

Lean Strategies as a Teaching Tool in a Collaborative Undergraduate Construction/Architecture Course

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In the academic disciplines within the built environment there has been a notable increase of collaboration among architecture and construction programs over the past decade. Most of these endeavors have taken place at the graduate level or upper-level of undergraduate programs with little focus at the undergraduate lower-level. This paper presents a qualitative case study of lean strategies used to support intended learning outcomes of a collaborative lower-level undergraduate architecture and construction course currently in its first year of implementation. The use of Lean strategies as a tool to support intended learning outcomes will be the focus. The paper provides a brief overview of the course structure while discussing aspects of lean construction and its relevance. Explanation of how three aspects of the Last Planner® System were implemented with intent to strengthen learning outcomes, and the course in general will be highlighted. The paper concludes with a brief discussion for validation of anecdotal evidence identified.

Key Words: Lean, Collaborative, Planning, Pull Planning, Studios, Efficiency

Introduction

Improving efficiency is an essential part of maintaining or increasing profitability for many, if not most industries. This is a continual battle for the construction industry in an effort to improve profits. Logistical considerations of labor, equipment, and material are of paramount concern. Most industry segments in the U.S. have seen quantifiable increases in overall productivity. However, the construction industry is the only major segment that has failed to do so. The U.S. Department of Labor indicates the construction industry has a half-century history of little, if any, growth in overall productivity - much of which is attributable to poor project management and planning.

For decades the design-bid-build delivery method has been the standard approach for project delivery. This method situates a hierarchical system to construction project delivery in which design is completed first and then a bidding process to select a contractor. Benefits of this approach have been proposed to include – 1) Lower Project Cost, 2) Avoiding Contractor Favoritism and, 3) Improved Owner Clarity of Design Prior to Construction (Gordon, 1994). Research to the contrary, identifying flaws in the approach such as increased timelines, inadequate contractor experience, poor communication, and adversarial relationships have given rise to adoption of more collaborative delivery methods (Kramer, et al. 2007). With support from various tools, models such as design/build, and integrated project delivery (IPD) have seen quantifiable improvements in overall project success.

One such tool supporting improved outcomes of collaborative project delivery methods is Lean Construction. The Lean delivery system has begun to gain traction over the last decade as case studies highlighting implementation strategies have been developed (Naney, et al, 2012). While these studies address both advantages of its implementation and barriers to adoption, the overwhelming message conveys adoption of Lean Strategies is growing in the construction industry (Demir, et al, 2012). In the vein of preparing our students as industry leaders it seems only appropriate we educate them on strategies adopted by industry.

In the academic disciplines within the built environment, there has been a notable increase of collaboration among architecture and construction programs over the past decade. Many institutions have demonstrated successful models that feature interdisciplinary work at their core. However, most of these models have been conducted at the graduate or advanced undergraduate level. The College of Architecture, Art, and Design at Mississippi State University recognized this as an opportunity to conduct a pilot study for a collaborative lower-level undergraduate architecture and construction course.

Currently in its inaugural year, this course brings together undergraduate architecture and construction students during their second year of study within their respective disciplines. The goal of the course is to expose students to collaborative aspects of their discipline early in their educational development. Notably, there are additional pedagogical challenges to be considered in this approach. In addition to typical challenges associated with an interdisciplinary pedagogy, course developers must also consider fundamental knowledge needed by lower-level students at this stage of their education.

This paper presents an introduction to a collaborative undergraduate architecture and construction course currently in its first year of implementation and how Lean Strategies were utilized to support intended learning outcomes of the course. Due to the course infancy, this paper will not focus on quantitative data outcomes of the course nor the lean strategies utilized as teaching tools. Rather, it highlights the strategies and their implementation to promote development of communication among students while teaching fundamental aspects of scheduling, resource allocation, and time/team management. Qualitative measures through anecdotal evidence are discussed as a basis for further quantitative study. Discussion on aspects of Lean Construction, addressing its background, development, industry perception, and implementation provides support to understand the role of Lean in the AEC industry and its subsequent relevance within the course.

