

CONSTRUCTION EDUCATION**PAPERS PRESENTED ON UNDERGRADUATE EDUCATION**

A Case Study in Integrating Lean, Green, BIM into an Undergraduate Construction Management Scheduling Course

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This case study explores the integration of lean construction, sustainability, and BIM into an undergraduate construction management scheduling course. Lean construction, sustainability, and BIM are currently reshaping the construction industry. Industry members are challenged to effectively implement these trends in projects. Likewise, academia is faced with its own unique challenges in adding these trends within an existing curriculum. As a case study, an undergraduate construction scheduling course was restructured using the framework of the Last Planner™ system to incorporate these trends. The course added a 4D assignment (BIM), which allowed students to visualize the construction of a LEED certified project (green) in the course. The course also added the key aspects of the Last Planner™ system (lean) throughout the course. The result was a highly successful course that engaged students and improved effectively introduced students to these important topics.

Key Words: Construction Scheduling Education, BIM, Sustainability, Lean Construction, Last Planner System

Introduction

The construction industry is on the precipice of significant shift in the way that projects are executed. This shift promises to greatly improve the overall design and construction process. There are three primary trends that are driving these changes in the industry. These trends are building information modeling (BIM), sustainable design and construction (green), and lean construction (lean). They are not only re-shaping the design and construction industry, but also the construction management education. (Johnson & Gunderson, 2009)

Building Information Modeling – “BIM”

Perhaps the most prolifically adopted innovation throughout the industry is BIM. Formally, BIM is defined as the parametric modeling of a building. Simply stated, BIM allows the project team to virtually design and construct the building. BIM is not only a technological innovation, but also a significant shift in the overall design process.

Although BIM is primarily a preconstruction tool, it is growing fastest among construction managers and contractors. The most recent McGraw-Hill Smart Market Report found that “71% of contractors report positive results with the use of BIM”. Additionally, the report states “contractors see many of the most obvious and dramatic benefits of BIM.” Finally, the report showed that contractors are adopting and using BIM faster than any other group in the industry, increasing to 50% in 2009 from 13% in 2007 (Young et al. ,2009). Because of this growth contractors are looking more and more for undergraduate construction management programs to produce graduates with the knowledge and skills to use BIM on projects.

A study of the construction industry’s expectation of construction management graduates’ BIM skills found that using BIM for “constructability” and “visualization” were in the most demand. This study also found that about half of the respondent firms currently used BIM for 4D modeling (Mojtaba, 2010). The term 4D modeling refers to the

addition of the time element to the 3D model established within BIM. Typically a 4D model creates a schedule simulation that can be used by the project team and/or presented to other project stakeholders. The 4D modeling aspects of BIM allow project teams to visualize construction plans, identify construction sequences, and improve communication within the team. These benefits of 4D modeling greatly increase the construction manager's ability to plan and schedule a construction project.

Sustainability – “Green”

The sustainable design and construction movement has steadily gained popularity in the United States over the past decade. One of the primary drivers for this movement has been the widespread acceptance of the U.S Green Building Council's green building rating system titled Leadership in Energy and Environment Design (LEED). Perhaps the greatest benefit of the LEED rating system is that it provides a structured approach to designing and building sustainable projects. The system also provides common definitions and terminology for sustainable building practices.

Another one of the key aspects of sustainability in the industry is the need to develop projects in an integrated manner. This requires owners, designers, and constructors to collaborate on sustainable projects. “Current thinking in engineering reinforces this idea in realizing that cross-disciplinary thinking and skills are key elements of sustainability” (Chau, 2007). It makes sense that LEED is best suited for fully integrated project teams. The team members, both designers and constructors, should collaborate throughout the entire process.

There are also some significant improvements as LEED gains momentum in the United States. Most notably is the improvement in project planning of sustainable projects. LEED projects are best built when the owner is fully committed to achieving a desired certification level. This allows projects to be planned and designed in a more collaborative and efficient manner (Beheiry et al., 2006).

