# DIFFERENT PERSPECTIVES ON TEACHING LEAN CONSTRUCTION

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## ABSTRACT

There has been limited documentation in the literature on the structure of Lean Construction (LC) teaching. This may be due to the existence of multiple theoretical interpretations of LC and how its concepts may be adapted and applied in different project life cycle phases by using various tools, systems, and processes. To contribute to the discussion on teaching LC, this paper describes three distinct perspectives based on the authors' experiences teaching in universities in the U.S. and Brazil. Specifically, we discuss how our teaching approaches involve readings, lectures, discussions, simulation exercises, team projects and assignments, field trips, and guest speakers to mix theory with action. This paper seeks to (1) document experiences and lessons learned from multiple LC course offerings and (2) promote the exchange of ideas between those teaching LC. Leveraging our unique teaching approaches and lessons learned, we develop basic recommendations for teaching an introductory course on LC in universities. While this paper's primary audience will be those who teach university students, we hope those who teach practitioners will also benefit from the proposed instruction structure, participate in the conversation on teaching LC, and offer new ideas for providing "proof of concept" to students.

## KEY WORDS

University Teaching, Syllabus Design, Instruction Structure, Lessons Learned

## INTRODUCTION

After reviewing International Group for Lean Construction (IGLC) conference papers from 2001 to 2010 and Lean Construction Journal (LCJ) papers from 2004 to 2012 that have titles that contain "teach," "learn," "instruct," "educate," or "train," we found only a few papers that specifically address university teaching. For example, Emmitt (2003) discussed how lean thinking emerged within an architectural teaching module that emphasized sustainability, and Roudebush (2007) discussed implementing Lean Construction (LC) fundamentals within a hands-on laboratory project. Considering this limited documentation, this paper seeks to describe experiences and lessons learned from multiple LC course offerings within a university setting. As Tommelein et al.'s (1998) description of the Parade Game helped others understand how to use "a very simple game" to teach the impact of variability on work flow, the descriptions of our university courses aim to help others

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understand how a variety of teaching approaches may be used to teach different LC principles and techniques.

This paper also seeks to promote a conversation that facilitates an exchange of ideas between those teaching or preparing to teach LC amongst the approximately 348 members of the IGLC Yahoo! Group, 346 members of the IGLC LinkedIn Group, and 120 members of the Lean Construction Institute (LCI) Academic Forum's Google Group (71 of whom are identified as teachers of LC by LCI Academic Forum Chairperson Tariq Abdelhamid).

## TEACHING LEAN CONSTRUCTION BY LCI

Since its inception in 1997, LCI has shared resources for learning and teaching LC with the general public. Anyone can join LCI's e-mail list to access introductory readings and white papers on LCI's website. Through the years, LCI co-founders Greg Howell and Glenn Ballard have provided tips and guidance to students and instructors who were learning and learning to teach LC. LCI's 2-day "Introduction to Lean Construction" seminars include a history of LC, LC simulations, basic LC principles and techniques, and case studies in LC implementation.

In January 2001, LCI started the LCI Academic Forum (AF) and designated Professor Tariq Abdelhamid of Michigan State University (MSU) as its chairperson in early 2002. The AF's mission is to "increase LC research and teaching activities in institutions of higher education, and act as a liaison to industry associations and/or organizations seeking to establish research and professional development programs (LCI 2012)." The 'academic' in the forum's title refers to LC issues related to instruction and research initiatives managed by practitioners and academics. Annual AF meetings review the history of LCI, the AF, the Lean Project Delivery System™, instructional simulation models, and the status of LC teaching and research. Attendees included students and faculty as well as a few researchers from practice.

## TEACHING LEAN CONSTRUCTION BY AGC

Since Associated General Contractors of America (AGC) member companies found it challenging and expensive to develop their own LC education programs, AGC issued a request for proposal (RFP) for a LC education program in the summer of 2009 to provide a more cost-effective approach for training professionals in LC.