Literature Review

Productivity

The construction industry's productivity has been declining since the mid-1960s at a compound rate of -.48% per year (Teicholz, 2001). Teicholz further points out in contrast that all non-farm industries over the same time period show an increase in labor productivity of 1.71% per year. Management ineffectiveness has been widely cited as the principal factor affecting productivity. A study published in 1983 by the Business Roundtable identified that poor management practices account for more than 50% of wasted time on construction projects (BRT 1983). Project planning and scheduling is noted as having a key contribution in affecting on-site craft worker productivity (Olson, 1982). Recent data collected from a survey of the craft-worker community, trades of which comprise approximately 54% of the construction workforce (Bureau of Labor Statistics, 2011), indicates material availability and sequencing of work assignments as top factors affecting job-site productivity (Dai et al. 2009). One craft worker account in the study by Dai highlights this notion:

> "In general, there's a lack of planning. It seems there is a lack of coordination amongst the management ranks. As a craft worker, that's all we really can do is plan our day. And the people above us have to plan the rest of the work. Getting material, keeping the tools out here, keeping what we need out ahead of us. Planning leads to productivity."

The critical path method (CPM) has traditionally been the technique of choice for planning and scheduling of construction projects (Mendes and Heineck, 1998). It is so widely accepted in academia, it's listed as required topical content by the American Council for Construction Education in its Document 103 (ACCE, 2012). CPM is a linear organizational strategy focusing on identifying the logical order of material placement, affecting the projects overall assembly timeline. However, affective project planning involves more than just putting activities in order, as CPM indicates (Bertelsen, 2003).

Some research indicates critical path-based planning techniques are not adequate for eliminating waste within construction projects (Elzarka, 2006). Because CPM incorporates activities that are of a non-critical influence, this would indicate a factor of waste has been built into the project schedule (Melles and Welling 1996). This contention supports the previous data identifying stagnant productivity trends associated with current methods of planning and scheduling. With the concept of establishing "critical" elements to the project execution inherent in critical path planning, resource capacity and material requirements are abstract at best within development of the schedule (Mendes and Heineck, 1998). Mendes and Heineck further explain that CPM plans commonly lack accuracy into the future of the project due to lack of information about actual delivery and durations.

Lean Construction

Lean Construction is a method developed from the concept of lean production put forth through the Toyota Manufacturing System focusing on maximizing effectiveness of production while also maximizing efficiency of the process (Faniran, 1997; Pheng and Fang, 2005). In other words; only have the necessary material on hand to produce the product for a given work cycle. While this seems common sense on the surface, it's contradictory to the traditional assembly line approach implemented by Henry Ford where maximizing production meant running the line at full capacity focusing on cost optimization (Elzarka, 2006). Elzarka explains this one-dimensional approach created defects where the multi-dimensional Lean system addresses customer satisfaction, waste minimization, and quality; among others. Lean Construction draws on this philosophy.

Lean construction utilizes the lean manufacturing philosophy as a framework for developing a more affective management planning process. This process is defined as clearly defining objectives of the delivery process to maximize performance for the customer at the project level (Howell, 1999). The challenge is manipulating the lean manufacturing strategy to fit the unique characteristics of construction. Some of these characteristics are identified as large projects, immobility of the built product, and changing material types (Gann, 1996). Opportunity to address these concerns draws on other innovative approaches such as BIM and Prefabrication.

The question could be raised whether lean is appropriate for the construction industry when considering its differences from other manufactured products (Gann, 1996). Some might even describe it as a "fad" or buzz word. This perspective alone could call into question the value of teaching it period, let alone discussing it's pertinence as a course or class topic. Established research has identified a multitude of factors (see table 1) as potential barriers to the use of lean in a construction context (Demir et al. 2012; Gann, 1996; Ankrah et al. 2005; Andersson et al 2006). Given this perspective Demir proposes the AEC industry has two options when considering the adoption of Lean; change the projects complexity, or change how you manage the process. The authors propose these can be viewed as one in the same and by extension, suggests industry is actively pursuing both aspects of this paradigm.

Table 1

Potential barriers to the use of LEAN Construction

o Industry fragmentation	o Changing project conditions
o Negative relationships between parties (architects, contractors, sub-contractors)	o Lack of client support
o Number of parties involved in construction projects	o Disparity between design and execution
o Changing project teams	o Perspective of Lean being process focused and not people focused

Widely published research on the employment of BIM and collaborative project delivery approaches including design-build and IPD support this position (Gerber and Kent, 2010). In this context industry participants can no longer wonder if a lean concept approach is good, rather they must consider what will happen if they don't adopt it (Naney, et al. 2012). Practitioners in the built environment are moving toward adoption of more innovative approaches aimed at improving the goods and services they provide. This includes acquiring individuals with the knowledge and understanding of these industry transforming concepts, confirming lean is a strategy deserving of a seat in higher education curriculums.