Lean Construction – “Lean”

Lean construction is based upon the principles developed by Toyota and led by Engineer Ohno to increase efficiency in automobile manufacturing. The main objective was to eliminate waste. Despite the success of lean manufacturing, application of lean principles to construction projects has been around for a relatively short period of time. Thus the definitions and applications of lean principles in construction often vary greatly throughout the industry. However, the Lean Construction Institute lists three linked opportunities in lean construction: impeccable coordination, projects as production systems, and projects as collective exercises. The key to maximizing these opportunities is to implement a production planning and control system. (Howell, 1999)

The Last Planner™ system (LPS) was developed as a production planning and control system based upon lean construction principles. LPS has been successfully implemented on many construction projects. Projects that have used LPS have increased the reliability of project planning, increased production performance, and improved workflow in design and construction operations (Ballard & Howell, 2004).

Though some argue that lean construction has the greatest potential to transform the industry, it has been the slowest of these trends to penetrate the construction industry market place. This may be due the lack of a clear definition of “lean construction”. Another reason may be that lean construction lacks an accepted lean construction “system” in the industry. Whatever the reason, lean construction has yet to be fully embraced throughout the industry.

Contemporary Undergraduate CM Curriculum

Like the construction industry, construction management programs have steadily incorporated these key trends within their curriculum. Some programs have opted to create stand-alone courses that cover each of these trends. Other programs have integrated various levels of these trends throughout their curriculum. Although the approach varies, the focus on adding these topics within the existing curriculum remains strong.

BIM in CM Courses

This increase in demand for students with BIM knowledge and skills has led to the implementation of BIM within various aspects of undergraduate construction management curriculum. Some programs opted to offer full courses in BIM. Other programs have implemented BIM as a portion of existing courses. Perhaps the best recommendation by an educational adopter is summarized by this statement, “we do not advocate a silver bullet course to add to an already packed curriculum, but rather promote the use of BIM as a means of better integrating a construction curriculum” (Taylor et al., 2008). This approach of integrating BIM into the existing curriculum seems like an approach that is well suited for construction management programs since it matches the integrated approach that most construction professionals are using on projects.

Despite the increasing demand in the industry, inclusion into undergraduate construction management curriculum has been slow. A recent study of 45 institutions affiliated with the Associated Schools of Construction found that “BIM is currently being addressed in only about 10% of undergraduate programs”. The study noted the following barriers for inclusion in courses: (a) no room for new courses in existing curriculum (82%); (b) Faculty time and resources required to develop new courses (86.7%); and (c) Lack of textbooks and other educational resources for students (53.3%) (Sabongi, 2009). This final factor is the most significant hurdle for adding BIM topics into existing courses.

Despite the many experiments demonstrating the positive uses of BIM, there remain few resources for implementing BIM into undergraduate construction scheduling education in a manner that is easily repeated on a wide scale basis. Most experiments used high-end virtual reality systems that are not available to most educational institutions (Messner, 2003). Additionally, the lack of interoperability of BIM software systems remains a key barrier for adoption across the industry and within education settings (Young et al., 2009).

Sustainability in CM Courses

Construction management programs in the United States have successfully incorporated sustainability topics in various courses. According to a recent study, over 80% of programs have implement sustainable construction in some manner (Johnson & Gunderson, 2009). The most progressive programs have developed sustainable construction programs over the past decade (Kilbert, 2010). Other programs have partnered with industry to provide resources for achieving professional accreditation in sustainable construction (Brown, 2009). Regardless of the approach, incorporation of these sustainability ideals requires “a radical reorientation in order to enable a new generation of professionals to more effectively and positively confront the transition toward a sustainable society and act to influence it” (Chau, 2007).

Despite these successes, the delivery of sustainability content remains diversified and inconsistent across programs (Wang, 2009). This puts the pressure on faculty members to add sustainable construction content into courses. Additionally, faculty members are also burdened with staying current with a field of construction that is quickly changing.

