

Incorporating lean in CM education to improve the construction industry - proposing a model

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This research project takes an in depth look at the current state of education on lean principles in undergraduate programs across the United States in order to recommend improvements in implementation. A strong, standardized lean curriculum will enable students to carry that knowledge into future jobs, thereby eventually providing the entire industry with the benefits of lean construction. A review of schools affiliated with the Associated Schools of Construction (ASC) indicated that 49 of the 103 schools that offer a lean curriculum have lean in their construction programs. There are 8 schools with lean principles integrated into their civil engineering programs and 47 schools with lean principles included in other engineering programs. The 61 courses in construction programs, nine courses in civil engineering programs, and 69 courses in all other engineering programs account for 61 percent of the lean courses offered. The remaining 39 percent are distributed across business, management, manufacturing, statistics, supply chain and operation management, technology, and all other programs. Recommendations on developing a standardized lean curriculum include inviting guest lecturers from industry practitioners, and field visits with local contractors as an opportunity for lean construction learning.

Keywords: Lean, Lean Construction, Lean Project Delivery, IPD, BIM

Introduction

Lean Construction has caught the attention of the design and construction industry. The McGraw Hill Company conducted an extensive survey of lean practices in 2013, reporting that "*business as usual can no longer be an acceptable approach in the construction industry. Lean Construction offers an alternative that allows companies to thrive in any economic conditions*." This Smart Market Report cited the percentages of companies reporting improvements as: Higher Quality Construction 84%, Greater Customer Satisfaction 80%, Greater Productivity 77%, and Improved Safety 77%. Many researchers and professionals have stated a need for improvements as well. Many public projects have experienced cost and schedule overruns that point to the shortcomings of traditional construction. The "Boston Big Dig" experienced a cost growth of 460 %; the Kennedy Center Parking Lot, 210% cost growth, and the Denver Airport Expansion experienced 180% cost growth. Private projects have likely experienced the same problem although under-reported, so change is needed in the industry.

The design and construction of built facilities represents a major sector of the US economy, hence its productivity has a major impact on the country's economic and competitive position. Productivity is the ratio of outputs to inputs (Sumanth, 1984) and provides a reference point for comparing different project types with other industries. Although estimates by researchers vary, construction productivity grew over a 30 year period at approximately half the two percent plus rate exhibited by manufacturing and non-farm industries (Adrian, 2008; Eastman & Sacks, 2008; Siriwardana & Ruwanpura, 2012). As construction has accounted for as much as eight percent or more of the US GDP, underperformance significantly influences the national economy and the country's competitiveness.

Labor costs account for 40 to 60 percent of typical job costs, yet activity sampling studies have shown that 40 to 60 percent of labor hours are unproductive (Oglesby et al., 1989). A study by the Construction Industry Institute (CII Report RT191) identified non-value-added time in projects of 50 to 75 percent. The diverse causes include poor communications, waiting on assignments or resources, rework, accidents, and lack of supervision. This significantly affects job profitability; industry-wide studies suggest that most construction projects yield net profits of two to three percent of project cost. Given that labor costs are often over 40 percent of project costs, a five percent improvement in labor productivity could potentially improve a contractor's profit by over 60% (Forbes and Ahmed, 2011). While there are competitive pressures in the industry, the similarity of bidding and operating practices masks the need for change.

Construction project performance measures have historically focused on project level outcomes rather than on processes, and their measurement is often delayed until project completion (Formoso & Marosszeky, 2004). These measures have traditionally made simple comparisons between planned and actual time and expenditure. By not addressing the process level they cannot directly drive process improvement. Lean construction addresses that shortcoming by applying weekly (and sometimes daily) measurements, using the lessons learned in the next week and not just in the next project.

Lean Principles

Lean Construction (LC) is an innovative project delivery approach that addresses many of the shortcomings of traditional project management. It has several interpretations, including Lean Design, Lean Project Delivery, Integrated Project Delivery, Collaborative Project Delivery, and Lean Project Management. It is based on the lean production methods developed by Taichii Ohno in the 1950s and used successfully in the Toyota Corporation (Howell, 1999). In the mid – 1970's Toyota reduced the time needed to produce a car from fifteen days to one day. Lean maximizes value and reduces waste. Overproducing, idle time, transporting/conveyance, processing, inventory, excessive operator motion, and producing defective goods are the seven wastes that were identified as inhibiting performance. Later, the waste of human potential was added. The Toyota Production System (TPS) addressed those wastes with the Just-In-Time (JIT) philosophy; its three tenets were minimizing waste in all forms, continuous improvement of processes and systems, and maintaining respect for all workers. The system has led to reduced inventories (and space), higher human productivity, better equipment and material utilization, shorter lead times, fewer errors, and higher morale.