In Phase I of the program, Enovio Consulting worked with Professor Abdelhamid of MSU to develop a 175-hour curriculum plan that was announced in January 2010. Enovio then developed a business plan with AGC that reduced the curriculum plan to 45 hours to make the program more sustainable. In the revised curriculum, students will first take a one-hour "Lean Construction 101" online course. Then, they will take the following courses through AGC chapters: (1) Variation in Production Systems, (2) Pull in Production, (3) Lean Workstructuring, (4) Production Management, (5) Management by Values, (6) Lean Supply Chain, (7) Lean Assembly, and (8) Problem-solving Principles and Tools. As of March 2012, Lean Construction 101 and Units #1 and #2 have been released as part of Phase II of the program, with the remaining units to be rolled out over 2013 and 2014 in the third and final phase.

After completing the eight courses, "participants will be qualified to sit for an exam [to] earn AGC's Certificate of Management – Lean Construction (CM-LC)" (AGC 2012). Although the AGC program is geared for practitioners, it is important for university instructors to not only be aware of the emerging program but also learn how to align their courses to complement AGC's as well as any other practitioner training programs that may develop. Then, students can better communicate with potential employers about the LC training that they have already acquired in school.

## TEACHING IN THE LEAN COMMUNITY

Howell et al. (2011, p.741) made a bold statement about the state of Construction Engineering and Management (CEM) as a discipline: *"The design of project-based production systems and the structure of work are not addressed in CM beyond specifying trades. CM is taught in these programs and understood more broadly in the industry as the management of contracts organized by CPM."* With this in mind, Howell et al. called on CEM programs to develop students in the design of production systems in construction as an intrinsic part of the CEM discipline. To do so, courses should include production system design assignments in their curricula, in addition to more traditional topics (e.g., CPM scheduling and contract management).

Teaching a course on LC typically requires the instructor to assemble a variety of texts that suit the learning outcomes of the course, which may encompass gaining a broad understanding of how LC can be applied to construction contracts, design and office activities, field operations, supply chain relationships, and ownership of capital projects. There are different interpretations of what LC means in academia and in the industry (Green and May 2005). This might be viewed as critical to advancing LC research, practice, and education as tools and concepts are conveniently picked by practitioners and educators but not applied with a true north in mind and used in an integrated fashion (Alves et al. 2010). So far, no single textbook has provided a definitive interpretation of what LC means, even though attempts have been made towards unifying the multiple streams of theory that are recognized as such (e.g., Forbes and Ahmed 2011). In addition, some manufacturing-oriented books have served as the basis for graduate courses and industry book reading clubs. Some examples include Factory Physics (Hopp and Spearman 2000), The Toyota Way (Liker 2003), and the seminal Toyota Production System (Ohno 1988).

In a recent study with members of the Associated Schools of Construction in the U.S., in which most of the respondents were from Construction Management programs, only a handful of them had courses solely focused on LC (Johnson and Gunderson 2009). Johnson and Gunderson (2009) also investigated other trends in the AEC (e.g., BIM, LEED) and questioned: Should accreditation requirements be updated to require programs to educate students about specific industry trends?

Along these lines, Hyatt (2011) developed an undergraduate course in which Lean, BIM, and sustainability were integrated in a single course to make students aware of these trends in the industry and how they are intertwined in a project. To overcome the challenges in developing such a course, Hyatt used the Last Planner System's (LPS) four phases (i.e., master schedule, phase schedule, lookahead plan, commitment plan) to detail the plans for a LEED project throughout time so that students could learn about the importance of planning and making sound commitments over time. Similarly, Izquierdo et al. (2011) developed a Basic Management Functions Workshop (BMFW) to train construction company employees in competencies to promote employee growth and adherence to LC principles (maximize value and minimize waste for their clients). Based on qualitative participant feedback, Izquierdo et al. suggested that the development of real case studies was the preferred means to teach the Lean philosophy.

To contribute to this ongoing discussion, what follows is a discussion of the authors' individual experiences in teaching undergraduate and graduate LC courses at different institutions of higher education in the U.S. and Brazil.

