night/Day	Day	Night	Night	Day	Day	Night	Day	Day	Day	Evening	Evening	Day
Guest lectures	1 to 2	0	5	0	1 to 2	0	2-3	1	2-3	3-4	1-2	None
GRADING												
Assignments	X	X	X	X	X	X	X	X	X	X	X	X
Contribution	X	X	X	X	X	X	X	NA	X	X	X	X
Discussion forums					X			NA			X	
Exams	X	X	X	X	X	X	X	X	X	X	X	
Field trip	Toyota						Toyota	X	X		X	LCI Kansas Cty
Reflection papers	X				X			X	X	X	X	
Simulations	X	X	X	X	X		X	X	X	X	X	X
Team projects	X	X	X	X	X	X	X	X	X	X	X	X
Additional:												
Video presentation										X		
READINGS												
Ballard 2000							Required	Required	Required	Required	Optional	
Factory Physics			Recommend								Optional	
Gilbreths 1963							Required				Optional	
Goldratt 1992	Required	Required					Ch 13 req'd	Required		Required	Optional	
IGLC papers		Required	Required	Required	Required		Required	Required	Required	Required	Required	
Journal papers				Required	Required		Required	Required	Required	Required	Required	
Koskela 1992	Required	Required	Required				Required	Required		Required	Optional	
LCI white papers			Required					Required	Required		Optional	
Liker 2003	Required	Required	Recommend	Required	Required	Required	Required				Optional	
Oglesby 1989		Required						Required		Required	Required	
Taylor 1947							Required			Required	Optional	
Womack at al.1990	Required	Required				Recommend		Required			Optional	
Additional:												
AGC Textbook											Optional	Required
Aker, 2nd ed.											Optional	Optional
Forbes & Ahmed 2010											Required	
Martinez 1996											Required	
Schmaltz 2017											Required	
SIMULATIONS												
5S Game							X				X	
Airplane Game	X		X	X	X		X	X	X		X	
Cocktail Napkin							X					
Cups Game		X				X						
Delta Design	X										X	
Deming's Red-Bead							X			X	X	
Helium Stick	X				X			X				
Leapcon				X		X					X	
Magic Tarp	X											
Maroon-White					variant		X				X	
Origami Game	X											
Parade Game	X	X	X	X	X	X	X	X	X	X	X	X
Radioactive Popcorn				X								
Silent Squares			X	X	X	X		X	X		X	
TVD Game							X				X	
Win As Much As…	X				X	X				X	X	
Additional:												
Ball Game											X	X
DPR Block Tower									X			X
Gemba Walk									X			
Last Planner (AGC)											X	
Leadership Styles											X	X
Lego Hotel/Tower											X	X
Light Fixtures										X	X	
Make-a-Card											variant	X
Marshmallow Challng											X	
NASA Survive/ Moon											variant	X
No./Task Switching											X	
Oops								X				
Original Dice Game											X	
Prison Door Case											X	
Repairman												
Villego								X			X	X