Seminal work by Lauri Koskela (1992) examined design and construction practices and proposed applying a continuous flow approach – as used successfully in the TPS – instead of the disjointed practices of construction project team members. A number of researchers built on this foundation including Glenn Ballard, Greg Howell, and others. Ballard developed a system called The Last Planner System in 1994 and further refined it in 2000 (Ballard, 2000). This refinement focused on managing flows in the construction process, involving the use of buffers to limit the impacts of variability, and using the principles embodied in the TPS. Ballard also developed the Lean Project Delivery System (LPDS) based on those principles.

LC applies these principles to design and construction practices (Forbes and Ahmed, 2011). Traditional construction approaches reward individual crew performance – crews in one discipline tend to focus on their tasks, often to the detriment of other crews. At the design level, professionals often work in "silos" to apply their individual disciplines to the owner's project requirements, but are limited in addressing constructability issues. In the lean approach, all involved disciplines work collaboratively to optimize the overall project, often yielding significant cost savings.

A "lean construction movement" began with the formation of the International Group For Lean Construction (IGLC) in 1993, and the Lean Construction Institute (LCI) in 1997. The advocacy of these non-profit groups has led to a dissemination of lean construction information to industry practitioners in the USA and in other countries. In the wake of those events, universities have begun to respond to a perceived need for a curriculum on lean construction. LC has evolved into several variants such as Lean Project Delivery, Integrated Project Delivery (Matthews and Howell, 2005), Collaborative Project Delivery, and others mentioned above. Various forms of contract such as the Integrated Form of Agreement (Lichtig, 2006) and industry alternatives have evolved to facilitate the close project team collaboration that surpasses the limitations of traditional construction contracts. A number of lean projects use a form of contract that shares cost savings between the owner and the project team, essentially rewarding the team members for improved performance.

In lean projects, it is desirable for each facility (or project) and its delivery process to be designed together to better reveal and support customer requirements. Work is structured throughout the process to maximize value and reduce wastes such as lost time, miscommunication, incorrect design interpretation, and gaps in hand-offs from one discipline to another. Technologies such as Building Information Modeling (BIM) are used to support the collaborative team interactions that are an essential component of the lean methodology.

Although LC is still evolving as a discipline, its benefits have been highly visible since 1994. Research studies such as Ballard, G. and Kim, Y. W., (CII Report 234-11) have documented significant positive outcomes with lean projects – both tangible and intangible. They documented savings of 10% or more and high levels of satisfaction for owners as well as project team members. These include:

- The Sutter Health Care System – the Cardinal Glennon facility, a $43 million, 120,000 sq. ft. addition. The “Last Planner” system was used. Completion was achieved on August 15, 2007, two months early, with only 63 RFIs (requests for information) and no disputes. Safety incidents were only 1.45 reportable per 200,000 hours versus an industry average of 5.9.
- The Terminal 5 project – this Heathrow airport project was completed on time and on budget. The civil phase was 10% under budget, with savings of approximately $125 million.
- Walbridge Aldinger - a multi-phase 5-year project with savings of $9 million over 3 years, (65% of total savings were returned to the owner).
- Westbrooke Mechanical – Integrated Project Delivery (IPD). In this original IPD project the facility was designed and built in 8 months for $600,000 under the $6 million GMP, representing 10% savings.

Construction management (CM) educators are challenged to have students graduate adequately prepared to lead LC projects. Although past graduates have performed well in traditional construction programs, no significant impact on the industry has been visible. Howell and colleagues (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). Howell, a co-founder of LCI advocates the development of students in the design of production systems as an intrinsic part of the CEM discipline (Tsao et al., 2012). Construction Management education has been preparing professionals to staff positions in the construction industry, and the content of this training has been attuned to its long-established needs. Change is needed in the culture and systems to significantly improve performance, but it is not clear how well construction management program graduates are equipped to influence cultural changes in their respective future organigations.