Academic Opportunity

Mimicking the industry in practice, the design and construction disciplines within academia have historically been segregated in the U.S. (Holley and Emig, 2011). In recent years however, the concept of multidisciplinary collaborative education has become a topic of major priority as the AEC industry is rapidly changing from the traditional design-bid-build model to a more collaborative design-build delivery method (Septelka, 2002). Programs implemented at the University of Washington and Auburn University provides two examples of initiatives taken by higher education institutions to adapt to this change (Septelka, 2002; Holley and Emig, 2011). Various other ad hoc projects have been undertaken by other universities across the country, such as the University of Oklahoma and California Polytechnic State University (Ryan and Callahan, 2007; Montoya, et al. 2009). These projects are reflections of industry advancement of productivity and efficiency affected by integrated management practices.

Initial industry practitioner interaction, common among many of these studies, indicates the models better prepare students for challenges of the industry, and help develop a collaborative discipline early in their career (Montoya, et al. 2009; Holley and Emig, 2011). In addition, a 2003 case study of a Collaborative Sustainable Construction and Design course highlighted student's discovery of the extent to which design and construction rely on each other to deliver a complete solution (Holley and Dagg, 2005). Through the positive student/ industry feedback, initial successes of these programs suggest a cross-disciplinary collaborative model improves the potential for an increase in management effectiveness within the architecture and construction disciplines. Further, they provide foundational support to consider how an interdisciplinary pedagogical model might affect positive change in job-site productivity.

Course Approach

Recognizing the positive outcomes of peer institutions to interdisciplinary pedagogy's at advanced student levels, the Building Construction Science Program and School of Architecture at Mississippi State University saw opportunity to explore such an approach at the lower level. The collaborative course pedagogy brings together undergraduate architecture and construction students in their second year of study. Over the course of a full semester students, housed in a studio classroom, work in team and individual scenarios on problem-based projects. Atypical to a studio format, the course comprises a semblance of lecture, and a lab component. The lecture component is utilized to provide students with foundational information necessary to address intended learning goals within projects assigned. The lab component allots time for students to work through the projects assigned while receiving continual feedback from the instructor(s).

Developing topical content for the course required a collaborative approach amongst architecture and construction faculty to ensure necessary learning outcomes were being met. In-depth evaluation of American Council for Construction Education (ACCE) and National Architectural Accrediting Board (NAAB) requirements were conducted. The results of which form the goals and objectives of the course (Table 2).

Table 2

Course Objectives and Accreditation Criteria

OBJECTIVES:

- Develop a working knowledge of the principle construction material families and their related construction methodologies
- Learn fundamental concepts of formal and spatial manipulation
- Develop an understanding of the relationship between design and construction professionals and their respective values
- Use drawing (analogue and digital) as a means of testing and developing design concepts and construction means & methods
- Understand how design is an informed process which gathers information and parameters from many sources of input
- Build verbal and non-verbal communication skills
- Develop awareness of cost, time, and quality as a factor affecting project outcomes

ACCE (American Council for Construction Education) CRITERIA

GE.1	Oral presentation, tech writing, business writing
CS.1.D	Soil Mechanics
CS.2.B	Analysis and design of architectural systems
CS.2.E	Analysis and design of structural systems
CS.3	Construction Methods & Materials
CS.4.E	Computer applications (CAD and BIM)
CS.5	Construction Surveying

CN.1.A-C	Cost control data and procedures
CN.2.A-D	Planning and Scheduling
CN.5	Safety
CN.6.F	Quality control philosophies and techniques

NAAB (National Architectural Accrediting Board) CRITERIA

A.2	Design Thinking Skills: *Ability to* raise clear and precise questions, use abstract ideas to interpret information, consider diverse points of view, reach well-reasoned conclusions, and test alternative outcomes against relevant criteria and standards.A.3 Visual Communication Skills: *Ability to* use appropriate representational media, such as traditional graphic and digital technology skills, to convey essential formal elements at each stage of the programming and design process.
C.1	Collaboration: *Ability* to work in collaboration with others and in multi- disciplinary teams to successfully complete design projects.
C.6	Leadership: *Understanding* of the techniques and skills architects uses to work collaboratively in the building design and construction process and on environmental, social, and aesthetic issues in their communities.

Projects assigned throughout the semester were developed as stages of an overarching goal of designing, estimating, resourcing, and building full-scale products. This particular semester focused on design and construction of bus stop shelters for a neighboring community. The semester starts with basic aspects of understanding design conventions along with materials & methods of construction. Over the course of the semester varying degrees of constraints are introduced with respect to materials, cost, time, and logistics. During this time architecture and construction students collaborate to understand respective intricacies and project evolution to address each challenge.

