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 Macomber claims 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.

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).
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
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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?

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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.”

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| Exam | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
| Fieldtrip | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
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Simulations:

| SS Game | X | X | X | X | X | X | X | X | X | X |
| Ansara Game | X | X | X | X | X | X | X | X | X | X |
| Colonial Ramp | X | X | X | X | X | X | X | X | X | X |
| Cupa Game | X | X | X | X | X | X | X | X | X | X |
| Delta Design | X | X | X | X | X | X | X | X | X | X |
| Daring’s Red-Bead | X | X | X | X | X | X | X | X | X | X |
| Halmam Skill | X | X | X | X | X | X | X | X | X | X |
| Leipoco | X | X | X | X | X | X | X | X | X | X |
| Magic Tape | X | X | X | X | X | X | X | X | X | X |
| Marion-White | X | X | X | X | X | X | X | X | X | X |
| Origem Game | X | X | X | X | X | X | X | X | X | X |
| Parade Game | X | X | X | X | X | X | X | X | X | X |
| Radiactive Popcorn | X | X | X | X | X | X | X | X | X | X |
| Silent-Squana | X | X | X | X | X | X | X | X | X | X |
| T/C Game | X | X | X | X | X | X | X | X | X | X |

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| Gentle Walk | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
| Last Planner (AGC) | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
| Lean Startup Skills | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
| Lego HotelTower | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
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| Mass/Weight-Chaining | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
| NASA Survival Moon | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
| No-Task Switching | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
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| Original/Off Game | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
| Prison Door Cage | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |
| Repairman | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required | Required |

Teaching Lean 1023