Lean Education

The literature on the structure of LC teaching is very limited (Tsao et al., 2012). A literature search of conference papers of the International Group for Lean Construction (IGLC) and the Lean Construction Journal (LCJ), both premier sources of knowledge on LC, yielded a very small sample of papers that address university-level teaching (Tsao et al., 2012) that does not facilitate detailed analysis. A study of Associated Schools of Construction (ASC) member organizations reported by Johnson and Gunderson (2009) mentioned few instances of lean construction courses, although BIM and LEED courses were being offered. Hyatt, (2011), reported in an ASC Conference on a course integrating Lean, LEED and BIM in an undergraduate course.

As lean construction is still emerging as a discipline, there are different interpretations of the concept both in academia and among construction industry professionals. A number of programs have begun to expand curricula with topics such as Building Information Modeling (BIM), LC, and environmental sustainability, but standardization has yet to occur. A brief overview of some of the topics to be included in a lean training program are presenting the question "Why Lean?", an overview of the industry's ills and need for solutions, Henry Ford's pioneer work, Lauri Koskela's 1992 thesis on lean applications, TPS, Toyota Foundations: continuous improvement and learning, people and partners, the philosophy of long-term thinking, the basic lean principles: value, mapping the value stream, flow, pull, and seeking perfection, the concept of the seven wastes and their negative impacts on productivity, eliminating waste from processes, JIT, Supply Chain Management, and Relational Contracting: the benefits of collaboration and the Integrated Form of Agreement.

The lean curricula are often augmented with simulations that have been used by the LCI to demonstrate and reinforce lean concepts. For example, the Airplane Game uses LEGO blocks in a mock assembly line to produce model planes. Through a variety of operating rules, participants can clearly see that team collaboration and quality consciousness produce the highest number of "good" planes, and by extension, successful construction. The Parade of Trades has players representing construction disciplines tossing dice and passing chips around a table to represent work tasks. Specially numbered dice assigned to different tables emphasize the impact of work variability on job progress through differences in outcome. The following are examples of the variance found in education about LC:

- University of Cincinnati: As described by Tsao and colleagues (2012) the program evolved over a 4 year period. Course topics included: An introduction to lean manufacturing, lean principles, The Last Planner System and The Lean Project Delivery system. Simulations were used to illustrate the lean principles - such as the Airplane Game, the Parade Game, and the Delta design game. There were presentations on 1-piece flow, 5S, and Kanban. Readings included: The Goal (Goldratt and Cox), The Machine that Changed the World (Womack, Jones and Roos) and The Toyota Way (Liker). A field trip to a Toyota plant illustrated many of the lean concepts at work. Guest lecturers were also brought in to present specific topics.

- Arizona State University: Lean was incorporated in a traditional productivity course (Tsao, Alves and Mitropoulous, 2012). In a 16-week productivity course, 8 weeks were dedicated to a lean agenda. The lean curriculum was divided into two parts – Part 1 – Improving independent operations and traditional productivity approaches with some introduction of lean methods. Part 2 – Improving the workflow in interdependent operations, with an emphasis on the overall production system. Topics in Part 2 included: The importance of reliability, lean principles, the Last Planner System, and relational contracts. The readings were similar to those of U of Cincinnati. Simulations included the Parade Game, the Cups game, and the Last Planner System.

- San Diego State University: A graduate 15-week course is defined by the following desired outcomes - recognize and explain the impact on performance of AEC practice, recognize, compare and contrast traditional with innovative AEC practices, recognize, explain and apply concepts and principles from other industries, evaluate the current design of AEC production systems and recommend improvements, design production systems and operations in different life cycle stages, formulate production planning and control systems. The readings and simulations are similar to those used in the preceding programs.

Methodology

The data were collected over the course of several months by referencing every school listed in the Associated Schools of Construction's (ASC) database across all regions (N = 129). The schools were found on the ASC website in the "by region" section - (http://www.ascweb.org/directory/regional-directory/). The data were organized first by region, then by school with the course number, program name, etc. The curricula were reviewed, referencing program names such as Construction Management (CM) or related descriptions (i.e., CM Engineering Technology, Construction Technology, and Building Construction). The data were gathered from public online methods, for example, searching the course catalogs, bulletins or program course descriptions at each university.