Lean Construction in CM Courses

As with the construction industry, lean construction has the least amount of focus within construction management programs. Not surprisingly, a recent study of programs found that less than half include lean construction within their curriculum (Johnson & Gunderson, 2009). This lack of focus provides the most significant challenge for faculty members. There are minimal course materials available within the market place. Even more problematic is the lack of resources for undergraduate students in this area. Most resources have been focused on graduate level students.

Challenges to Incorporating Trends

In summary, there seem to be two primary challenges to implementing these trends within existing curriculum. The first is the lack of widespread expertise among academia in these areas. This is likely due to the relatively new focus on these trends within the industry. Second, these trends are best suited and based upon a collaborative environment.

This collaborative environment in the industry takes the form of multidisciplinary design and construction teams. Thus, this would require a multidisciplinary approach across academic departments. This would be a significant challenge for institutions that are not structured in a manner conducive to this requirement. (Johnson & Gunderson, 2009)

The Case Study: Restructuring a CM Scheduling Course

A summer intersession course was restructured with the goal of incorporating all three current industry trends into the course. The course was an undergraduate construction scheduling course. This course was selected because each of these trends closely aligned with the course content. And despite the inherent challenges, all of these trends provided unique opportunities to enhance the overall course curriculum. This provided some inherent advantages that supported the existing student learning outcomes.

First, the overall framework of the course was based upon the Last Planner™ system because of the phases within the system. This framework provided a structure for the course and provided several key assignments that supported lean construction education. Second, a LEED project was selected for students to work with throughout the semester. Finally, a schedule simulation (4D BIM) exercise was added in the course.

Scheduling in CM Educations

The initial step entailed identifying the key topics within the typical undergraduate construction scheduling course. First it was found that many of the courses focused on teaching several types of schedules. These schedules included bar charts (or Gantt charts), critical path method (CPM), and line of basis (LOB) schedules. (Galloway, 2006)

In addition to the typical course content, the requirements by an academic accreditation body was researched. The American Council for Construction Education (ACCE) requires that the following topical areas in scheduling:

1. Parameters Affecting Project Planning,
2. Schedule Information Presentation,
3. Network Diagramming and Calculations with CPM,
4. Resource Allocation and Management,
5. Computer Applications. (ACCE, 2009)

Finally, many construction management programs formally or informally follow the scheduling processes outlined by the Project Management Institute. These processes include: activity definition, activity sequencing, activity resource estimating, activity duration estimating, schedule development, and schedule control. (Galloway, 2006)

Overall Course Framework (Lean)

The framework of the Last Planner™ system (LPS) was selected because it provided a well-defined process for planning, scheduling, and controlling a construction project (Hamzeh & Bergstrom, 2009). This system is based upon the “lean” concepts of production control throughout the entire construction process. The four-phase process also incorporates typical scheduling techniques with lean production concepts. Thus the course in this case study was restructured based upon the following LPS phases:

LPS Phase 1/Course Module 1 (Master Scheduling)

Phase 1 (Master Scheduling) in LPS creates a master schedule for the project. This phase lists the milestone dates of the project based upon the front-end planning activities of the project team (Ballard, 1997).

The first module in the revised course utilized this LPS phase to introduce students to project planning (ACCE topic 1) and to create bar chart schedules (ACCE topic 2). Additionally, students were also expected to identify, sequence, and estimate the duration of activities during this module. In order to assess these outcomes and expectations, students were tasked with creating a “master” bar chart schedule for a selected project. This assignment not only assessed the two primary learning outcomes, but it also provided a foundation for future class activities and

assignments. Finally, CPM scheduling (ACCE topic 3) was introduced at the end of this module in order to demonstrate a more common method of scheduling complex projects.

LPS Phase 2/Course Module 2 (Phase Scheduling)

Phase 2 (Phase Scheduling) in LPS creates a more detailed schedule for each project phase. Common construction project phases may include foundations, structural framing, core/shell, interior finishes, and/or tenant improvements. The key aspect of this phase is the use of a collaborative planning effort where key project participants (specifically specialty contractors) identify “handoffs” between each participant in order to best achieve milestones set in the master schedule. This effort uses a “pull” scheduling method that employs reverse phase scheduling (Ballard & Howell, 2004).