## INDIVIDUAL EXPERIENCES IN TEACHING LEAN CONSTRUCTION

### UNIV. OF CINCINNATI: UNDERGRAD + GRAD LEVEL, 10-WEEK QUARTER (TSAO)

The University of Cincinnati set the course title as "Case Studies in Construction" to provide flexibility for different instructors. Likewise, Tsao selected broader course objectives to provide flexibility in course design and adjustment. In 2008, this course's objective was, *"Introduce students to Lean Project Delivery through games and examples that illustrate lean theory, principles, and techniques."* Thus, Tsao aimed to provide students a basic background in lean manufacturing and LC.

Grading factored in a combination of class attendance, class facilitations, field trip attendance and reflection, weekly reflections, team projects, final exam, guest lecturer attendance and reflection, Last Planner System™ (LPS) assignments, Value Stream Mapping (VSM) assignments, and simulation exercises. Table 1 illustrates the workflow of readings, simulations, field trips, and guest lecturers every year.

Table 1: Tsao's Course Design at Univ. of Cincinnati (Nos. represent Week #)

| **READINGS** | **'05** | **'06** | **'07** | **'08** | **SIMULATIONS** | **'05** | **'06** | **'07** | **'08** |
|---|---|---|---|---|---|---|---|---|---|
| Kubal '94 | 2-4 | 6-7 | | | Airplane Game | | 1 | 2-3 | 2-3 |
| Womack '91 | 6-8 | 1-2, 5 | | | Origami Game | | 5-8 | 4-5 | 2, 5-6 |
| Koskela '92 | 9 | 9 | 8 | 8 | Delta Design | 1 | 8-10 | 8-9 | 7-9 |
| Goldratt '92 | | 3-4 | 1-2 | 1-2 | Parade Game | 5 | 3 | 6-7 | 6-7 |
| Liker '03 | | | 3-6 | 3-7 | Win As Much… | | | | 10 |
| **Field Trip** | 8 | 6 | 6 | 6 | **Guest Lecturer** | 8 | 4 | 9 | 9-10 |

The next sections describe how certain course elements facilitated lean learning as Tsao modified the course each year based on student feedback and lessons learned.

**Readings** – Tsao scheduled readings to provide students a background in lean manufacturing before delving into LC. Due to an overwhelmingly positive student response to Goldratt and Cox (1992), Tsao started beginning the course with the novel. When students used the novel as a learning framework in 2007, they realized by the course's end that they were behaving like "Alex" and Tsao was like "Jonah."

**Field Trip** – Tsao coordinated visits to the Toyota Motor Manufacturing Plant in Georgetown, Kentucky so students could observe lean principles and techniques in action, including the use of the Andon cord, Kanban cards, 5S, one-piece flow, takt time, and small buffers of Work-In-Process (WIP). Tsao scheduled these visits after the lean manufacturing readings but before the LC readings so that students were able to use the field trip as a reference point for discussing LC implementations.

**Simulation Exercises** – Tsao scheduled the students to play the Airplane Game and the Origami Game before the field trip to help them learn about the impact of batching work, introducing one-piece flow, balancing work between stations, and managing quality control. Then, Tsao scheduled the students to play the Parade Game to demonstrate the impact of variability on workflow so that they can appreciate why the Last Planner System™ (LPS) encouraged workers to increase their reliability in keeping commitments. Tsao used the Delta Design Game to help students appreciate the challenges of design management and explore how lean thinking can help. Finally, Tsao scheduled students to play the Helium Stick Game and Win as Much as You Can Game to segue into the discussion on Target Value Design (TVD) and Integrated Project Delivery (IPD).

**LPS Assignment** – Since all undergraduates enrolled in the LC course were also enrolled in the senior capstone course, Tsao coordinated with the capstone instructor to introduce an LPS assignment that bridged both courses. Tsao provided instruction on Weekly Work Plans within the capstone course, and students were required by both courses to track their Percent Planned Complete and constraints analysis for their capstone team. Thus, after playing the Parade Game, students not only learned about the LPS, they experienced first-hand the challenges of keeping their commitments. Unfortunately, there was not enough time to review in greater detail the challenges that current AEC projects face in using the LPS.