The nature of a collaborative pedagogical approach contains inherent challenges regardless of knowledge possessed by the team members. This facet is exacerbated when adding limited knowledge on the content being addressed; i.e. lower-level undergraduate student's still learning discipline specific foundational knowledge. Given the underlying objectives of Lean Strategies to promote communication, efficiency, and project quality, the author proposed incorporating three approaches into the course. The goal of this approach was to circumvent some of the inherent challenges within group collaborative work while developing foundation knowledge. Students are anticipated to develop improved communication, appreciation for discipline, and foundational skills respective of design & construction process, quality control, and resource management.

Lean in the Curriculum

Three-Fold Approach

One of the well recognized aspects of lean construction is the Last Planner® System (LPS). The Lean Construction Institute describes LPS as "a production planning system designed to produce predictable work flow and rapid learning in programming, design, construction and commissioning of projects" (LCI 2013). Toward achieving these goals LPS is delineated into the following five strategies:

1. Master Scheduling – Developing overall project schedule based on milestones and long-lead items
2. Pull Planning – Coordination of work stakeholders to identify conflicts and specify relationships
3. Make Ready Work Planning – Confirming work is ready via look-ahead planning and re-planning as necessary
4. Weekly Work Planning – Coordinated commitment by work stakeholders to complete work in a particular manner and sequence
5. PPC (Percent Planned Complete) – Identifying percent of planned work actually completed and reasons why any work wasn't completed

Considering some of the goals and challenges identified with the "Collaborative Studio" and similarities to that of the framework of Last Planner® the author recognized opportunity to implement three aspects of LPS within the course. Given the nature of the course, intended learning outcomes and challenges, weekly work planning, master scheduling, and percent planned complete were incorporated.

Weekly Work Plan

Challenges within any group work environment are centric to communication and establishing individual accountability. Lack of communication promotes incorrect perceptions of accountability often tying to project failures. In the course described, this opportunity for failure is exacerbated due to student's lack of knowledge in the content being practiced. This circumstance promotes a tendency for the more motivated students to take the lead on work while less motivated team members fall in their shadow. The "motivated" students in this course have referred to this trait as "riding the coat tails". Consequences of this can begin to spiral out of control if not carefully observed; ultimately leading to team breakdown, decreased learning, and animosity among students. In addition students feel accurate assessment of performance is obscured.

The weekly work plan was facilitated as a tool to curb the issues of accountability and assessment clarity while also providing learning outcomes relative to communication, team work, and management,. Through the approach students are required at the beginning of every project to develop a work plan identifying all required activities/deliverables to be completed, individual responsible, and when it will be completed. Through this measure students and instructors are clear at the onset of the project who is responsible for what work. Student accounts indicated a heightened level of responsibility and accountability contributing to a more successful team project. Additionally, they noted feel more confident about their responsibilities and how their work would be assessed.

Master Scheduling

The projects students will construct must be completed within the course semester and they are provided the last three to four weeks of the semester for this purpose. Framing the class in this manner provides for real-world simulation of construction constraints. For this reason it is imperative an accurate estimation of schedule is defined.

Students are required to develop a CPM-based schedule comprising all the project's milestone components and material procurement requirements. This aspect ties with learning objectives associated with communication, scheduling, project control, and general management. Oftentimes this is where scheduling education stops, leaving students missing the aspect of implementation and evaluation. Because students in this course will be building what they schedule, they are afforded opportunity to evaluate their scheduling skills and design strategies, reflect and then respond. One student summed up the experience saying "I thought my schedule was well thought out until we started building the project. Then I realized it had many flaws."

Percent Planned Complete

Percent planned complete is the analysis portion of reflection on the weekly work plan and schedule development. This provides the final aspect of learning outcomes in which students have the opportunity to evaluate how they scheduled their work in comparison to how the work was actually performed. Bloom's taxonomy refers to this as "evaluating" and is considered one of the highest forms of learning (Anderson 1999). Expanded understanding of scheduling concepts in work sequences, critical path, and resources; greater understanding of materials, methods, and productivity rates is gained.

Conclusion

Previous research has identified institutions of higher education are addressing aspects of both interdisciplinary pedagogies and lean construction. Combining both of these areas into one curriculum at the lower-level of undergraduate education seems to be an area of little study to date. While the collaborative course at Mississippi State University is only in its first semester of study, preliminary outcomes suggest increased learning benefits. Anecdotal evidence indicates some positive outcomes toward development of discipline specific knowledge and cross-disciplinary understanding, as well as improved communication skills. While this evidence is positive, quantitative analysis needs conducting to further confirm or deny efficacy of skills development respective to the objectives in the course.

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