The second module of the course focused on CPM scheduling, reinforced project schedule development, and introduced resource allocation (ACCE topic 4). There were several assessment activities within this module. The first method was the creation of a “phase schedule” for the project. In this activity, students were tasked with creating a CPM schedule for the core and shell phase of the project using Primavera Suretrak. The next assessment activities focused on evaluating and improving the schedule that they created in the previous assignment. Students would use two methods to evaluate the schedule. The first was to create a schedule simulation in Autodesk Navisworks Manage in order to visualize the construction process (this is described in more detail in the 4D Simulation Activity section below). The second method required students to participate in a “team scheduling” activity. During this activity, each student would assume the role of a subcontractor and participate in the LPS phase scheduling exercise. The phase scheduling activity introduces the concept of “pull” scheduling and reverse phase scheduling. The last assessment activity was the allocation of resources to the CPM schedule. In this assignment, students were tasked with allocating and leveling resources (in this case manpower) for the project.

LPS Phase 3/Course Module 3 (Look Ahead Scheduling)

Phase 3 (Look Ahead Planning) in LPS “signifies the first step of production planning with a time frame usually spanning between two to six weeks. At this stage, activities are broken down into the level of processes/operations, constraints are identified, responsibilities are assigned, and assignments are made ready.” (Hamzeh & Bergstrom, 2009)

This module of the course primarily focused schedule updating, evaluation, and reinforcing resource allocation and management (ACCE topic 4). Students were also introduced to line of basis schedules during this phase. The primary assignment for this module tasked students with updating an existing schedule and then generating a “3 week look ahead” schedule based upon the update. Students would evaluate the current status of the schedule and generate a brief report summarizing the status of the project. The final aspect of this assignment entailed outlining the responsibilities and specific resources required to complete the activities shown on the “look ahead” schedule.

LPS Phase 4/Course Module 4 (Commitment Planning)

Phase 4 (Commitment Planning) creates the most detailed plan in the system, which drives the production process. At the end of each plan period, assignments are reviewed to measure the reliability of planning and the production system. The percent plan complete (PPC) metric is used to track the performance of promises made at the weekly work plan level. PPC measures the percentage of tasks completed relative to those planned. This provides a snapshot of the overall reliability of the planned work. Reviewing plan failures and analyzing the reasons for the failures is one of the most important ways to ensure continuous improvement (Ballard, 2000).

The final module of the course focused on following through with the production process and applying principles of continuous improvement. A final exercise in the class was a “PPC” simulation. This simulation provided students with an opportunity “to act” out the commitment planning and review process. Another key focus of this simulation was to apply learning process of determining why a plan failure occurred. In this exercise, students were again required to assume the role of a subcontractor (the same one previously assigned in module two). The exercise was a mock “production planning meeting” in which they were asked to update to their schedule activities on the “3 week look ahead” schedule generated in the previous course module. Each student was provided a cue card, which described their specific activity updates. Some of these activity updates included detailed reasons why their activity

was unable to be completed during the previous week. The class was then taken through the process of identifying the plan failure of those activities. Finally, students were asked to make ‘commitments’ for their tasks for the next week. The three key objectives of this exercise were establishing commitments, tracking “PPC”, and analyzing plan failures.

Scheduling of a LEED Project (Green)

The prevalence of LEED projects in the industry provided ample opportunity to select an appropriate project for the course. Therefore, the focus of this aspect of the course was to select a project with sustainable features. In this case study, the project included daylighting, photovoltaic panels, on-site storm water treatment, and water efficient landscaping. All of these features provided unique scheduling challenges for the project that were discussed throughout the course.

An important new assignment for this course was the “means and methods” paper. Students were tasked with researching one “activity” within the project schedule and presenting it to the class. The requirements of the paper included estimating the duration, listing quality control requirements, discussing safety requirements, and describing any sustainability features of the activity. This assignment provided the background knowledge required for future assignments, while also focusing on the challenges of scheduling LEED project.