**Google Document Assignment** – Tsao tasked students with posting photos and explanations of non-AEC examples that illustrated lean principles and techniques on a common Google Document. This assignment encouraged students to develop visually engaging lean examples, thus enabling students to learn from each other.

**Reading Facilitations** – To encourage more student discussion, Tsao formed students into small groups responsible for giving presentations about reading assignments. While some presentations were more interactive than instructor lectures, others were dry and over-loaded. As a result, Tsao tasked the following year's student groups with facilitating discussions about reading assignments. This subtle change resulted in better discussions as students encouraged participation by their peers.

### ARIZONA STATE UNIV.: GRADUATE LEVEL, 16-WEEK SEMESTER (MITROPOULOS)

This course was taught at ASU from 2004 to 2010. In this case, the teaching of LC was "injected" in a traditional productivity improvement course, and the lean portion of the course occurred over 8 weeks of the 16-week semester. The course was organized into two parts: Part I focused on improving independent operations, and Part II focused on improving the workflow in a system of interdependent operations.

Table 3 on the next page illustrates key concepts that the course is trying to introduce to students, along with associated readings and activities. Although "Lean" is formally introduced in Part 2, several important lean concepts are also introduced in Part 1. For example the importance of work planning, removing constraints, and reliable commitments has always been a part of productivity improvement (Oglesby et al. 1989), although not specifically with these terms. Similarly, the discussion of material management introduced the concepts of Just-In-Time (JIT) and the requirements for JIT (e.g., reliable planning horizon vs. cycle time).

Part 2 focuses on the importance of workflow for overall project performance. The concept of system performance vs. resource efficiency is first introduced with

Goldratt and Cox (1992). This leads into the discussion of different production systems. Womack et al. (1991) and the Cups Game (the poor people's version of the Airplane Game) are used as the basis for comparing traditional and lean manufacturing. The Parade Game then demonstrates the basic principle of "Dependence and Variation = Waste." This leads to the discussion of Last Planner System™ (LPS) as a method to increase plan reliability. The issue of reliable work commitments is discussed next, as the reliability of the LPS depends on the project organization's ability to make reliable promises in removing constraints. Next, Integrated Project Delivery (IPD) is discussed as a contractual framework that promotes global optimization by motivating project participants to improve the whole production system, rather than their own operation.

Table 3: Structure of Mitropoulos' Traditional Productivity Improvement Course

| CONCEPTS | READINGS | ACTIVITIES |
|---|---|---|
| **Part I: Improving individual activities** | | |
| Continuous improvement | Leadership at Toyota | |
| Operations design (coupling) | Subcycles (Howell '93)<br>Cases (Oglesby '89)<br>Video: Cable pulling | Team Project 1: videotape and analyze operation |
| Material management system | Several readings | Team Project 2: Describe material management system, evaluate effect on productivity |
| Work planning | Oglesby et al. 1989 | |
| Work design for productivity and safety | Task demand assessment | Team Project 3: Analyze operation for productivity & safety |
| **Part II: Improving the production system** | | |
| Optimize system vs. function | Goldratt & Cox 1992 | |
| Production systems (waste, batch, stop the line, etc.) | Womack et al. 1991 | The Cups game |
| Importance of Reliability (effect of Dependence *and* Variation) | | Parade Game |
| Lean Principles | Liker 2003 | Team Assignment: Divide principles to groups to lead discussion. |
| System to increase reliability (Last Planner System™) | Several readings | Team Project 4: Evaluate plan reliability (PPC) on a project |
| Behaviors to increase reliability | Language/Action Perspective | |
| Contracts to support system optimization | Matthews and Howell 2005 | |

Mitropoulos integrated several lean concepts with traditional productivity improvement material. An important observation was that it was easier for the students to understand the lean concepts first through examples, activities, and cases before discussing the principles. As a result, readings that are "heavy" on principles (e.g., Koskela 1992, Liker 2003) were either removed or assigned after the students had an understanding of the specific techniques that the principles refer to.