The keywords of interest included "lean" first and if that came up, then the courses were included. If that did not work, the search included "productivity" but only for construction courses as the word is more ambiguous. A double check was done of the construction and civil engineering- related programs, in order to be thorough. Because of resource and time constraints, no university was contacted to provide additional information.

Business courses were included (as with all other programs) if they were lean-related. (In principle, construction students could take advantage of specific lean-related business courses). While it would have been desirable to rate the extent of lean content in the programs, it was recognized that lean adoption is a work in progress and not yet standardized. A future study can explore this issue in greater detail.

Results

An analysis was conducted on 129 ASC schools to determine if lean principles were part of the Construction Management or related program curricula. Additionally, all other programs offered by each respective university were addressed in the search. Overall, 103 universities were found to have a course that included or was based on lean principles. The remaining 26 universities did not list any courses focused on lean principles. However, only 49 of the 130 schools offered a lean curriculum in construction management and related programs.

A total of 229 courses are offered across all programs that include lean principles in the curricula. Examples of the programs observed in the study are: Architecture and Manufacturing Sciences, Architectural Engineering and Construction Technology, Aviation Education, Bioengineering, Building Construction, Building Construction Management, Building Sciences, and Building and Construction Technology. These programs are listed in Table 1 in conjunction with their respective categories.

Table 1

Categories for Programs Offering a Lean Curriculum

1	Business	Business, Business Studies, Business Administration, Business Management, Business, Marketing and Logistics
2	Civil Engineering	Civil Engineering, Civil Engineering Technology
3	Construction	Architecture Engineering and Construction Technology, Building Construction, Building Construction Management, Building Sciences, Building Construction Technology, Construction, Construction Engineering Technology, Construction Engineering Management, Construction Management, Construction Technology, Construction Science, Project Management
4	Management	Industrial Management, Management, Management and Quantitative Methods, Management Information Systems
5	Manufacturing	Architecture and Manufacturing Sciences, Machines and Manufacturing Trades, Manufacturing Engineering Technology, Manufacturing Technology
6	Other	Aviation Education, Bioengineering, Industrial Distribution, Industrial Studies, Medicine, Product Design and Development
7	Other Engineering	Electrical Engineering, Engineering Technology, General Engineering, Industrial and Systems Engineering, Industrial Engineering, Industrial Engineering and Manufacturing, Integrated Systems Engineering, Mechanical Engineering, Mechanical Engineering Technology
8	Statistics	Quantitative Methods, Statistics
9	Supply Chain and Operations Management	Design Sciences, Information Systems and Operations Management, Operations Management, Process Technology, Quality Assurance, Quality Assurance Management, Supply Chain Management, Supply Chain Management Systems
10	Technology	Industrial Technology, Technology, Technology Management

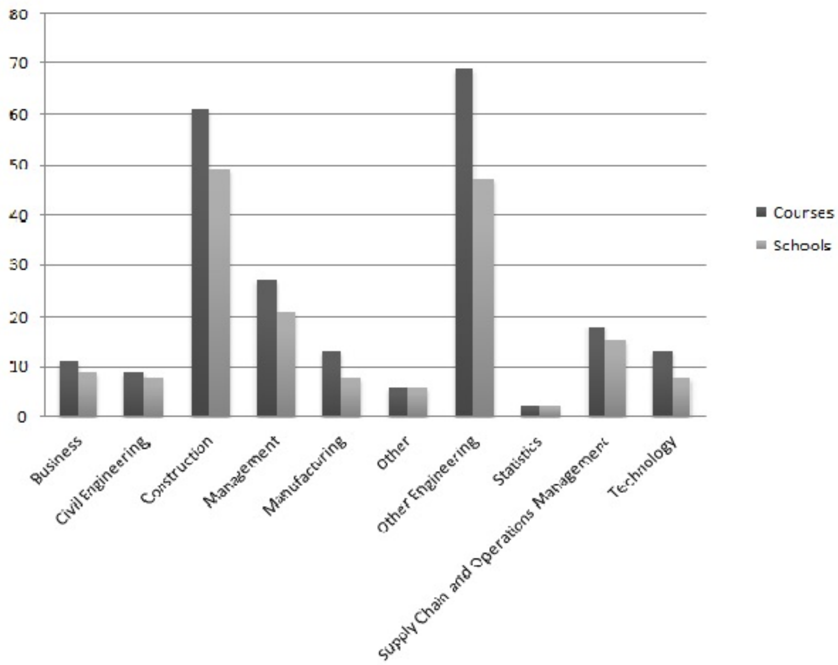

Figure 1: Number of Courses and Schools Offering Courses in Lean Construction by Category

The programs were then subdivided into 10 categories in order to determine frequencies of occurrence for those that offered lean-related courses. These categories were created based on the similarity of course work and topics. For example, the Civil Engineering category consists of Civil Engineering and Civil Engineering Technology programs. Table 1 below shows a full list of the category breakdown. The resulting categories and frequencies for the courses offered and the number of involved schools are shown in Figure 1.