4D Simulation Activity (BIM)

The basis of the assignment was to create a 4D model or schedule simulation by utilizing the construction schedule established in the previous exercises. The student would then be able to visualize the construction schedule as they had developed it. The use of schedule simulation to identify potential schedule errors has been demonstrated as a highly effective learning tool in previous experiments (Messner, 2003). Also, the schedule simulation had the potential to make “the learning activity more interactive by allowing students to review and critique different solutions” (Wang et al., 2009).

In the previous assignment, the students were provided 30 construction activities for the project. The students were tasked with creating a CPM schedule for these activities based upon the 2D drawings and specifications provided. The CPM was assessed based upon the calculations of the CPM schedule and if any significant logical errors were made. However, several minor logical errors were not identified during this assessment so that the students would have the opportunity to “catch” these errors in the schedule simulation assignment.

The software selected for this assignment was the 2010 version of Autodesk Navisworks. This software was selected for two reasons. First, the software provided a platform to easily import a Microsoft Project schedule and link it to a model. Second, the software was available for students to download for free. The software was also provided in the university student computer lab for activities in and out of the classroom setting.

An Autodesk Navisworks 2010 model of the project was provided to the students. The model was a modified version of the actual project model in order to simplify the assignment. The students were then walked through an exercise that demonstrated how to import a schedule (Microsoft Project), link the schedule to the model, run a schedule simulation, and export the simulation to a movie file (.avi). Upon completion of this exercise in class, students were tasked with linking their schedule from the previous assignment to the model of the project. The students were told that the schedule simulation would be assessed based upon the following factors:

- Creation and submission of the schedule simulation movie (.avi),
- all construction activities were “linked” to elements within the model, and
- identification of any changes that were or would be made in the sequence.

Students were not required to make changes to their schedule simulation, but were asked to identify any errors and logic and provide a solution for the errors.

Student Survey Results

A survey was also conducted at the completion of the term in order to gage the students' perceptions of the course and of the assignments. Here are the most significant findings:

- 87% of the respondents selected the CPM activities (including the phase scheduling exercise) as most beneficial in understanding the sequence of construction,
- Only 14% selected the BIM assignment as most beneficial in understanding construction “means and methods” (Individual Report was the highest at 43%),
- 43% strongly agreed and 29% agreed with the statement: “The Lean Construction topics and activities were interesting and added value to the course”,
- 100% of respondents were interesting in learning more about “Lean Construction”,
- 57% selected the BIM assignment as most beneficial in being able to visualize the construction process (Field Trips were next with 14%), and
- 100% of respondents were able to accurately describe LEED (compared to an average of 80% from previous courses).

Finally, here are some comments that were provided in conjunction with this survey:

- “BIM was the most helpful”,
- “I believe the field trips were beneficial”,
- “The field trips were extremely important when it came to seeing the actual application of the schedule and learning how changes affect it.”

Recommendations

The following recommendations were developed from this case study. First, the use of a single project throughout the course was very effective. This allowed students to build upon their knowledge of the project as they progressed throughout each module. The primary concern with this approach would be to select an appropriate project. Second, one of the major challenges in the class was the lack of prior knowledge in these new areas by the students. This meant that at least one lecture introduced students to these trends prior to the activities in the course. As these topics become more prevalent with the curriculum these introductory lectures could be phased out. Last, although many of the students truly enjoyed the BIM exercise, the use of field trips remained the most favored method of actually understanding the schedule of a project. This should remain an important aspect of any scheduling class.

Conclusion

The construction industry is in a period of substantial transition. It is at the confluence of three significant trends driving this transition. Therefore, construction management programs should seek for innovative ideas to present the trends of BIM, sustainability, and lean construction. This case study demonstrates one example of how all three trends can be incorporated into existing course curriculum.

The incorporation of all three key trends within the scheduling course was a challenging endeavor. However, the results were very positive. Students gained valuable knowledge about important trends within the industry. Additionally, there were many positive recommendations for future improvements for this concept. In summary, this case study provides a feasible structure for future scheduling curriculum without sacrificing the key components of the course.

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