### SAN DIEGO STATE UNIV.: GRADUATE LEVEL, 15-WEEK SEMESTER (ALVES)

The course outcomes were defined to promote the view of construction-related systems from a production standpoint. Students should be able to:

*A. **Recognize and explain** how characteristics of AEC practice and in project-based systems affect performance.*
*B. **Recognize, compare and contrast** traditional vs. innovative practices used in the architecture, engineering, and construction (AEC) industry and project-based systems.*
*C. **Recognize, explain and apply** concepts, principles and tools from other industry/service sectors to the AEC industries and project-based systems.*
*D. **Evaluate** the current design of project-based production systems and operations and **recommend** improved future states.*
*E. **Design** production systems and operations in different stages of the AEC processes and buildings life cycle (design, construction, operation and maintenance).*
*F. **Formulate** production planning and control systems for project-based production systems.*

To help students build these abilities throughout the semester, Alves designed the course to provide an overview of topics related to LC starting with the characterization of project-based production systems and the AEC industry, and what makes these systems different from other commonly found production systems (e.g., batch systems, linear production, job shops). This topic (first week), is followed by a discussion of how production management systems evolved (from Taylor and Ford to Toyota) and how waste was perceived in different points in time. At this stage, students play the Airplane Game and debrief what they learned and how that applies to the AEC industry, and get more familiar with how production system parameters are inter-related (e.g., batch size, cycle/lead time first pass yield, buffers). From previous student feedback, the Airplane Game simulation was placed in the beginning of the semester because they can always refer to it and relate to the concepts later.

Next, the discussion shifts to lean production and LC principles, and students develop an assignment in which they have to choose one of the 11 principles outlined by Koskela (1992) and find an example outside AEC and another one in AEC where the principle is used or could be used and discuss specific details about the example. This exercise was designed by professor Aguinaldo dos Santos (UFPR, Brazil) in late 1990s and it is very useful to help the students develop a sense of benchmarking other sectors for good examples that can be applied to the AEC. Following this discussion, the LPS™ is presented as a means to help the AEC gain stability through the shielding of production. During this stage students are asked to reflect upon the need to plan in stages: the concept of planning as a multi-stage process (not solely focused on scheduling) and the need to develop plans in different hierarchical levels to account for uncertainty in different points in time.

The next stage of the course focuses on presenting how these LC can be used in different areas of the industry namely: office-related activities, product development, contractual arrangements to support lean construction projects, and supply chain management. Also, during these classes, students play the “silent squares” simulation and develop an activity to identify/measure value (e.g., how much they value items in a classroom v. how much they are satisfied with the current conditions followed by a discussion based on their feedback). This is followed by a week on how technology supports basic tenets of LC, and how technologies should be analyzed based on how they support the delivery of projects with better value for the customer while improving processes for those involved. The semester closes with a more detailed discussion on how LC and sustainability practices are inter-related (Lean and Green). This last topic helps students think about LC as a means to design, build, operate, and maintain more sustainable structures, and to highlight the synergistic effects between LC and the "green" movement.

Students are required to develop two major team projects. One is to create an educational video illustrating specific concepts, principles, and tools in action. The other is the analysis of the production system design and the planning system of a construction project. Other course elements include guest speakers, simulations, metaphors, and acting to represent what they learned. These elements help students build an understanding about the concepts and principles and link them to AEC work. These are valuable for students without much AEC experience to help them build confidence about how the concepts are used, and they are also used to help veterans demystify the idea that these concepts are not applicable in the AEC industry.

## RECOMMENDATIONS BASED ON OUR EXPERIENCE

Table 4 on the next page outlines recommendations for learning modules, outcomes, and teaching strategies for an introductory LC course based on commonalities amongst the teaching approaches taken by the authors, LCI, and AGC. While this list may serve as a starting point for those teaching LC for the first time, we encourage new instructors to develop and test their own unique approaches to teaching LC.