Discussion

The majority of schools in the ASC offer courses on lean principles. Specifically, 49 of the 103 schools that offer a lean curriculum include lean in their construction programs. There are 8 schools that have lean principles integrated in civil engineering programs and 47 schools that have lean principles included in other engineering programs. The programs offering courses are also important to note. The 61 courses in construction programs, nine courses in civil engineering programs, and 69 courses in all other engineering programs account for 61 percent of the lean courses offered. The remaining 39 percent are distributed across business, management, manufacturing, statistics, supply chain and operation management, technology, and all other programs.

The findings from studies to date suggest that lean construction is still in the early phases of adoption in university curricula (Tsao et al., 2012). Universities like Arizona State, San Diego State, and Michigan State independently developed lean curricula while other universities are still developing related courses. Thus, standardization is lacking.

In the course of the study it was noted that the Associated General Contractors Organization (AGC) has developed a lean construction education and training program in conjunction with LCI. The AGC curriculum holds much promise for the future, but its development is only somewhat over 50% complete at this point. Access to the site by university programs could be very helpful in the future. The LCI has extensive readings on its website that provide extensive, up-to-date knowledge on lean issues. They hold annual conferences as well as regional presentations and chapter meetings.

Conclusion

It is very important for lean curricula to be standardized and furthered implemented in construction programs. This can provide future professionals with the knowledge needed for industry growth and success. The ASC schools provide ample courses in lean principles, just not necessarily in construction and related programs. Students could be offered the opportunity to take a lean course from a different program until it is implemented in construction.

By way of proposing a model for lean CM education, starting with the question "Why Lean" while reviewing the construction industry's shortcomings can establish a foundation for standardization. Introductory readings such as "The Goal" lend an understanding of bottlenecks in production systems. The proposed ACCE Student Learning Outcomes address four potential outcomes that could be enhanced with Lean applications. They include:

1. *Understand different methods of project delivery and the roles and responsibilities of all constituencies involved in the design and construction process.*
2. *Understand construction risk management.*
3. *Understand construction project control processes.*
4. *Apply construction management skills as an effective member of a multi-disciplinary team.*

With course work that explores innovative methods of project delivery through lean practices and methodologies, students can begin to investigate and analyze effective solutions for site and project challenges. They can evaluate the practices of lean construction and develop quality control-based construction outcomes. They can recognize and analyze the potential risks that might be mitigated through lean construction practices. Finally, it will allow students to work collaboratively in architectural, engineering, technology and construction disciplines to formulate concepts for success using lean concepts in design, development, and construction.

Discussions in the classroom format reinforce the lessons learned from the readings. Simulations such as the Airplane Game create interest, and provide tangible evidence of production systems operating under different rules, such as batch processing and 1-piece flow. Site visits such as those made to the Toyota plant provide excellent learning experiences, but may not be practical for many schools. However, there are manufacturing operations in many cities and towns. If any can be found that use the lean methodology, then that would offer a great learning experience as well. Guest lecturers from local manufacturers may have a background in lean manufacturing and can explain the concepts very well. They also bring an aura of "real world" experience that is usually lacking in the classroom. Faculty should use the field visits with local contractors as an opportunity for lean construction learning. If a contractor can be persuaded to apply lean methods it can be a very instructive exercise for both students and practitioners. If a lean course is not available, then a productivity-oriented course can be adapted so that a portion of the time is devoted to the lean curriculum. If possible, seek partnering through teams with schools of architecture as students need to learn how to coexist with other professionals in the real world. Similarly, contacts should be established with the LCI to provide students with information on the latest developments. Students could attend chapter meetings held in their respective cities. Overall, the lack of maturity of lean course development in universities renders efforts at research as only exploratory at this stage. Future studies will build on this foundation to better align university program offerings with the needs of the construction industry.

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