## CONCLUSIONS

This paper described LC teaching approaches from: (1) LCI, (2) AGC, (3) the community as a whole, and (4) the authors' experiences at different universities. While many more individuals will share their ideas on teaching LC in open forums on social networks, this paper seeks to make explicit essential LC topics for students and seasoned practitioners. Specifically, we clarified the basic foundations and structures of our own courses and identified learning modules, outcomes, and teaching strategies to assist those preparing to teach LC. We hope to inspire researchers from academia and practice to share their own approaches and lessons learned to fuel an active discussion on teaching LC. Then, future research may begin studying the effectiveness of the more popular teaching approaches being used by instructors.

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## REFERENCES

AGC (2012). "AGC's LC Education Program." Available at: http://www.agc.org/galleries/career/AGC_LCEP_Flyer_Overview_0212.pdf, accessed on 4/10/2012.

Alves, T.C.L., Milberg, C.T., and Walsh, K.D. (2010) "Exploring Lean Construction Practice, Research, and Education," *18th Intl. Group for Lean Construction Conf. Proceedings* (IGLC-18), Technion, Haifa, Israel, pp. 435-444.

Table 4: Recommendations for Teaching Introduction to Lean Construction

| LEARNING MODULES | | LEARNING OUTCOMES |
|---|---|---|
| Management of Production: Concepts, Variables, and Types of Systems | A | *Differentiate* push/pull/hybrid systems. *Differentiate* types of production system organizations (project, job shop, batch, assembly line, continuous flow, make-to-stock, -order, etc.). |
| | B | *Identify* production variables, *explain* how they are related, *predict* systems behaviors: lead time, cycle time, takt time, batch sizes, buffers, first pass yield, productivity. |
| | C | *Explain* Koskela's Transformation/Flow/Value categorization. *Recognize* different views on waste (e.g., Taylor, Ford, Ohno, Shingo) and how activities might be categorized into value-adding, supporting, and waste-generating. |
| Koskela's (1992) "11 LC Principles" | D | *Explain* concepts and characteristics related to Koskela's 11 principles and *illustrate* how they are used in and outside of AEC: transparency, flexibility, value (client's perspective), variability, complexity, continuous improvement, & benchmark. |
| Basic Tenets of Last Planner System™ | E | *Recognize* and *explain* concepts related to the LPS™: shielding production against variation, planning as a multi-stage process, planning in different levels (detail as more information becomes available), First Run Studies, make ready process, pull planning, constraints analysis, workable backlog. *Recognize* the LPS™ as a network of commitments. *Explain* Language/Action Perspective. *Engage* students in weekly work planning and measure PPC to experience LPS in action. |
| The Toyota Way's 14 Lean Principles (Liker 2003) | F | *Explain* lean principles in student-led discussions. *Identify* visual non-AEC and AEC examples illustrating lean principles. |
| Integrated Project Delivery | G | *Compare and contrast* traditional vs. IPD contracts in terms of organization, commercial terms, and operational systems. *Clarify* how projects determine who pays vs. who gains. |
| Work Structuring and Supply Chain Management | H | *Investigate* how projects structure work. *Understand* how techniques such as Set-Based Design, Target Value Design, and Choosing By Advantages can assist with work structuring. |

**TEACHING STRATEGIES TO ACHIEVE LEARNING OUTCOMES**

| | |
|---|---|
| Published Case Studies<br>Reading Assignments | Comprehensive collections of LC readings in "Readings" section of LCI's webpage, iglc.net, and leanconstructionjournal.org provide peer-reviewed case studies free of charge. |
| Simulations | Effective way to demonstrate in a controlled environment how the concepts are inter-related. Provide framework for anchoring discussions during the semester. Facilitate comprehension of concepts by students without AEC experience and helps practitioners relate the variables to their own environments. |
| Team Projects | Help students conduct a deeper-dive into lean concepts and techniques. Challenge students to engage in critical thinking. |
| Discussion Facilitations | Develop facilitation skills in students. Increase student ownership of course. Explore cause and effect relationships in AEC practice. |
| Guest Speakers<br>Field Trips | Expose students to how course concepts are adapted and applied in real project environments. Provide proof of concept to the theory as students see its implementation by different professionals. |
| Value Stream Mapping (swim-lane / process maps) | Make the analysis of systems more visual. Increase transparency of workflow and handoffs of work between AEC practitioners. |

## REFERENCES (CONTINUED)

Emmitt, S. (2003). "Learning to Think and Detail from First (Leaner) Principles." *11th Intl. Group for Lean Constr. Conf. Proc.*, Virginia Tech, Blacksburg, VA. Forbes, L. and Ahmed, S.M. (2011). *Modern Construction: Lean Project Delivery and Integrated Practices.* CRC Press: Boca Raton, FL. 490 pp.

Goldratt, E.M., and Cox, J. (1992). *The Goal: A Process of Ongoing Improvement*, North River Press, Great Barrington, MA, 384 pp.

Green, S.D. and May, S.C. (2005) "Lean Construction: Arenas of Enactment, models of Diffusion and the Meaning of 'Leanness.'" *Bldg Res. and Inf.*, 33(6), 498-511.

Hopp, W.J. and Spearman, M.L. (2000). *Factory Physics.* 2nd Ed. McGraw-Hill International Editions: Boston, MA, 698 pp. (First Edition 1996)

Howell, G., Laufer, A., and Ballard, G. (1993). "Interaction between Subcycles: One Key to Improved Methods." *J. Constr. Engrg. & Mgmt.*, ASCE, 119(4), 714-728.

Howell, G., Ballard, G. and Tommelein, I. (2011). "Construction Engineering – Reinvigorating the Discipline." *J. Constr. Engrg. and Mgmt.*, 137(10), 740-744.

Hyatt, B.A. (2011). "A Case Study in Integrating Lean, Green, BIM into an Undergraduate Construction Management Scheduling Course", *Intl. Proc. of the 47th Annual Conference*, ASC, University of Nebraska, Lincoln, NE, 8 pp.

Izquierdo, J.L., Cerf, M., and Goméz, S.A. (2011). "Lean Construction Education: Basic Management Functions Workshop." *19th Intl. Group for Lean Construction Conf. Proceedings* (IGLC-19), Lima, Peru, 344-355.

Johnson, B.T. and Gunderson, D.E. (2009). "Educating Students concerning Recent Trends in AEC: A Survey of ASC Member Programs." *Intl. Proceedings of the 45th Annual Conference*, ASC, University of Florida, Gainesville, FL, 8 pp.

Koskela, L. (1992). *Application of the New Production Philosophy to the Construction Industry*, Stanford Univ., Dept. of Civil Eng., Center for Integrated Facilities Engineering, Technical Report No. 72, Sept., 75 pp.

Kubal, M.T. (1994). *Engineered Quality in Construction: Partnering and TQM*, McGraw-Hill, New York, 318 pp.

LCI (2012). "The Lean Construction Institute Academic Forum." Available at: https://www.msu.edu/user/tariq/Forum.htm, accessed on 4/10/2012.

Liker, J. (2003). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw-Hill, New York, 350 pp.

Matthews, O. and Howell, G.A. (2005). "Integrated Project Delivery An Example of Relational Contracting." *Lean Construction Journal*, 2(1), 46-61.

Oglesby, C.H., Parker, H.W., and Howell, G.A. (1989). Productivity Improvement in Construction, McGraw Hill: Boston, 588 pp.

Ohno, T. (1988). *Toyota Production System: beyond Large-Scale Production.* Productivity Press: Cambridge, Mass. 142 pp.

Roudebush, W.H. (2007). "Inclusion of Lean Construction in Construction Education." *15th Intl. Group for Lean Construction Conf. Proceedings* (IGLC-15), Michigan State Univ., East Lansing, MI, 254-259.

Tommelein, I.D., Riley, D., and Howell, G.A. (1998). "Parade Game: Impact of Work Flow Variability on Succeeding Trade Performance." *6th Intl. Group for Lean Construction Conf. Proceedings* (IGLC-6), Guaruja, Brazil, 14 pp.

Womack, J.P., Jones, D.T., and Roos, D. (1991). *The Machine That Changed the World*, Harper Collins / Perennial, New York, 336 pp.